Celtic Sea Trout Project

Technical Report

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Reference

CSTP (2010) Manual on Sea Trout Ageing, Digital Scale Reading and Growth Methodology (R. Poole, Ed.) Produced by the participants of the Celtic Sea Trout Project Workshop on Sea Trout Age Determination and Digital Scale Reading Methodology, 24th-28th May 2010.

Other outputs generated from:
Ireland: the Wetted Area model (McGinnity et al. 2012). Land use data for Ireland were from the CORINE project (Environmental Protection Agency 2000).
England & Wales: Catchment-based environmental variables: digital elevation model (Nextmap DEM - a 50 metre resolution elevation model) and from the Land Cover Map 2000.
Geological data: British Geological Society 1:625000 maps adapted for development of Water Framework Directive river and lake typologies
Flow statistics for the river at head of tide were derived from the Low Flows Enterprise Model (Wallingford Hydrosolutions 2008).
Scotland: WFD river Basin plans published by SEPA, and from specific data requests to SEPA via the Boards and Trusts including Nith District Salmon Fishery Board, River Annan District Fishery Board & Galloway Fisheries Trust
Northern Ireland: AFBI datasets

Executive Summary

Project Background

The Celtic Sea Trout Project (CSTP) was an INTERREG IVA Ireland Wales Programme collaborative project which investigated the status, distribution, genetics and ecology of sea trout populations around the Irish Sea.

The project objectives were:

- To understand and describe sea trout stocks in the Irish Sea and thereby to enhance sea trout fisheries and strengthen their contributions to quality of life, to rural economies and to national biodiversity
- To explore the use of sea trout life history variation as a tool to detect and understand the effects of climate change
- To convert new information and understanding into improved practical management of fisheries
- To develop long-term collaboration amongst fisheries workers and users of the fisheries across the Irish Sea
- From a list of nine key strategic research needs identified at the 1st International Sea Trout Symposium in 2004 (Harris & Milner, 2006) the CSTP framed four areas where the projects research effort would focus including:
  - Where do sea trout go at sea and how are their stocks structured and interlinked?
  - What is the marine ecology of sea trout (feeding, growth, survival and life history variation)?
  - What environmental and other pressures are sea trout exposed to?
  - How do sea trout life histories (and thus fishery quality) respond to environmental variation?

Various work packages within the project, several of which were inter-related, were designed to answer these questions.

Project Tasks and Summary Results

The project was broken out into seven tasks:

Task 1 related solely to project management and was reported directly to the Wales-Ireland administrative section.

Task 2 was primarily a review of available information from published and unpublished sources on the sea trout fisheries in each of the four geographical regions of the Project Area bordering the Irish Sea (i.e. Scottish Solway, Northwest England, Wales and the east and south coast of Ireland). It provides an inventory and description of identified sea trout fisheries, assesses their societal and economic benefits and reviews their importance in maintaining and sustaining those benefits at a regional and local level. The importance and value of sea trout fisheries is contextualised by comparing with salmon fisheries in the same regions.

Detailed descriptions of sea trout fisheries and catch records, including commercial and angling fisheries, angling regulations and data collection methods are provided. The principal conclusions were that the catch recording systems differed substantially between the regions due to legislative and administrative circumstances. Neither in Scotland nor in Ireland are data collected on seasonal distribution of catches or catch effort. Nevertheless, since 1994, common trends are evident from regional rod catch data in fisheries in the Irish Sea area. The size distribution of fish captured varies considerably across the Irish Sea, with the major difference being the predominance of finnock in the Irish fisheries, which emphasises the importance of recording size data in Irish rod catch statistics.

Measuring the economic value of angling is important particularly to those commissioning such studies (usually Government Departments and their respective Agencies) but it is now widely recognised that the social benefits of angling are equal if not more important than economic values. This review noted that recent socio-economic studies observed that the imported expenditure by non-resident (visiting) anglers was significant in a national context, although the imported expenditure by resident anglers who fished in different parts of the UK and Ireland may be important at a regional and local community level, particularly in remote rural areas. In this regard evidence from Wales showed that minor rivers are important, not because of their contribution to the total catch of fish within the region, but by their collective contribution to the social and economic benefits of the region in general and to the many small, often remote, rural communities within their separate catchments. It is important to note that it is the sea trout and not the salmon that sustains and maintains that collective fishing effort throughout the entire season for all ten minor rivers and that it is this that is of paramount importance in providing social and economic benefits derived by many communities throughout Wales. Sea trout are shown to be an increasingly important component of the migratory recreational fishing resource in all countries.

The history of stocking of migratory and non-migratory forms of *Salmo trutta L*. across the various jurisdictions was reviewed. It was evident that all statutory agencies in the UK and Ireland have adopted policies and criteria to regulate the release of reared fertile non-local salmonid fish into the natural environment to limit any potential issues including introgression or loss of biodiversity.

Sampling was carried out in freshwater and at sea under Task 3 to provide samples for Task 4 (Genetic Stock Identification), Task 5 (Stock Movement Patterns) and Task 7 (Marine Ecology and Life History). 10,555 individual juvenile tissue samples (5,358 0+ fry and 5,185 ≥ 1+ parr) were collected, by electrofishing, for the genetics work package. Out of these totals 2,611 fry from 55 sites in 38 systems were retained for growth studies and 1,138 parr were retained from 51 sites in 36 systems for the microchemistry baseline. An estimated 34,000 scale envelopes were distributed to anglers to collect scales from rod caught sea trout over the course of the project. Distribution was supported by numerous presentations about the project by CSTP biologists to angling groups throughout the Project Area, and by establishing a network of scale collectors at river level. Scales were submitted from 68 catchments and the majority were from rivers identified as priority rivers by the CSTP project team. Anglers contributed the majority with 5,577 samples (70.5%) of the 7,909 total.

The marine project area was subdivided into 30 different marine zones to facilitate design of the sampling programme. A total of 1,367 marine caught sea trout samples were available for analysis. 1,094 of these fish, including 1,094 bodies, were sampled over the course of the project, mainly from inshore sites, using various sampling methods supplemented by samples from commercial fisheries. Surface trawling was undertaken in the northern part of the Irish Sea and along the south Wales coast. Trawling resulted in a total of 69 sea trout being captured from three areas: outer Solway, off Morecambe gasfields and Dundalk Bay.

A broad range of tissue samples was taken from retained fish and distributed to the various laboratories for downstream processing and analysis. A comprehensive project database was developed which incorporated all field and laboratory sampling data, including a library of scale images and samples.

Sampling populations in freshwater for juveniles was successful due to the relatively confined extent of watercourses and the periodic availability of sampling teams that undertook juvenile sampling. For adult sea trout the contributions of fisheries managers and angler volunteers who collected scale samples from rod fisheries was a criticial success factor. Large samples, exceeding the 300 sample target, were obtained from several systems. Sampling in the marine environment was challenging due to the extent of the British and Irish coastline within the project area, the logistics and cost of marine sampling, the overreliance on in-kind sampling effort, and, in some cases, restrictions imposed under the terms of sampling permits.

Genetic stock identification (GSI) is a cost effective and reliable method of acquiring knowledge of the migration and geographical distribution patterns of marine sea trout (Task 4). For the CSTP 22 microsatellite markers with sufficient variation to resolve stock structure and enable population discrimination were selected. DNA extracted from 5,500 juvenile fish, from 111 sites in 99 individual river systems, was genotyped to produce a baseline consisting of approximately 120,000 novel pieces of genetic information. The comprehensive sampling programme of Irish, Welsh, Scottish, English and Manx rivers, was designed to include the majority of the potentially contributing rivers to the sea trout stock in the Irish Sea. The resulting genetic baseline is the largest and most comprehensive assembled for the study of sea trout in a defined ecosystem.

Nine major genetically distinct regional and phylogeographic groups within the British and Irish database were identified. Genomic DNA was extracted from 1,099 adult trout captured at sea. This sample represents an exponential increase in the numbers of sea trout compared to previous studies for which population specific marine data are available. The genetic data show that sea trout in the Irish Sea originate from a large number of rivers and are distributed widely. Although the majority occurred in the proximity of their natal river long range feeding migrations up to 300km were recorded for some individuals.

The nuclear SNP analysis revealed a nearly identical structure to that revealed by microsatellites, separating Great Britain from Ireland samples along the first principal component, and segregating latitude along the second principal component. A genome-wide inbreeding coefficient was calculated and these were generally low. However, inbreeding was much more prevalent in the Lough Currane sample – signifying significant genetic isolation, a distinct population, and maintenance of an extraordinary and unique long lived phenotype when considered in the context of other Irish populations.

The nSNPs analysis identified a number of markers as potentially being associated with parr growth rate. Further analysis revealed a larger list of SNPs potentially associated with parr growth, and two environmental variables, namely latitude, a surrogate for river temperature, and river length, which could be associated with river productivity and intra and interspecific competition.

A novel panel consisting of 152 mtSNP markers have been developed within the project for and are readily available for future brown/sea trout studies. It is anticipated that both nuclear and mtDNA SNP marker will provide a valuable addition to the molecular toolbox for the monitoring of sea trout.

Task 5 (Microchemistry) was designed to investigate movement patterns of sea trout *Salmo trutta* L. within the Irish Sea. Two biogeochemical tags, otolith microchemistry (using Mn, Mg, Sr and Ba) and scale stable isotope chemistry ($\delta^{13}C$, $\delta^{15}N$), were used. A freshwater microchemistry baseline was established by sampling parr from 36 rivers located within 9 potentially discrete subregions of the Irish Sea (southwest Scotland, northwest England, north Wales, mid Wales, south Wales, east coast of Ireland, south coast of Ireland and the Isle of Man). Differences in parr otolith microchemistry were observed between river / region for Mg:Ca, Mn:Ca, Sr:Ca and Ba:Ca concentrations. Individual trout parr were assigned back to river / region of origin with 74% assignment success to river and 66% assignment success to region respectively.

The otolith microchemistry for the freshwater and marine phases of the life cycle of 231 marine-caught sea trout (caught in coastal waters in the Solway Firth, Isle of Man, north Wales and east coast of Ireland) was measured using laser ablation ICPMS. Very few differences were observed in otolith chemistry in the marine section of the otoliths between fish caught in the different locations. The freshwater assignment Mg:Ca, Mn:Ca, Sr:Ca and Ba:Ca concentrations allowed for assignment to region of origin and results indicated that sea trout may undertake more extensive migrations in the Irish Sea than previously assumed.

Isotope $\delta^{13}C$, $\delta^{15}N$ concentrations/signatures were measured in scales from in-river adult sea trout from 7 rivers (5 – 19 fish per river) in the eastern Irish Sea. No differences in scale $\delta^{13}C$ isotope chemistry, in the section of the scale corresponding to the last period of summer growth at sea, were observed between rivers but the $\delta^{15}N$ chemistry suggested spatial segregation between fish from rivers flowing into the Irish Sea on the east coast of Ireland and mid / south Wales. Reference to the Irish Sea $\delta^{15}N$ isoscape of Jennings and Warr (2003) suggested that fish tended to stay in coastal waters close to their river of origin.

The overall aim of Task 6 was to describe the freshwater production capacity of sea trout in rivers in the CSTP Project Area and to determine key production drivers. Several catchment scale datasets were compiled to develop a production model, and to produce maps of the distribution and abundance of trout; this was achieved for relevant waters in England and Wales but detailed data for Scotland and Ireland were limited. Some detailed data for spawning areas in North Wales and Cumbria were available but, in general, only sparse data were available for other areas. Impassable and potentially impassable barriers to migration were also mapped, for Ireland, Scotland, North-West England and Wales.

This task developed a general linear model relating adult sea trout rod catch per unit effort (for England and Wales from 2000-2010) to catchment-scale environmental variables. Important predictor variables were those of total catchment stream length, alkalinity and land cover by coniferous and broadleaved woodland, and improved grassland. This shows that generally, shorter rivers of low alkalinity in catchments which are relatively poor in nutrients and less-intensively farmed, with good spawning and nursery areas easily accessible from the sea, tend to be the better sea trout rivers. Conversely larger rivers whose headwaters are distant from the sea, with calcareous geology and productive, more intensively-farmed catchments are more likely to be salmon and/or brown trout dominated. Other exploratory analyses highlighted the importance of lower productivity and calcium availability in creating favourable conditions for good runs of sea-trout. No significant relationship was observed for total juvenile trout production in catchments and sea-trout rod catches, indicating that sea trout production in rivers is driven by an innate propensity of trout to become anadromous rather than density-dependant factors. Caveats relating to these models are that a large proportion of the variation in sea trout rod catch between rivers is due to differing characteristics of the fishery rather than the catchment, and increasing evidence from other studies that anadromy is at least partly under genetic control. The latter means that adaptive genetic differences between stocks from different rivers are likely to influence how they interact with their environment which is unlikely to be observed in modelled production.

Task 7 described marine ecology, life histories and population dynamics of sea trout in the Irish Sea and models relationships with key environmental features in order to provide management advice. A detailed analysis found that rod catches in rivers around the Irish Sea demonstrated synchronous variation. Although temporal variance (the synchronous component) contributed only 35% of the total variance in catches, it nevertheless points to the influence of some common factor/s on different river stocks or river entry.

The estimate of marine biomass in the Irish Sea placed sea trout low in the order of other teleosts and showed them to be a small part, in terms of nett biomass, of the marine ecosystem. The analysis highlighted the abundance of small coastal streams (<10km^2 catchment area) which, although having a small wetted area contribution and hence low numerical component of the whole stock, nevertheless offer a potentially significant contribution to overall biodiversity and thus increase overall variation in life histories and local adaptations, also known as the port-folio effect.

Stock descriptions through scale reading and analysis of biological features of fish sampled in rivers demonstrated a wide variety of life histories and traits, characterised by smolt age, time of first return and multiple spawning, marine growth and annual post-smolt survival. Broad stock characterisation showed that stocks in SE Ireland rivers tended to be dominated by finnock/whitling/.0+ sea age, had lower marine growth rates and lower annual survival (post sea age 1). On the eastern seaboard (Galloway to Wales) statistically significant latitudinal variation was evident in marine growth rates, with lower values in more northerly rivers, a variation tentatively attributed to sea temperatures which decreased with increasing latitude. The latitude effect was less marked along the Irish east coast and was not statistically significant.

There was evidence of long-term changes in stock life history features. The average size of whitling in rivers of the eastern Irish Sea (i.e. UK coast) has increased significantly since the 1920s, but recent trends are unclear and no data were available for the rivers on the east coast of Ireland. No temporal variation in annual survival could be detected between samples from the late 1990s and the present day. These long-term changes might be the consequences of climate change, but the proximate factors and mechanisms are unclear. Of the Irish rivers, the Currane consistently stood out compared with rivers draining to the Irish Sea, by having higher growth rates and annual post-smolt survival, more typical of South Wales.

Matrix projection models were developed using stage specific approaches with stages defined by the re-created life history based on the scale reading. Eigen analysis was used to estimate several population parameters including population growth rate (λ), net reproductive rate(R_0), generation time, stable stage distribution and stage specific reproductive value. Although there were commonalities, sea trout populations from rivers draining into the Irish and Celtic Seas were heterogeneous and followed different population dynamics patterns. For example, population growth rate (λ) ranged from slightly negative values in rivers on the North East of the Irish Sea to strongly positive values for most rivers in Wales while the strongest population growth rate was found in the Isle of Man. The outcomes of the population dynamics analysis of the sea trout population of each of 22 rivers, where sufficient data were available, were summarized into individual river outputs.

Rod catch size structure changes between 1976 and 2007 in some Welsh rivers showed different trends in different rivers, with some North Wales rivers (particularly the Afon Conwy) displaying a large decline in abundance of large sea trout in contrast to increases in the rivers of Cardigan Bay. This corresponded with an increase in the abundance (and proportion) of smaller fish (mainly whitling) and appears to indicate sub-regional scale influences on the time of first return and/or survival.

Hydrodynamic modelling was undertaken to describe the possible pattern of movements of sea trout from different rivers/regions in the Irish and Celtic Seas and to estimate the environmental conditions that may be experienced by these fish during the marine phase of their life-cycles. A particle tracking module within this model was used to evaluate scenarios for the possible movements of sea trout post-smolts during the first year in the sea. These scenarios were compared with information on the distribution of sea trout in the Irish and Celtic Seas derived from the genetic assignment of fish sampled at sea back to their region of origin. The results indicate that a significant proportion of the fish remain relatively close to their river of origin. Where fish undertook longer distance migrations, these appeared to be strongly influenced by the prevailing currents.

Sea trout are naturally parasitized by two species of caligid copepod sea lice, *Lepeophtheirus salmonis* and *Caligus elongates,* in the marine environment. This study, conducted over a wide geographic area, provided an opportunity to assess sea lice levels on sea trout, both spatially and temporally, in estuarine and marine waters in an area devoid of marine salmon farming. Significant variation in *L. salmonis* abundance was observed between marine areas within the Irish Sea; higher abundance was observed along the east coast of Northern Ireland, whereas *C. elongatus* showed highest abundance along the English and Scottish coast. However, the relative stability in prevalence and mean intensity of both lice species, the low mean abundances and the very low proportion of juvenile life stages of *L. salmonis* reported are similar to those reported from other studies in areas devoid of salmon farming and likely represent natural background salmon lice levels on sea trout. In terms of coverage this study represents one of the largest studies of sea lice infestation patterns on sea trout in an area removed from finfish aquaculture influences.

Dietary analysis showed that trout at sea fed mainly on fish, principally sand eel and sprat and there was some evidence that a prevalence of sprat in the Northern part of the Irish Sea was consistent with a higher incidence of sprat in the diet of sea trout. The biotope description of the Irish Sea showed that it has highly structured seascape offering contrasting habitats for sea trout. The eastern side, from Wales to Scotland, is characterised by a more featured coastline, shallower water, lower residence times and higher freshwater inputs leading to higher nutrient status and more variable temperature regimes. However, although primary production is higher on the east coast, particularly in north of Liverpool Bay, there was no simple relationship with overall trophic dynamics and consequent potential effects on post smolt growth potential. Evidently, spatial patterns of various trophic levels are complex and influenced by hydrographical phenomena, such as the formation of seasonal fronts and stratification.

Climate change impacts on sea trout at sea are likely through (a) direct effects of temperature change and (b) indirect effects through diet availability as influenced by oceanographic changes and factors such as plankton composition and consequent food web effects. The preliminary analysis here indicated that future temperature change will affect sea trout marine growth differently in the northern and southern parts of the Irish Sea and that they may be beneficial in the north and natural or slightly negative in the south. However the effects are expected to be small under likely climate change scenarios and translating these to life history and stock level changes is not possible at this stage. In freshwater, other studies have shown that climate change has already influenced salmonid growth rates and consequent smolt size and age distributions. It was not possible to investigate such effects in the CSTP.

Links with broad-scale climatic factors were equivocal; therefore such relationships require further, more penetrating study. Long term changes in growth and proportional abundance of small fish in some rivers (data from Welsh rivers only) were attributed speculatively as responses to climate change, probably through sea surface temperature increase and food web changes. However, climate influences acting through freshwater environmental change and subsequent smolt attributes could also be involved.

Management Implications and Further Research Needs

Each of the various tasks identified implications for sea trout management and further research needs. These are summarised below and presented with some general strategic recommendations which emerged over the course of the project.

The comprehensive baseline data on catches and stocking history and the review of the economic value of sea trout and the analyses undertaken in Task 2 provide a reference point for managers which underpins the value of sea trout at multiple scales. Additionally the output provides managers with these data, in an accessible format, which facilitates analysis of current and future fishery performance.

Task 2 identified that neither catch effort nor seasonal catch distribution data are collected in Scotland or Ireland and that finnock dominate catches in Ireland. The current Irish catch recording system significantly underestimates the scale of sea trout rod catches as only sea trout > 40cm are required to be recorded in the tagging and log book system. Adopting a comprehensive approach to recording catch data in all sea trout fisheries throughout the Irish Sea would substantially enhance future sea trout assessment and management functions in this relatively confined waterbody.

The genetics and microchemistry tasks reported that sea trout in the Irish Sea originate from a large number of rivers and are distributed widely within the waterbody. Although the majority occurred in the proximity of their natal river long range feeding migrations up to 300km were recorded for some individuals. Otolith microchemistry and ecological profiling provided complementary estimates of reliability of genetically based assignments and provide strong corroborating support for the veracity of the microsatellite (GSI) based designations.

Both tasks also demonstrated that there is potential for sea trout from different systems to be caught in any fisheries operating in coastal waters in most areas of the Irish Sea. The potential for both coastal and estuarine fisheries to exploit mixed stocks of sea trout supports a need to conduct further genetic studies of sea trout caught in estuary and in-river fisheries to determine and quantify the extent of mixing.

The utility of genetic stock identification (GSI) was well demonstrated in the CSTP and the development of a comprehensive genetic baseline represents a major advance for further stock assignment and ultimately for management. Additional research is recommended to refine the juvenile genetic database which demonstrated some evidence of the presence of non-migratory trout in the samples. In addition, the quality of the baseline is, to a large extent, a function of the sampling design (e.g. its comprehensiveness). Thus it is important to ensure that all potential contributing rivers-populations are sampled. A novel panel consisting of 152 mtSNP markers has been developed within the project and is readily available for future brown/sea trout studies. It is anticipated that both nuclear and mtDNA SNP marker will provide a valuable addition to the molecular toolbox for the monitoring of sea trout and the basis for new sea trout research initiatives. For management further assignment of existing samples of marine caught sea trout to river level would provide quantitative area-specific advice necessary to develop local conservation management plans for sea trout and its habitat thus contributing to an integrated resource management plan for sea trout in the Irish Sea.

A substantial focus for CSTP, and a strategic priority for sea trout (Harris & Milner, 2006), is the marine ecology of sea trout. As reported in Task 7, the synchronous variation amongst widely dispersed sea trout stocks is evidence that sea trout were responding to some common factors operating across the Irish Sea. It was not possible to determine what these factors were or at what stage in the life cycle they operate. Arguments can be presented for impacts acting at sea, in freshwater (affecting smolt production) or both. Long-term changes in size at ages and size composition of catches suggest that marine stage influences acting through post-smolt growth are involved, but that does not rule out other factors. Further analyses on the factors contributing to synchrony, particularly climate change, are recommended.

The direct effects of temperature change and indirect effects arising from changing food availability are likely features of climate change impacts on sea trout at sea. Investigations of impacts on salmonids in freshwater have demonstrated change and complementary studies, using the available CSTP marine sea trout scale samples, would allow investigation of such effects and of the links between growth and subsequent life history variation. More detailed analyses of the complex relationships between broad scale climate drivers and stock features, over an extended time–series, are warranted.

The sea is not a black box into which sea trout migrate and disappear in their adult feeding phase. Marine habitats are highly variable and structured in the Irish Sea. Task 7 identified a research priority whereby marine habitats need to be better described, understood and managed as important determinants of sea trout stock well-being, just as freshwater habitats are for juvenile production.

In that regard Task 6 dealt with identifying factors that are important to sea trout production in freshwater. Models were developed which account for some of the variability in production and provide useful indicative tools for managers to evaluate fishery performance and identify potentially influential environmental factors. However, as observed for rod catch data, the absence of standardised environmental datasets across the project area hindered modelling. Developing capacity for standardising data categories and sampling protocols, which would to facilitate integration of datasets for modelling, will be important to harmonise in order to allow for cohesive management of the sea trout resource in the Irish Sea. Better understanding of the influence of environmental features on sea-trout production will only be gained by undertaking catchment-specific, detailed studies of trout production and movement using a combination of marking and trapping, stable isotope analysis, scale microchemistry and genetics. In this way catchment-specific nursery habitat could be identified and more detailed studies of those areas undertaken to elucidate key features relevant to sea trout production and anadromy.

Hydrodynamic modelling of the Irish Sea demonstrated that the simulated distributions of sea age 0/0+ fish appear broadly consistent with the information obtained from the genetic and microchemistry assignments and suggest that sea trout adopt a behaviour which tends to keep them in coastal waters close to their river of origin. More detailed tracking studies of sea trout in coastal waters will be required to determine the precise behaviours used by the fish.

Life history models that can simulate population responses to environmental pressures or changes in fishing regulations are at an early stage of development for sea trout due to the complexities of their life cycle. However, the CSTP data and preliminary development of such approaches enhances the use and further development of practicable models. Progression is feasible but will require more time and investment.

Attempts to model growth in the sea using a conventional trout growth model were unsuccessful, as others have found. This might be due to the effects of a predominantly high protein and lipid fish diet, salinity or other confounding environmental and physiological factors and the comparatively large size of the fish. The possibility of compensatory growth remains, but the evident variation in growth between regions, suggests that if it occurred it was not a major factor. Although temperature was shown to be an important influence on growth, the absence of a process-based growth model that adequately describes marine growth of trout (conditions of high salinity and typically high lipid fish diet) remains a knowledge gap.

Sea trout fed mainly on fish, principally sand eel and sprat and some diet partitioning was evident. The complexity of the Irish Sea biotopes in terms of varying hydrography and trophic status, combined with limited routine stock assessment of the key prey species (for sea trout and many other marine fish and birds), constrained any evaluation of biotopes in this project. To build on the progress in sea trout dietary analysis achieved in the project and to increase understanding for management enhanced monitoring of sand eel and sprat populations in the Irish Sea is recommended. The lack of knowledge about coupling in sea trout food webs and the mechanisms governing them is also a significant research need.

Prey species monitoring and food web investigations are priorities in the context of increasingly intensive use of coastal waters of the Irish Sea for a wide range of activities such as shipping, aggregate extraction, renewable energy infrastructures. It is a topic that points to the need for enhanced and common approaches to marine ecosystem monitoring to support consistent Strategic Environmental Assessment.

Sea trout are vulnerable to human activities in the sea, by virtue of their coastal occupancy and dependency of their life histories on marine ecosystem health. Marine spatial planning and the implementation of the EU Marine Strategy Framework Directive offer routes for integrated environmental protection that could benefit sea trout. However at present these policy processes do not appear to register the environmental dependencies of sea trout, which should therefore be promoted more explicitly.

From a technical perspective, within the CSTP, scale reading was an important technique but the difficulties in ensuring common interpretation across multiple readers in different locations were significant. Moreover, collection of adequate unbiased samples from rivers by volunteers was also problematic. Protocols and some new scale reading terminology were introduced in the CSTP, but if this potentially valuable technique is to be used routinely in assessment, it requires significant further development and validation. Given the importance attributed to life history variation, a more robust and long-term protocol for sea trout scale collection and analysis is needed to make the method suitable for scientific assessment. The CSTP collection and other historical collections are invaluable resources and need careful curating to preserve and use for this purpose. Further research on these scale interpretation questions and on the use of combined microchemistry and scale reading is recommended.

The diversity of sea trout stocks is high in the Irish Sea. Some of this variety probably arises in small catchments that could not be covered in the CSTP surveys. Nevertheless they are discrete elements contributing to overall biodiversity and stability in productivity. A knowledge gap area lies in how these might combine with the populations from larger watercourses to provide a wider portfolio function around the Irish Sea. The potential for interdependencies within putative meta-populations of sea trout was not testable with current information but is important management information.

The CSTP has generated many varied outputs which are reported here. The extensive sampling programme and detailed analyses undertaken has provided valuable insight into many of the important research needs identified at the 1st International Symposium on Sea Trout, held in 2004, and will contribute to improving sea trout management in the freshwater and marine environments. The extensive outputs from the CSTP will function as a baseline and important reference point for other studies. In the future these baselines will be refined, modified and enhanced at local and broad scale levels to increase understanding of sea trout in the Irish Sea and further afield.

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1 Introduction to the Celtic Sea Trout Project

1.1 Background

Sea trout, the anadromous form of brown trout (*Salmo trutta*), are widely distributed in the north-Atlantic. Although sea trout are commonly targeted in coastal and estuarine net fisheries and in freshwater and marine recreational fisheries they remain less popular than salmon and consequently many aspects of sea trout population ecology, particularly in the marine environment, remain to be elucidated.

The biology of sea trout in the UK and Ireland was summarised by Le Cren (1985) while the Study Group on Anadromous Trout (ICES, 1994) reported the diversity and ecology of sea trout across its range. Subsequently the 1st International Sea trout Symposium in 2004 (Harris and Milner, 2006), where a broad suite of papers covering research, conservation and management issues were presented, updated the state of knowledge of sea trout populations across Europe.

Sea trout are important for tourism, the fishing industry and peripheral communities, and their fisheries are at risk from overfishing, and warmer waters arising from climate change (Elliot and Elliot, 2010). In recent years concerns about the status of sea trout has focussed attention on the need for detailed and sustained research, with a major focus on its marine phase where it is exposed to a variety of threats and pressures. Occupying freshwater zones for its early life, and coastal zones for the marine phase (for periods of a few months up to one or two years), the sea trout is a complex fish which uses freshwater, transitional and marine habitats over its life history. Sea trout require good environmental quality in freshwater, estuaries and at sea to survive. Moreover, current understanding suggests that the incidence of sea trout and the composition and status of their stocks is sensitive to changes in the environments in which they live. Their life history features and the sea trout's widespread occurrence, makes it a unique and potentially sensitive indicator of environmental change.

The Celtic Sea Trout Project emerged following the 1st International Sea Trout Symposium, Cardiff, June 2004, from discussions amongst organisations responsible for sea trout management, stakeholders and research institutes. Several key cross-border issues were identified as requiring attention, highlighting a need for collaborative work. These included the distribution and ecology of sea trout at sea, their fate in marine and estuarine mixed-stock fisheries and the response of their biodiversity and life histories to environmental pressures, particularly climate change. Resolving these matters in sea trout addresses four strategic issues:

1) providing a ubiquitous indicator of climate change
2) managing the response of the fishery to climate change
3) improving the health and status of a threatened natural resource that provides sustainable social and economic benefits to rural communities
4) providing a platform for developing permanent, synergistic cross-border collaboration and partnerships

The Celtic Sea Trout Project aimed to fill gaps in the knowledge and management of sea trout fisheries by investigating the distribution and movements of various sea trout life stages at sea; their ecology, environmental pressures; how their stocks are interlinked, and how to optimise economic benefits whilst protecting stocks and biodiversity. This required a fuller understanding of their distribution and the ecological processes affecting sea trout in its various habitats. This project provided this knowledge and improved advice for management of a joint resource. It contributed to enhancing and protecting stocks and fisheries, contributing to social well-being and inclusion in rural and peripheral communities, increased employment, improved understanding underpinning better management of climate change and protection of biodiversity.

The Irish Sea was identified as a discrete area where delivery of this project was feasible and, critically, was pertinent to the strategic development needs of Wales and Ireland. Sea trout and their fisheries are ubiquitous extending across the Irish Sea and across borders. Their genetic variations are important elements of marine and freshwater diversity; however, it was not known how many genetically distinct populations of sea trout there are in the INTERREG area, or how, and if, they interact when at sea. Without this knowledge the fundamental question of how climate change may affect the sea trout could not be answered, though this migratory trout provides a unique form of environmental indicator due to the diverse range of habitats it occupies during its life cycle.

The work plan required to understand these stocks and to investigate their marine ecology necessitated extensive cross-border collaboration, with work required in offshore waters, coastal, estuarine and freshwaters throughout the INTERREG IV-A area. This demanded operating a single study of sea trout in the area as a whole. The regulation of fisheries and communication links are through fisheries management agencies (EA and IFI in Wales and Ireland) operating through national statutory arrangements specific to each country. Thus each country brought benefits to the programme that were not achievable through the actions or capacity of one alone.

1.2 Project Aims

- To protect and enhance sustainable tourism, cross-border biodiversity and environmental quality by filling a major gap in the knowledge and management of sea trout fisheries, which are of particular importance to Ireland and Wales. The primary gap exists in understanding of sea trout in their marine phase.
- To harness a unique network of cross-border expertise which would collaborate to monitor, manage and protect sea trout in the coastal rivers of the region and the Irish Sea itself. Through a fully integrated and collaborative network of management agencies and public end-user groups, HEI and governmental research institutes the CSTP aims were to protect/enhance the health of stocks, the socio-economic value of fisheries and the status of cross-border biodiversity by determining the current status of sea trout stocks and fisheries, and by describing genetic and life history variation in the region.
- To develop an informed/coordinated management plan for the conservation, sustainable management and exploitation of this joint asset.
- Assess and predict the impacts of climate change on sea trout stocks, fisheries and biodiversity by harnessing the joint talents and capacity of the region's fisheries research and management expertise to develop and apply a spatially structured ecosystem model.

The CSTP work programme was split into 7 tasks: (1) management and dissemination, (2) review of fisheries, (3) sampling, (4) microchemistry, (5) genetics, (6) freshwater production and (7) marine ecology, life histories and modelling for management.

Specific objectives within the project were:

- To model/evaluate the potential effects of climate change on sea trout stocks and fisheries in the region (Task 7)

- To enhance cooperative working, networking, shared knowledge and awareness of sea trout fisheries, their environments and management amongst practitioners/stakeholders (T 1)
- To set up/deliver common programmes of research and data management involving practitioners in colleges, institutes, regulatory bodies and stakeholder groups (T1)
- To establish comprehensive databases and educational material on sea trout and their freshwater and marine environments in the region (T 1)
- To report on the location/size/composition of sea trout fisheries in the region, analyse the biodiversity/cultural/heritage/socio-economic value of sea trout and examine trends in performance and developmental potential (T 2)
- To investigate the relationship between location/concentration of juveniles and catchment/habitat features in order to model smolt production (T 6)
- To develop management units appropriate to migration/exchange, stock structure and biodiversity of sea trout in the region (T 4-7)
- To estimate optimum future capacity (feeding, growth, survival etc) of sea trout in the region (T 7)
- To advise on best practice for fisheries, biodiversity and environmental management to promote sustainable sea trout fisheries and related tourism with attendant socio-economic benefits to rural communities (T 7)

This was the first large scale project in Europe to develop a coordinated programme addressing common fishery and environmental understanding, management, best practice and advice for sea trout in their marine and freshwater phases. It contributes to raising the profile of the Cross-Border Area in the field of fisheries and environmental management. This innovative project delivers the following novel activities, none of which have been completed before:

- Development of understanding and advice regarding climate change impact on a common Irish Sea fishery resource by forecasting its response to climate scenarios
- Large scale (e.g. 65+ rivers) cross-border community involvement in climate change/natural resource topic through public awareness (e.g. angling clubs and River Trusts dissemination and education on aquatic environment) and participation (e.g. angling as sampling method, increased fishing)
- Training and standardisation in use of equipment, sampling methods and protocols across partner groups
- International review of sea trout fisheries and their socio-economic values, providing a first ever perspective on common cross-border issues and fishery development opportunities
- Application of modern genetic methods to very large scale stock structuring of sea trout
- Development of SNPs for sea trout (high resolution genome markers with strong repeatability between laboratories)
- Large scale application of micro-chemical methods to determine sea trout stock distribution and origins from chemical composition of scales
- Development and coupling of hydrodynamic and life-history models for sea trout fish at sea, to examine the causes of variation in life histories and stock composition

The Celtic Sea Trout Project (CSTP) was an INTERREG IVA Ireland Wales Programme collaborative project which investigated the status, distribution, genetics and ecology of sea trout populations around the Irish Sea. It was designed to improve the management and long term future of sea trout in the Celtic seas by providing information and management advice, and by establishing a wider awareness and a network of people working to secure the future of sea trout.

The project was delivered through an Ireland Wales Cross-Border partnership and, because of the wide-ranging distribution of sea trout, work was carried around the Irish Sea in a multi-partner collaboration. Lead partners were Bangor University, Inland Fisheries Ireland, University College Cork, Environment Agency (EA) Wales (now Natural Resources Wales (NRW)), the EA England, and subcontractors APEM Ltd, Fishskill Consultancy Services and CEFAS.

The Dept. of Environment, Food and Agriculture (Isle of Man), Nith District Salmon Fisheries Board, Galloway Fisheries Trust, Annan District Salmon Fisheries Board and Buccleuth Estate (Border Esk) undertook a significant amount of sampling and supported the project. Many groups and individuals sustained the project and many provided letters of support (see Appendix 1). A high level of stakeholder involvement from anglers was essential to ensure that sufficient scale samples were collected from systems throughout participating regions.

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2 Fisheries Inventory, Socio-economic Value and Stocking History

2.1 Preface

Task 2 of the Celtic Sea Trout Project is primarily a review of the available information from published and unpublished sources on the sea trout fisheries in each of the four geographical regions of the Project Area bordering the Irish Sea. It provides a general background and perspective to the overall Project and includes supporting information for other Tasks within the Project: namely Task 3 (Sampling), Task 4 (Genetics), Task 5 (Microchemistry) and Task 6 (Freshwater Production) and Task 7 (Marine Ecology & Life-History). It has three separate objectives:

1) To provide a general inventory and description of the sea trout fisheries
2) To assess the importance and value of those fisheries
3) To review the history of stocking programmes with migratory and non-migratory forms of *Salmo trutta* L

While there is some overlap in the information included under objectives 1 and 2, this report is presented as three separate and free-standing parts covering each of the above aims as:

- Section 2.2: Fishery Inventory & Descriptions
- Section 2.3: Importance and Value
- Section 2.4: Stocking History

The management of sea trout stocks and their associated recreational rod and commercial net fisheries in the UK and Ireland have been inextricably linked with Atlantic salmon in many important contexts for over 150 years. Therefore, it was necessary to expand the scope of Parts 1 and 2 to include parallel information on the salmon fisheries within the Project Area to provide a broader perspective and a better understanding of the relative status, performance and value of the sea trout fisheries in each region.

2.1.1 Fishery Inventory and Descriptions

These are presented for the four areas: Scottish Solway (2.1.2), Northwest England (2.1.3), Wales (2.1.4) and Republic of Ireland (2.1.5).

2.1.2 The Scottish Solway Region

2.1.2.1 Introduction

Scotland is one of the major salmon producing nations of the North Atlantic. It is renowned for the widespread distribution, variety and overall quality of the salmon fishing in its numerous river systems throughout the mainland and the Islands. Some of the largest salmon rivers, such as the Tweed, Spey, Tay and Aberdeenshire Dee, are internationally famous. Although sea trout occur in all Scottish salmon rivers and a multitude of other small coastal streams, very few of the Scottish sea trout fisheries have achieved any widespread recognition in the angling literature over the last 150 years. There are a few notable exceptions, such as some of the many smaller rivers and lake-fed systems in the Northwest and the Islands, but these are relatively uncommon and their reputation is based largely on the personal views of angling authors rather than on their broad appeal and attraction within the angling community. Nevertheless, some of the better-known salmon rivers on the southeast coast, such as the Tweed, Spey and South Esk, contain significant numbers of sea trout that attract a modest number of dedicated sea trout anglers.

Scottish law relating to salmon and sea trout fisheries differs from other regions of the UK and Ireland in several important respects. These are discussed below, but the principal differences to note here are: (a) the existence of a private right of ownership of fishing rights for salmon and sea trout in the sea, and (b) the absence of any system of statutory licensing for the rod and the net fisheries.

Unlike other regions of the UK and Ireland, the administrative arrangements for the management and regulation of salmon and sea trout fisheries in Scotland have been remarkably stable for many years. Scotland is divided into 101 Salmon Fishery Districts each covering one or more river catchment areas and the fishery owners within a District are empowered to establish a District Salmon Fishery Board (DSFB) for the management of their fisheries. Each board is self-financing and has the power to levy a fishery rate on the separate owners within a district based on the capital value of the fishery.

Fishery Districts

The rivers bordering the Northwest coast of the Irish Sea are collectively grouped under the Scottish Solway Region (Figure 2.1.1). It extends from the River Annan entering the upper part of the Solway Firth in the east to the River Luce in the west and contains 8 principal rivers under the control of 7 District Salmon Fishery Boards. These are (from east to west):

1. Annan	Annan DSFB		5. Fleet	(as 6 below)
2. Nith	Nith DSFB		6. Cree	Cree & Fleet DSFB
3. Urr	Urr DSFB		7. Bladnoch	Bladnoch DSFB
4. Dee	Dee DSFB		8. Luce	Luce DSFB

The River Esk is a cross-border river entering the upper funnel of the Solway Estuary. Its headwaters arise largely in Scotland and the river then forms part of the national boundary between England and Scotland before flowing through England to enter the sea. Although generally regarded as a Scottish river, the Border Esk has been under English jurisdiction since 1860 and the management and regulation of its fisheries are currently the responsibility of the Environment Agency for England & Wales. Catch records for Border Esk are included under the English North West Region (see Section 2.1.3).

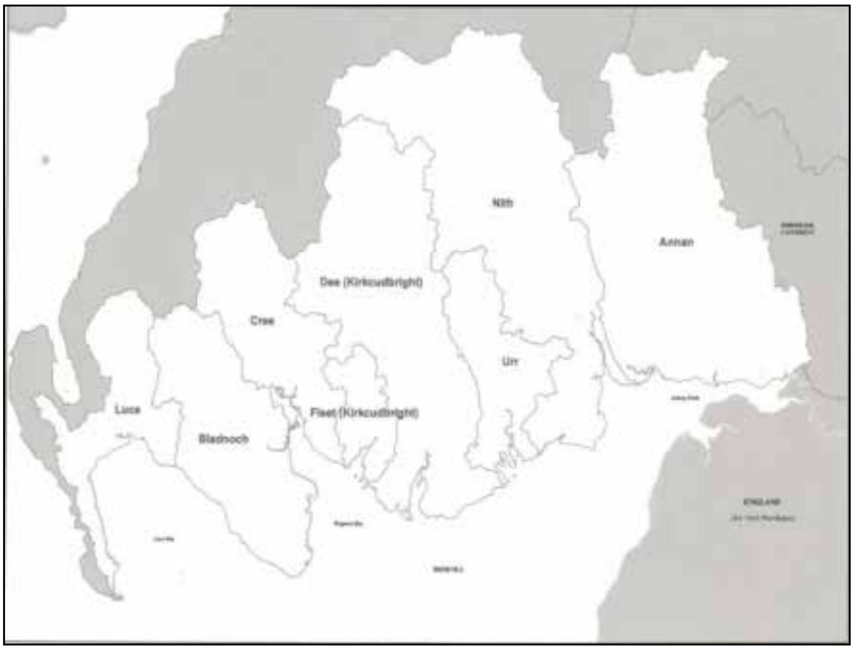


Figure 2.1.1 District Salmon Fishery Boards Areas and Principal River Systems within Solway Region

2.1.2.2 General Background

General Fishery Features
The length of the main river (from source to upper-tidal limit) and catchment area of the 8 principal rivers in the Region are listed in order of decreasing size as:

River	Nith	Annan	Dee	Cree	Bladnoch	Urr	Luce	Fleet
Length (km)	86	67	76	55	49	43	29	25
Area (km^2)	1,230	960	1,020	433	284	317	202	144

A notable characteristic of the region is the existence of both early (spring) and late (autumn) runs of MSW salmon in addition to the normal summer runs of 1SW grilse. The runs of autumn fish are locally significant as they extend the angling season by several further weeks. While the runs of early spring salmon have declined in recent years, they remain an important angling attraction throughout the region.

Sea trout exist at various levels of relative abundance in all rivers, including the Piltanton Burn (Luce DSFB) and several of the minor rivers and streams that do not feature in the official catch records. In general, terms, the strength of the sea trout runs is related to size of the catchment area, with the Annan and Nith as the most productive and the Urr, and Fleet as the least productive in terms of rod catches. This generalisation does not apply to the Dee (the third largest river in the region) where the construction of a major dam at Tongland some 3 km above the tideway as part of the Galloway Hydro-electric scheme in the 1930s restricted subsequent upstream migration and the access of sea trout and salmon to significant areas of spawning and nursery stream.

In addition to native brown trout, which provide attractive angling opportunities on the Annan, Nith and Dee, various non-native fish species have successfully colonised various catchments where there is suitable habitat. Of these, the grayling (*Thymallus thymallus*) has become an important and valuable angling attraction on the Annan and Nith. The River Luce is one of the few rivers in Scotland known to contain a spawning population of *Osmerus eperlanus* (smelt or sparling).

Ownership of significant sections of the rod fishing remains under the control of various large estates, but access to the fisheries by the public has improved markedly in recent years. While large sections of fishing throughout the area are now controlled by angling clubs who issue permits to local residents and visiting anglers, other sections are subject to timeshare or limited syndications schemes (e.g. Nith, Annan and Luce). Some estates now issue permits directly to the angling public. There are now relatively few sections of fishing that remain the exclusive preserve of the owners.

The general decline in the nature and extent of the overall commercial fishing effort for salmon and sea trout that has taken place in recent years in England, Wales and Ireland is also evident in Scotland. The public right of fishing for migratory salmonids in the sea outside Scotland has been progressively derogated and controlled by statutory regulations over the last few decades. Scotland became the first major salmon producing nation to prohibit the use of drift nets (1962) and subsequently banned other gill nets set at sea (1971) and from the shore (1986). However, the more recent reduction in commercial fishing effort in the Solway Region has resulted largely from self-imposed, voluntary constraints adopted by the owners of the private rights of fishing in tidal estuaries and near coastal waters. Consequently, the only rivers where commercial fisheries operated on a consistent and regular basis from 1994-2011 are the Annan, Nith, Urr and Cree.

There are now only four types of commercial fishing gear currently in used in the Region: stake nets, half nets, poke nets and net & coble (= seine net) fishing. One or more stake nets previously fished in all Districts but this method of fishing is now localised in the Annan, Nith and Urr. Active net-and-coble fishing is now limited to the Cree. Poke nets are found only on the Annan and an extensive haaf net fishery operates on both the Annan and Nith.

2.1.2.3 Fishery Rules & Regulations

Measures to control the nature and extent of fishing to protect stocks from over-fishing by the rod and net fisheries encompass a range of statutory regulations and voluntary rules imposed by the owners of the fishing rights. The most significant of the statutory regulations at a National level are:

1) A complete prohibition on any form of fishing for sea trout and salmon on a Sunday.
2) A ban on drift net fishing in coastal waters from 1962.
3) A ban on the sale of rod-caught fish from 2002.

In general terms, the commercial fisheries in the Scotland are lightly regulated compared with other regions bordering the Irish Sea. Statutory regulations at a local district level relating to the commercial net fishery define the types of fishing methods, their general location and their lawful fishing season, while similar regulations fix the lawful fishing season for rod-and-line fishing.

The statutory fishing seasons for salmon and sea trout are the same throughout the Region. The current (2011) starting and finishing dates of the fishing seasons vary by a few weeks between districts as follows:-

1) Rod-and-Line Fishing:
   - 25th February to 30th November - Annan, Nith and Urr.
   - 11th February to 31st October - Dee and Bladnoch.
   - 25th February to 31st October
   - 1st March – 14th October – Cree.
   - 11th February to 31st October – Bladnoch.

2) Commercial Fishing:
   - 25th February to 9th September - Luce, Fleet, Urr, Nith & Annan.
   - 11th February to 26th August – Bladnoch & Dee.
   - 1st March to 13th September – Cree.

In addition to fixing the length of the close season when no fishing is authorised, a weekly close period of 48 hours when nets must not operate applies between Friday and Monday during the season.

As an adjunct to the statutory measure, individual fishery owners may impose a wide range of voluntary fishery rules on anglers as condition of a grant of permission to fish their private waters. Such rules may differ widely within and between different river catchments. The fishery owners in most fishery districts have now adopted common ‘Codes of Conduct’ for all anglers fishing within a single district in accordance with local needs and circumstances. Although these voluntary constraints may differ between fishery districts, they promote the general principle of catch-and release by defining size limits, bag limits and restrictions of different forms of bait fishing at certain times of the year. While there are few restrictions relating specifically to sea trout, the more relevant constraints on rod fishing in each fishery district are summarised below:

- **Annan:** All salmon to be returned before 1st June. Bag limit = 2 sea trout a day after 1st June and catch-and-release of all sea trout above 3 lbs. Catch-and release during late extension to salmon season from16th - 30th November.
- **Nith:** Catch-and-release for all salmon caught before 1st May. Bag limit = 2 salmon or 2 sea trout per day with all sea trout over 3 lbs to be released.
- **Urr:** No salmon angling before 15th March. No bag limit for either sea trout or salmon.
- **Fleet:** Season from 1st May to 31st October.
- **Dee:** Anglers requested not to fish before 1st April. Bag limit = 1 salmon and 1 sea trout per day.
- **Cree:** Catch-and-release for all salmon taken before 1st June and after 30th September. Bag limit = 2 salmon per day and 6 salmon per week. There is no bag limit for sea trout.
- **Bladnoch:** All fish to be returned before1st June. Bag limit = 1 salmon per week. No bag limit for sea trout - but all fish in excess of 2 lbs to be released.
- **Luce:** Catch-and-release of all hen salmon caught after September. Bag limit = 3 salmon and 2 sea trout per day.

There is no statutory minimum size limit for sea trout as such, but a minimum size limit of 9-10 inches (23-25 cms) for brown trout in some districts provides an element of protection to seaward migrating pre-smolts and smolts in the spring.

2.1.2.4 Historical Catch Records

There is a long time series of historical catch data for the rod and commercial net fisheries for the many rivers and regions in Scotland that goes back to the 1850s for some of the more prestigious and productive salmon fisheries. However, it was not until the 1950s that catch records were systematically collected on a consistent and comprehensive basis for the country as a whole (Shearer, 1986). Catch data for the years 1952-1981 were summarised (DAFS, 1984) and annual reports of rod and net catch statistics have been published centrally for subsequent years. Data for the 62 Salmon Fishery Districts is currently aggregated into 11 geographical regions. The central agency currently responsible for collecting and publishing annual catch statistics is Marine Services Scotland.

2.1.2.5 Data Collection Methods

Unlike other parts of the UK and Ireland, there is no system of statutory licensing for either the rod or net fisheries in Scotland to provide the basis for collecting catch records directly from the individual participants in the fisheries. Consequently, a different system was adopted for the collection of catch records based on returns made by the individual owners of both the rod and net fisheries. Since this system has been in place since 1952 without any significant change over the 60-year period of the historical record, Scottish catch statistics currently provide the longest time series of catch for the UK and Ireland that has been compiled on a consistent and comparable basis over the period of the record.

Catch Return Information

Details of individual fishery owners are held on a central database and updated regularly to record changes in ownership when fisheries were sold. In 2009, this contained information on 2,940 separate fishery owners throughout Scotland. The annual catch records are obtained directly from the owners, their agents or tenants on a standard catch return form issued to each fishery owner. In recent years, this form was issued in September for completion and return by early December. A first-reminder notice was then sent if a return has not been submitted before that date and a second final notice is sent to non-respondents if a return is not submitted after the closure date. It is an offence not to submit a catch return.

The same standard form is used for a return of catch for both the rod and net fisheries. It requires the fishery owner to provide the following information:

- The total number and weight of wild salmon and sea trout caught for that year.
- The number and weight of fish caught in each month of the fishing season.

From 1994, the rod fisheries have been required to provide separate details of the number and weight of fish harvested (killed), and the number of fish returned alive to the fishery (catch-and-release). Since 2004 the net fisheries have been required to record monthly fishing effort as either the number of crew days fished and number of persons fishing in each month (net-and-coble fishing) or the number of traps and number of persons fishing in each month (stake nets and haaf nets). It is only since 2004 that a declaration was required for the catch of sea trout (known locally as herling or finnock) as a separate entry on the catch return form.

Some owners may control sections of fishing on more than one river in a District. The published catch records for each District do not relate to a single river as such but are an aggregated value for the whole of a District that may include several minor streams.

2.1.2.6 Fishery Performance

Catch Returns

A summary of the catch returns forms issued to the individual owners of the rod and commercial net fisheries in the Solway is given in Table 2.1.1. The annual number of forms issued and returned has remained broadly constant over the period on all rivers except the Cree and Dee, where the number increased over the period but has remained stable over the last 5 years at the present number.

Table 2.1.1 Summary of Owners' Catch Return Forms Issued and Returned for Solway Region (1997 – 2011).

River Fishery District	Forms Issued in 2011	Range issued from 1997 - 2011		Forms Returned in 2011		Forms Not Returned in 2011	
		Min	Max	With data	No data	No	%
Annan	40	39	40	16	19	5	12.50
Nith	38	38	41	27	8	3	7.90
Bladnoch	19	19	21	9	10	0	10.00
Urr	26	25	27	11	15	0	10.00
Dee	30	25	33	7	17	6	20.00
Fleet	5	4	5	2	2	1	20.00
Luce	5	5	5	2	3	0	0.00
Cree	40	23	40	12	22	6	15.00
Total	203	178	212	86	96	21	9.70

The seemingly high number of forms submitted with no data (nil returns) for different districts may have three explanations:

a) some owners with commercial fishing rights did not fish in certain years,

b) some rod fisheries may not have been fished (principally the smaller sections of fishing).
c) some rod fishing occurred but no fish were reported for the season.

The mean return rate for all Solway river districts in 2011 was 92.3% and ranged between 80 – 100% for the eight separate rivers. When considered alongside the proposition that the recording system covers all the major rod fisheries producing the largest catches, it is assumed that the historical record of catches from 1994 - 2011 represents a reasonably robust and comparable index of the general pattern of annual catches over the period.

Number of Fish Caught

Rod Fisheries

The total aggregated rod catch of salmon and sea trout from 1994-2011 is shown in Table 2.1.2 and Figure 2.1.2. It is apparent that the annual sea trout rod catch has fluctuated widely about the 18-year mean of 3,131 sea trout and ranged from 7,174 fish in 1998 to 1,274 fish in 2006. Salmon catches have varied about the long-term mean of 3,995 fish from 6,201 fish in 2008 to 2,137 fish in 2003. Between 1995 and 2001 the total annual sea trout catch exceeded the salmon catch; but this situation reversed from 2004 when the salmon catch was greater than the sea trout catch. The pattern of catches of sea trout and salmon within the region shows two very different long-term trends (Figure 2.1.2). Whereas salmon catches have increased since 2003 to approach their highest levels over the period, sea trout catches have steadily declined from a peak in 1997 to their lowest levels over the period.

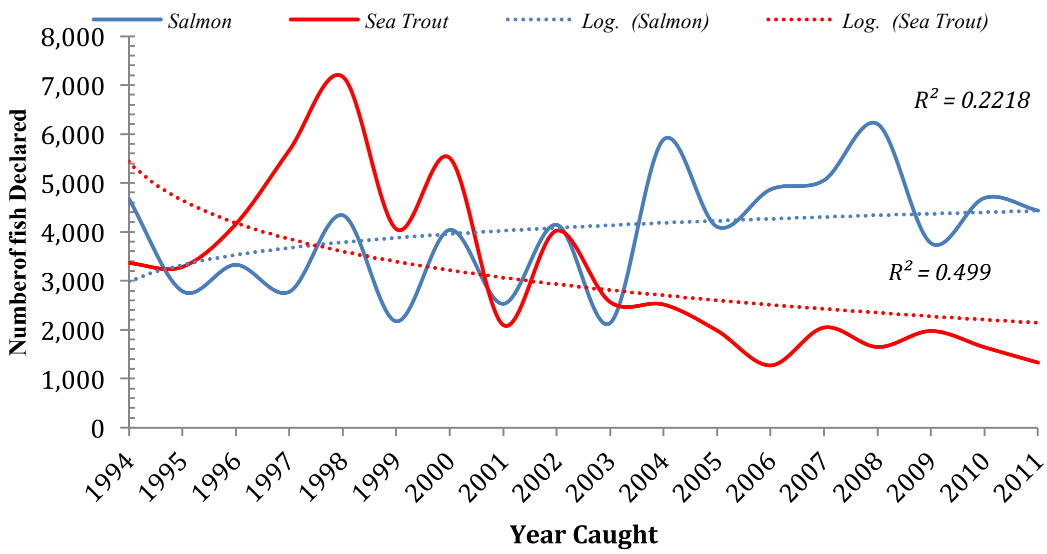


Figure 2.1.2 Aggregated Annual Rod Catch of Sea Trout & Salmon for Solway Region (1994-2011).

Table 2.1.2 Aggregated Total Annual Rod Catch of Sea Trout & Salmon for the Solway Region (1994-2011).

Year Caught	No. Fish Caught	
	Salmon	Sea Trout
1994	4,675	3,365
1995	2,787	3,287
1996	3,325	4,162
1997	2,773	5,669
1998	4,337	7,174
1999	2,171	4,062
2000	4,038	5,513
2001	2,528	2,101
2002	4,142	4,028
2003	2,137	2,569
2004	5,884	2,519
2005	4,101	1,986
2006	4,864	1,274
2007	5,052	2,048
2008	6,201	1,650
2009	3,766	1,977
2010	4,690	1,645
2011	4,432	1,332
Mean	3,995	3,131

Table 2.1.3 is a summary of the mean number and range of fish caught over the period and the status ranking (1-8) of each river based on the long-term average catch. While any regional summary is relatively insensitive to yearly fluctuations in annual catch and to general trends within and between different rivers over the period (particularly on the smaller rivers with low catches), it nevertheless provides a simple and concise summary of key features.

Table 2.1.3 Summary of Mean Annual Rod Catch, Catch Range and Group Ranking for the 8 River Districts in the Solway Region (1994-2011).

River & Fishery District	Salmon				Sea Trout			
	18-year Mean	Catch Range		Ranking (1 – 8)	18-year Mean	Catch Range		Ranking (1 – 8)
		Max	Min			Max	Min	
Annan	**860**	*1,723*	*203*	*2*	**987**	*2,734*	*208*	*2*
Nith	**2,143**	*3,345*	*983*	*1*	**1,557**	*3,384*	*489*	*1*
Urr	**197**	*419*	*23*	*4*	**62**	*204*	*12*	*5*
Dee	**65**	*106*	*20*	*7*	**35**	*218*	*0*	*6*
Cree	**409**	*608*	*209*	*3*	**261**	*615*	*65*	*3*
Fleet	**6**	*27*	*0*	*8*	**30**	*90*	*0*	*7*
Bladnoch	**166**	*331*	*83*	*5*	**3**	*16*	*0*	*8*
Luce	**142**	*264*	*57*	*6*	**129**	*274*	*53*	*4*

When ranked in order of the largest numbers of fish caught, the three most important Solway rivers are the Nith and Annan for both sea trout and salmon. The long-term mean catches for the Annan and Nith of 3,554 sea trout and 3,003 salmon represent 82% of the mean catch of 3,131 sea trout and 75% of the total mean catch of 3,965 salmon for the entire Solway Region. These two rivers have the largest catchments areas within the Region.

On the remaining 6 rivers, the mean annual catches were appreciably lower and ranged from as few as 3 - 261 sea trout and 6 - 197 sea trout overall; with only the Cree and to a lesser extent the Luce producing modest catches of both species. The Fleet, with means of 30 salmon and 6 sea trout and a 'nil' catch in several years, is clearly a fragile system. The virtual absence of any sea trout catch in excess of 16 fish in any year and a' nil' catch in several years for the Bladnoch also suggests a fragile system for sea trout. The low catches of both salmon and sea trout in the Dee (the third largest catchment in the Region) reflects the long-term impact of the hydropower development in the catchment since the 1930s.

The annual pattern of rod catches for sea trout and salmon in each of the eight Solway fishery districts is presented in Appendix 2.1 (as Figures 2.1A - 2.1G). The long-term trend of decrease in the aggregated rod catch of both species in the Solway Region is seen, to a greater or lesser extent, in the Annan, Nith, Urr, Cree and Fleet. It is not detectable for the Bladnoch or Dee, both of which have relatively low catches of both species.

Commercial Net Fisheries

Information on the pattern of commercial net catches within the Solway District is difficult to summarise in a comprehensive and detailed format for two principle reasons. Firstly, there has been a significant decrease in not only the number and location of the different fishing gears used throughout the area but also in their frequency of operation (= fishing effort) over the period. Some owners have ceased commercial fishing altogether while others have fished only intermittently in certain seasons. Secondly, while not all owners of the right to fish by commercial means also own upstream rod fishing rights, several owners of both rod and net fishing rights have ceased or reduced their commercial fishing operations to benefit the upstream rod fisheries by increasing the numbers of fish entering the rivers.

Table 2.1.4 and Figure 2.1.3 show the annual catches reported from all commercial fishing gears operated in the Solway Region over the study period. The annual catch of sea trout has varied about the long-term mean of 1,816 fish from 5,154 fish in 1994 to just 261 fish in 2006. Salmon catches have varied about a mean of 3,176 fish from 8,158 in 1995 to 1,388 in 2011.

Table 2.1.4 Annual Commercial Net Catch of Salmon and Sea Trout for the Solway Region (1994 – 2011)

Year Caught	Salmon No.	SeaTrout No
1994	7,597	5,154
1995	8,158	4,705
1996	5,899	1,109
1997	3,844	1,256
1998	2,432	1,814
1999	1,957	1,621
2000	2,543	4,156
2001	2,023	2,363
2002	2,380	1,466
2003	2,020	2,112
2004	2,329	1,656
2005	3,881	862
2006	2,841	261
2007	2,644	533
2008	1,714	929
2009	1,458	1,088
2010	2,055	899
2011	1,388	702
Mean	**3,176**	**1,816**

The overall decline in the total regional net catch between the start and end of the period (Figure 2.1.3) was more rapid and extensive for salmon than sea trout. A comparison of parallel catch data for the rods (Figure 2.1.2) shows a different relationship. While the sea trout catch has declined steadily for both the rods and nets over the same period, this trend is shown for the salmon net fishery but not for the rod fishery where salmon catches showed a slight increase over the latter part of the record.

Interpretation of any trends in the pattern of commercial catch for the separate districts of the Solway is compromised by lack of information on the number of different types of commercial fishing instruments that operated in any year and their individual fishing effort in each season over the review period. It was only since 2004 that the fishery owners were required to record monthly fishing effort. However, this did not include a monthly record of the number of days/part-days fished or, more meaningfully in relation to the large number of 'semi-recreational' haaf nets operating on the Annan and Nith, the number of tides fished in each month of the season. This difficulty in defining a robust measure of commercial fishing effort in the Solway is the reason that effort data for this Region, unlike the other Scottish Regions, is not included in Annual Statistical Fishery Reports.

Commercial fishing on the Dee, Bladnoch and Luce virtually ceased altogether from the late 1990s as owners stopped fishing or just fished in the occasional year. Consequently, the only Districts where commercial fishing continued on a consistent and comparable basis in each year throughout the 18-year review period are the Annan, Nith, Urr Fleet and Cree. Table 2.1.5 gives details of the total number of sea trout reported each year for these four districts. It also includes the combined catch for the Dee, Bladnoch and Luce under the heading 'Other Districts'.

Appendix 2.2 shows the pattern of catches by all commercial fishing gears for the 4 Districts where the combined mean catch of sea trout and salmon was greater than 100 fish in most years. It therefore omits the Fleet, with a mean catch of only 9 sea trout and 30 salmon, despite the continuity of the catch record. It is apparent that the sea trout catch for the Annan is of greater importance than the salmon catch in sustaining the commercial fishery when compared with all other districts. The mean catch of sea trout expressed as a percentage of the combined catch of both sea trout and salmon catch was 55% for the Annan compared with the Nith District at 23% and then the Urr at 14.2%, the Fleet at 23%, Cree at 11.8% and 'Other Districts' at 4.5%.

The Annan and Nith are neighbouring rivers with large catchment areas. They both support significant and productive rod and commercial net fisheries. Figure 2.1.3 compares the commercial catch of sea trout and salmon for both rivers.

The most significant feature shown in Figure 2.1.4 is the large difference in the pattern of the commercial catch of sea trout between the two rivers. The sea trout catch on the Annan exhibited a dramatic and sudden collapse 1996, followed by a rapid increase in 2000, a rapid decrease in 2002 and a steady decline to an all-time low in 2006. These marked inter-annual peaks and troughs were not apparent in the sea trout catch on the Nith and, while both sea trout fisheries indicated a steady decline over the period, salmon catches on both fisheries were broadly stable from 2000 with a common pattern of increase and decrease in most years over the remainder of the period.

The Annan is located to the east of the Nith and is further upstream in the narrower 'funnel' of the Solway Estuary. As such, the commercial net fishery on the Annan benefit from the better conditions for producing a greater catch of sea trout than the Nith. This area likely to be a more productive and attractive coastal feeding environment for mixed-stocks of sea trout from within and outside the general region. It will also contain large numbers of sea trout returning to a number of other productive sea trout fisheries in the immediate vicinity: principally the Border Esk and Eden but also several other minor rivers. In addition, the topography of the upper estuary, with shallower water and larger expanses of inter-tidal sand, is also favour the operation of the extensive haaf net fishery on the Annan. It is perhaps significant to note in this respect (Table 2.1.5) that the proportions of sea trout relative to salmon in the commercial catch for the eight fishery districts appears to decrease with the increasing westward distance from the upper Solway Estuary.

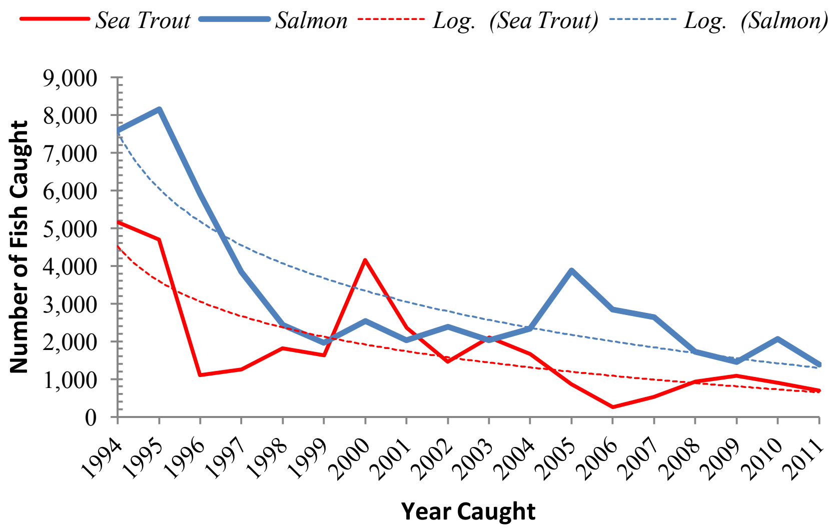


Figure 2.1.3 Annual Commercial Net Catch of Salmon and Sea Trout for the Solway Region (1994-2011).

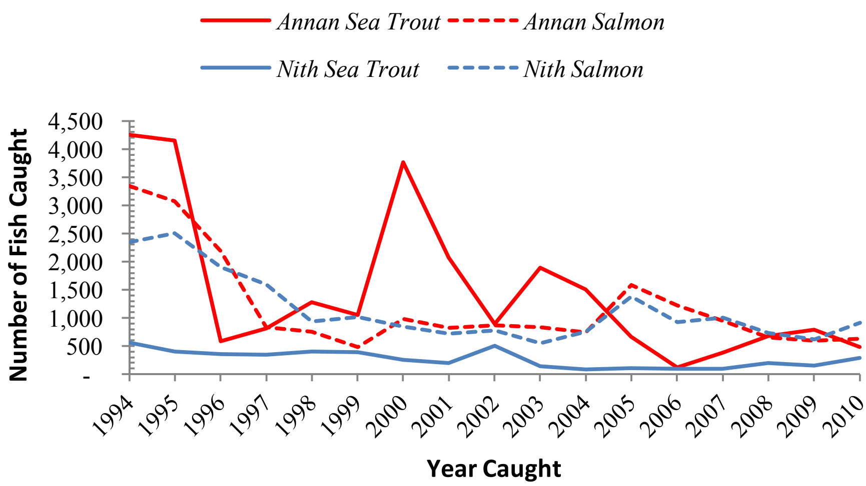


Figure 2.1.4 Commercial Catch of Sea Trout & Salmon in the Neighbouring Annan and Nith Fishery Districts (1994-2011).

Table 2.1.5 Commercial Catch of Sea Trout & Salmon for Fishery Districts in the Solway Region (1994-2011)

Year Caught	Annan		Nith		Urr		Fleet		Cree		Other Districts	
	Sea Trout	Salmon	Sea Trout	Salmon	Sea Trout	Salmon	Sea Trout	Salmon	Sea Trout	Salmon	Sea Trout	Salmon
1994	4,251	3,341	565	2,347	50	211	22	38	245	1,067	21	593
1995	4,153	3,077	409	2,507	5	160	21	54	92	1,196	25	1,164
1996	587	2,184	359	1,904	39	257	14	37	72	794	38	723
1997	812	830	349	1,599	13	247	25	37	24	658	33	473
1998	1,279	761	401	941	32	83	11	15	74	454	17	178
1999	1,049	482	390	1,012	6	68	6	23	158	290	12	82
2000	3,763	979	260	847	10	140	24	55	99	496	-	26
2001	2,073	826	204	725	35	97	10	21	41	354		
2002	897	869	506	779	20	113	1	29	42	590		
2003	1,894	837	145	553	12	56	3	32	58	542		
2004	1,509	743	89	753	1	115	9	22	45	549	2	147
2005	670	1,587	112	1,379	13	100	3	43	56	699	8	73
2006	122	1,220	96	921	1	54	4	30	38	616		
2007	384	944	92	1,001	1	71	-	18	56	610		
2008	673	649	200	736	-	76	3	15	53	238		
2009	791	597	158	624	50	80	3	18	86	139		
2010	484	635	293	920	46	74	4	30	69	396		
2011	590	681	94	545	6	43	2	21	10	98		
Mean	1,443	1,180	262	1,116	19	114	9	30	73	544	23	509

('Other Districts' includes the aggregated catch from Dee, Bladnoch and Luce Districts.)

Catch-and-Release Rod Fishing

An increasing number of anglers return all or part of their catch immediately after capture in order to conserve annual spawning stocks and subsequent recruitment into future generations of fish. Catch-and-release fishing in Scotland is not a statutory requirement but essentially a voluntary Code of Conduct encouraged by fishery owners or otherwise adopted by many individual anglers as a personal ethic. The ban on the sale of rod caught fish from 2002 now means that anglers cannot profit from harvesting large numbers of fish and has helped to reinforce C&R in several important respects.

Table 2.1.6 shows the numbers of fish released after capture as a proportion of the total rod catch of sea trout in each fishery district. Table 2.1.1 and Table 2.1.8 give a detailed breakdown of the annual numbers of sea trout and salmon caught and released from the Annan, Nith, Cree and Luce as the four Solway Districts with the largest catch of sea trout. This is also illustrated in Figure 2.1.5 and Figure 2.1.6.

Table 2.1.6 Summary of Catch Return Rates (%) for Rod-Caught Sea Trout in the Solway Region (1994-2011).

Year	Annan	Nith	Cree	Luce	Fleet	Urr	Bladnoch	Dee
1994	1.1	3.6	0.5	0.0	0	0.0	0.0	0.0
1995	0.9	3.3	29.2	0.0	13	0.0	0.0	0.0
1996	1.8	7.2	9.7	0.0	0	0.0	0.0	0.0
1997	9.0	6.8	11.6	0.5	0	0.0	0.0	0.0
1998	7.4	8.6	2.3	5.2	0	20	20	0.0
1999	25.8	13.3	4.8	4.0	4.8	68.8	68.8	0.0
2000	17.6	7.7	21.4	0.0	31	0.0	0.0	32.9
2001	23.8	13.6	24.0	0.0	0	0.0	0.0	83.3
2002	28.3	18.1	6.8	6.9	12.2	0.0	0.0	20.0
2003	30.0	16.3	24.4	16.9	0	33.3	33.3	33.3
2004	29.5	18.6	15.4	28.9	0	100.0	100.0	41.9
2005	20.9	21.1	6.0	89.4	38	100.0	100.0	68.2
2006	33.6	26.0	53.3	10.7	0	100.0	100.0	70.2
2007	47.0	41.2	43.2	39.2	53	50	50	67.4
2008	60.0	50.1	76.9	28.3	0	0.0	0.0	53.8
2009	46.7	46.4	76.0	68.3	25	0.0	0.0	0.0
2010	70.0	38.7	87.8	39.7	40	0.0	0.0	37.5
2011	57.9	45.4	83.6	48.2	0	0.0	0.0	50.0
Mean %	**20.1**	**15.8**	**19.7**	***19.8***	***11.9***	***36.4***	***36.4***	**44.9**

The mean release rates over the 18-year period represent the total number of fish returned as a proportion of the total catch over that period. For sea trout, they ranged from 11.9% on the Fleet to 36.4% on the Bladnoch. It is notable that the rivers with the lowest annual catches Bladnoch, Dee, Fleet and Urr show the widest variation in return rates; with means of 11.9% – 44.9% and a range of 0.0 – 100%) over the period. By comparison with sea trout, the mean return rates for salmon over the same period (Table 2.1.8), ranged from 14.8% on the Luce to 28.3% on the Cree. The Annan and Nith, as the two most productive salmon rivers in the Region, showed mean return rates for salmon of 28.1% and 27.4% respectively.

One significant and important trend over the period has been the steady increase in the proportion of the catch returned (Figure 2.1.5 and Figure 2.1.6).This is more apparent for sea trout than salmon in recent years.

Table 2.1.7 The Number of Sea Trout Caught-&-Released by Anglers in the 4 Major Districts of the Solway Region (1994-2011).

Year Caught	Annan			Nith			Cree			Luce		
	Caught	Released	%	Caught	Released	%	Caught	Released	%	Caught	Released	%
1994	996	11	0.6	1,795	65	3.6	382	2	0.5	63	0	0.0
1995	1,124	10	0.5	1,425	47	3.3	569	166	29.2	90	0	0.0
1996	1,132	20	1.0	1,914	138	7.2	843	82	9.7	216	0	0.0
1997	1,871	168	8.4	3,215	220	6.8	328	38	11.6	182	1	0.5
1998	2,734	201	10.1	3,384	291	8.6	615	14	2.3	249	13	5.2
1999	1,689	435	21.8	1,555	207	13.3	421	20	4.8	174	7	4.0
2000	1,976	347	17.4	2,695	207	7.7	210	45	21.4	274	0	0.0
2001	505	120	6.0	1,385	189	13.6	125	30	24.0	71	0	0.0
2002	1,240	351	17.5	2,117	384	18.1	147	10	6.8	232	16	6.9
2003	533	160	8.0	1,739	284	16.3	180	44	24.4	83	14	16.9
2004	831	245	12.2	1,217	226	18.6	65	10	15.4	190	55	28.9
2005	526	110	5.5	755	159	21.1	150	9	6.0	151	135	89.4
2006	298	100	5.0	653	170	26.0	45	24	53.3	28	3	10.7
2007	389	183	9.1	938	386	41.2	183	79	43.2	79	31	39.2
2008	455	273	13.6	811	406	50.1	121	93	76.9	53	15	28.3
2009	540	252	12.5	1,075	499	46.4	96	73	76.0	104	71	68.3
2010	467	327	16.3	865	335	38.7	98	86	87.8	73	29	39.7
2011	447	259	12.9	489	222	45.4	122	102	83.6	141	68	48.2
Total	**17,753**	**3,572**	**20.1**	**28,027**	**4,435**	**15.8**	**4,700**	**927**	**19.7**	**2,318**	**458**	**19.8**

Table 2.1.8 The Number of Salmon Caught-&-Released by Anglers in the 4 Major Districts of the Solway Region (1994-2011).

Year Caught	Annan			Nith			Cree			Luce		
	Caught	Released	%	Caught	Released	%	Caught	Released	%	Caught	Released	%
1994	654	23	3.5	2598	133	5.1	520	2	0.4	193	0	0
1995	443	30	6.8	1204	135	11.2	600	94	15.7	279	20	7.2
1996	651	54	8.3	1831	300	16.4	353	37	10.5	135	0	0.0
1997	517	32	6.2	1501	201	13.4	358	58	16.2	100	2	2.0
1998	1,069	107	10.0	2093	307	14.7	468	60	12.8	139	4	2.9
1999	649	144	22.2	983	203	20.7	261	26	10.0	75	6	8.0
2000	720	126	17.5	2130	319	15.0	426	152	35.7	217	11	5.1
2001	203	58	28.6	1764	468	26.5	264	53	20.1	110	2	1.8
2002	752	206	27.4	2574	873	33.9	242	62	25.6	112	2	1.8
2003	217	105	48.4	1438	490	34.1	209	63	30.1	57	21	36.8
2004	1,272	321	25.2	3424	1110	32.4	402	122	30.3	151	13	8.6
2005	937	233	24.9	2281	764	33.5	420	135	32.1	92	25	27.2
2006	979	278	28.4	2682	686	25.6	563	193	34.3	115	22	19.1
2007	1,230	532	43.3	2753	1131	41.1	387	184	47.5	115	26	22.6
2008	1,732	575	33.2	3345	1187	35.5	450	224	49.8	179	29	16.2
2009	1,051	372	35.4	1899	643	33.9	375	184	49.1	58	13	22.4
2010	1,013	499	49.3	2473	988	40.0	608	246	40.5	158	33	20.9
2011	1,385	654	47.2	1610	618	38.4	461	192	41.6	264	148	56.1
Total	**15,474**	**4,349**	**28.1**	**38583**	**10556**	**27.4**	**7,367**	**2,087**	**28.3**	**2,549**	**377**	**14.8**

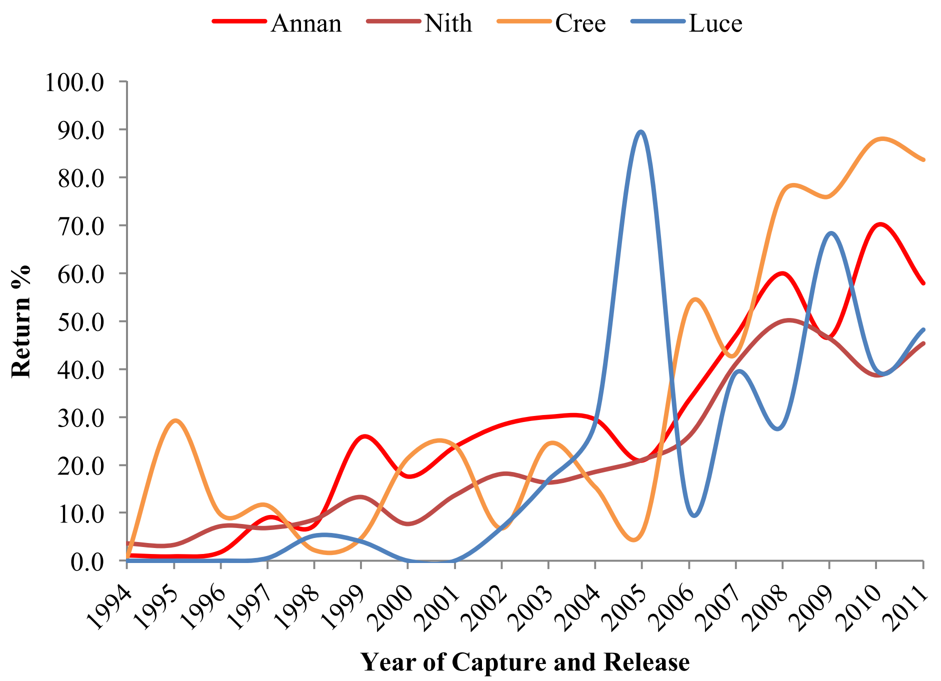


Figure 2.1.5 The Proportion of Sea Trout Caught-and-Released by Anglers in 4 Fishery Districts of the Solway Region (1994 – 2011).

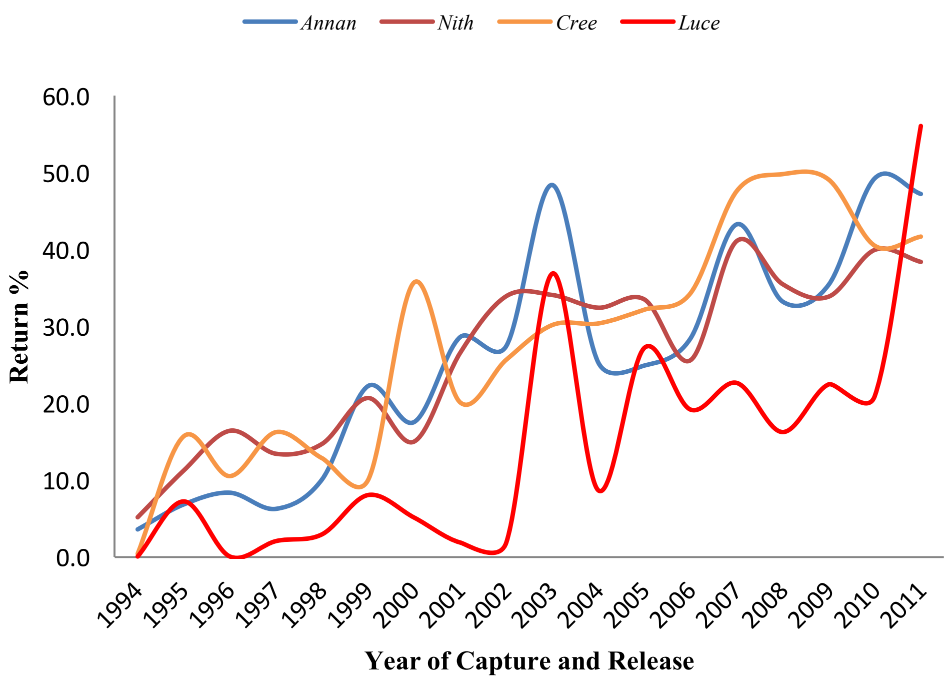


Figure 2.1.6 The Proportion of Salmon Caught-and-Released by Anglers in 4 Fishery Districts of the Solway Region (1994 – 2011).

Weight of Fish Caught

Information on the weight of fish caught by the rods on the rivers in the Solway District is restricted to the aggregated total weight of all fish caught over the season from each fishery based on the total weight of fish caught in each month. Since fishery owners are not required to report the weight of individual fish on the catch return form, it is not possible to describe the quality of the fishing in terms of the proportions of the catch across a range of different size classes of fish as is possible or England and for Wales (see Sections 2.1.3 and 2.1.4). Therefore, the only available data for the Solway is the aggregated mean weight of fish in each year. This has limited value other than to show the mean weight of each fish caught as a relative index of the health and quality of the fishery.

Rods

Table 2.1.9 shows the total number, total weight and mean weight of each sea trout and salmon caught each year by anglers in the Solway Region. The mean weight of sea trout ranged about a mean of 1.0 kg from 0.8 kg to 1.1 kg over the period and the mean weight of salmon ranged from 3.3 kg to 4 kg about a mean of 3.2 kg. On average, rod-caught, sea trout weighed about 30% less than salmon.

Table 2.1.9 Total Weight of Rod Catch and Mean Weight of Individual Sea Trout & Salmon for Solway Region (1994-2011).

Year Caught	Salmon			Sea Trout		
	Total Catch	Total Weight	Mean Weight	Total Catch	Total Weight	Mean Weight
1994	4,675	17,845	3.8	3,365	2,929	0.9
1995	2,787	9,702	3.5	3,287	2,522	0.8
1996	3,325	12,218	3.7	4,162	3,476	0.8
1997	2,773	9,601	3.5	5,669	5,405	1.0
1998	4,337	15,228	3.5	7,174	6,646	0.9
1999	2,171	8,094	3.7	4,062	3,939	1.0
2000	4,038	13,938	3.5	5,513	6,045	1.1
2001	2,528	9,000	3.6	2,101	2,118	1.0
2002	4,142	15,473	3.7	4,028	4,290	1.1
2003	2,137	8,237	3.9	2,569	2,753	1.1
2004	5,884	21,178	3.6	2,341	2,640	1.1
2005	4,101	15,294	3.7	1,721	1,811	1.1
2006	4,864	16,482	3.4	1,120	1,163	1.0
2007	5,052	17,173	3.4	1,877	1,966	1.0
2008	6,201	21,314	3.4	1,484	1,451	1.0
2009	3,766	13,627	3.6	1,869	1,830	1.0
2010	4,690	15,495	3.3	1,536	1,465	1.0
2011	4,432	17,776	4.0	1,240	1,218	1.0
Mean	**3,995**	**14,315**	**3.6**	**3,062**	**2,982**	**1.0**

Parallel information on the total annual weight and mean weight of rod-caught sea trout and salmon for each of the eight river districts over the same period is summarised in Table 2.1.10 to highlight any significant difference between districts that may reflect different stock characteristics. The annual mean weight of sea trout varied widely within seasons and between rivers over the period within the range of 0.3 and 1.9 kg. The Dee exhibited the highest mean weight (1.2 kg) and the Cree and Fleet the lowest (0.7 kg). The neighbouring rivers Annan and Nith showed identical mean weights (1.0 kg) and range of weights (0.8 kg to 1.2 kg). It is noteworthy that the highest mean weight for sea trout (1.3 kg) was recorded for the Dee, in addition to a wide range of mean weights (0.5 kg -1.9 kg).

Table 2.1.10 Mean Individual Fish Weights and Weight Range of Rod-Caught Fish for Rivers of Solway Region (1994-2011).

Fishery District	Salmon (kg)			Sea Trout (kg)		
	Mean	Max	Min	Mean	Max	Min
Annan	3.8	4.3	3.2	1	1.2	0.8
Nith	3.7	4.3	3.2	1	1.2	0.8
Urr	3.4	4.2	2.8	0.8	1.1	0.5
Dee	3.2	5.2	3.2	1.3	1.9	0.5
Fleet	3.1	4.5	2	0.7	0.5	0.3
Cree	3.2	3.4	2.9	0.7	0.9	0.5
Bladnoch	3.3	3.8	3	1.2	0.7	2
Luce	3.1	3.8	2.7	1	1.3	0.6

Commercial Nets

Table 2.1.12 shows the total weight and mean weight of sea trout and salmon from the commercial fishery for all fishery districts in the Solway Region. The weight of each sea trout caught by the nets ranged around a mean of 1.2 kg from 0.9kg to 1.8 kg, with no discernible trend of increase or decrease over the period. Similarly, the mean weight of salmon showed little variability and ranged about a mean of 3.6 kg from 3.3 kg to 4.0 kg. The mean weight of net-caught sea trout at 1.2 kg was greater than for rod-caught sea trout at 1.0 kg. It is likely that the mesh size used in the construction of the different net fishing gears used in the Solway allows the smaller sea trout of <0.75 kg to avoid capture so that the nets fish selectively for the larger sized sea trout.

Month of Capture

Detailed information on the month of capture of sea trout and salmon by the rod fisheries for each of the 8 districts within the Solway Region is summarised in Table 2.1.12.

Table 2.1.11 Total Weight (kg) and Mean Weight of Individual Sea Trout & Salmon from the Commercial Net Fishery in the Solway District (1994-2011).

Year Caught	Salmon			Sea Trout		
		Weight (kg)			Weight (kg)	
	No. Fish	Total	Mean	No. Fish	Total	Mean
1994	7,597	25,815	3.4	5,154	4,511	0.9
1995	8,158	26,190	3.2	4,705	4,524	1.0
1996	5,899	20,243	3.4	1,109	1,187	1.1
1997	3,844	11,343	3.0	1,256	1,287	1.0
1998	2,432	7,618	3.1	1,814	1,704	0.9
1999	1,957	6,933	3.5	1,621	1,752	1.1
2000	2,543	8,328	3.3	4,156	6,258	1.5
2001	2,023	6,081	3.0	2,363	3,422	1.4
2002	2,380	8,446	3.5	1,466	2,294	1.6
2003	2,020	7,304	3.6	2,112	3,441	1.6
2004	2,329	7,245	3.1	1,655	2,447	1.5
2005	3,881	12,374	3.2	862	1,166	1.4
2006	2,841	8,315	2.9	261	345	1.3
2007	2,644	7,576	2.9	533	584	1.1
2008	1,714	5,238	3.1	929	1,016	1.1
2009	1,458	4,898	3.4	1,088	1,968	1.8
2010	2,055	6,276	3.1	896	1,193	1.3
2011	1,388	4,850	3.5	702	812	1.2
Mean	**3,176**	**10,282**	**3.2**	**1,816**	**2,217**	**1.2**

Table 2.1.12 Monthly Mean Rod Catch Sea Trout & Salmon from the Solway Region (1994-2011).

Species / Stage		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
MSW Salmon	**No.**	134	323	533	786	1049	1838	4344	10754	17807	11841	49,409
	%	*0.27*	*0.65*	*1.08*	*1.59*	*2.12*	*3.72*	*8.79*	*21.77*	*36.04*	*23.97*	100%
1SW Salmon	**No.**	0	0	13	108	567	2327	4879	6998	5667	1283	22,492
	%	*0*	*0*	*0.06*	*0.48*	*2.52*	*10.35*	*21.69*	*31.11*	*25.20*	*5.70*	100%
All Salmon (*MSW +1SW*)	**No.**	134	323	546	894	1616	4165	9223	17752	23474	13774	71,903
	%	*0.19*	*0.45*	*0.76*	*1.24*	*2.25*	*5.79*	*12.83*	*24.69*	*32.65*	*19.16*	100%
All Sea Trout	**No.**	27	190	769	3970	14429	17782	8674	5140	2701	1434	55,116
	%	*0.05*	*0.34*	*1.40*	*7.20*	*26.18*	*32.26*	*15.74*	*9.33*	*4.90*	*2.60*	100%

Although the month of capture is not synonymous with the time when a fish first entered a river, it provides a general picture of the pattern of angling success over the year based on the increasing abundance of fish available for capture by the rods. It is to be noted that the fishing season for salmon and sea trout in the Solway Region has the same start and finish dates even though there are relatively few early and late running sea trout. These dates are respectively earlier and later than on most rivers in other regions of the UK and Ireland to allow anglers to fish for the early spring and late autumn runs of the larger MSW salmon. The Annan and Nith, in particular, are renowned for the strength of their autumn salmon runs.

Figure 2.1.7 shows the mean monthly numbers of sea trout and salmon caught in the Solway Region over the 18 years from 1994 -2011. Sea trout catches were low in the spring months and then increased steadily throughout May, June and July before falling off again from August until the end of the season in November. The monthly rod catch of salmon lags behind sea trout by about 2 months, starting to increase after June to a peak in October but still producing a large number of fish in November.

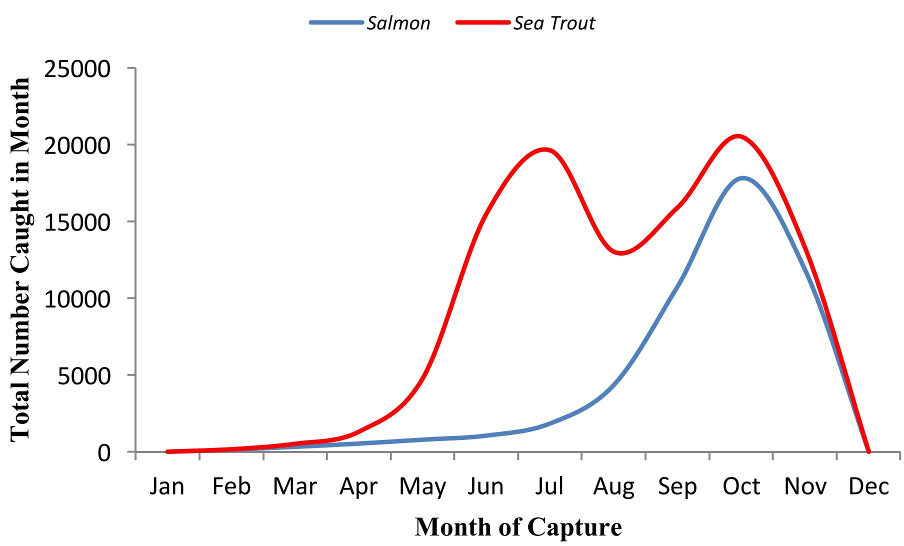


Figure 2.1.7 The Total Number of Sea Trout & Salmon Caught in the Solway Region by Anglers in Each Month of the Fishing Season (1994-2011).

This monthly pattern of salmon catches relative to sea trout is distorted by combining both the 1SW and MSW salmon stock components in the combined 'all salmon' catch in Figure 2.1.7. When the total salmon catch is broken down into the separate 1SW and MSW components and expressed as a proportion of the annual catch (Figure 2.1.8), a somewhat different picture appears, with the 1SW component representing a major part of the annual salmon catch in August and September.

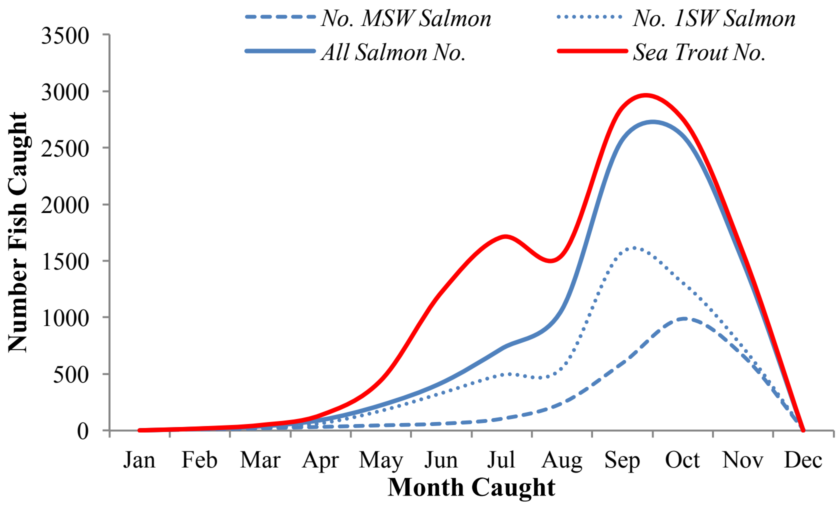


Figure 2.1.8 Total Number Sea Trout & Salmon Caught by Anglers in the Solway Region in each Month of the Fishing Season (1994-2011).

The importance of the sea trout in sustaining the rod-fisheries during the late spring and early summer months is illustrated by the cumulative percentage catches in each month over the season (Figure 2.1.8 and Figure 2.1.9). This shows that 67.5% of the sea trout were caught before August compared with 13.3% of 1SW grilse and 9.4% of MSW salmon were caught before August, while 92.5% of the sea trout catch been taken before October compared with 86.2% of the grilse catch and just 39.9% of the MSW salmon catch. This highlights the importance of sea trout to the Solway Region in sustaining the rod fishery throughout the late spring and summer months until the arrival of the summer runs of grilse and the autumn run of MSW salmon.

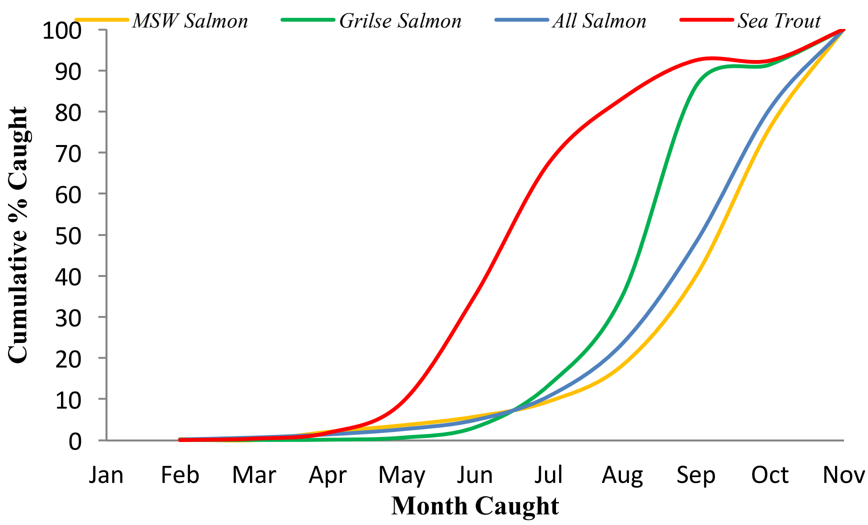


Figure 2.1.9 Cumulative Monthly Proportions of Sea Trout, MSW Salmon, 1SW Grilse Salmon & All Salmon Caught by Anglers in the Solway Region (1994-2011).

Catch-&-Effort Relationship (CPUE)
There is no system of licensing rod-and-line fishing in Scotland to establish the number of anglers participating in the fisheries each year and the annual catch return form submitted by individual owners does not require owners to state the number of angler rod days fished on their waters over a season. As with the recreational rod fishery, there is no published information on fishing effort by different types of commercial fishing gear in the Solway Region. Details of net fishing effort were not included in the annual catch returns from the owners of commercial fisheries until 2004 and the information then requested was not in a form that adequately covered fishing effort by the extensive haaf net fisheries on the Annan and Nith. Consequently, information on fishing effort and catch success for either the rod or net fisheries is not available.

Method of Capture
There is no information on the number and proportion of rod caught fish captured by the different angling methods (fly-fishing, spinning and bait fishing). Fishery owners are not required to provide this information in their annual return of catch. The different types of commercial fishing gear used in the Solway Region are, as noted elsewhere, stake nets, net-and-coble fishing (=seine nets), haaf nets and poke nets. A breakdown of catch by method cannot be included here as the information is not available in a complete and comprehensive format and because the number of instruments operated each year has not been consistent over the period within and between Fishery Districts.

2.1.2.7 Stock Assessment
There are no fish counters or fish trapping installations operating in the Solway District that routinely monitor the abundance and pattern of run-timing of sea trout and salmon stocks.

2.1.3 Northwest England

2.1.3.1 Introduction
The Northwest regions of England and Wales are very similar in several important respects. They are both under the aegis of the same Government Agency for the discharge of their statutory fishery management functions and operate over the same geographical regions without significant change since 1974. They both implement the same fisheries legislation and they have both adopted a statutory rod licensing system for salmon and sea trout since 1865 with a mandatory return of catch required in the same standard format since 1989.

Unlike Scotland, there is no private right of ownership of fishing rights in the sea in England and Wales (with a few ancient exceptions), but fishing rights in non-tidal waters are also subject to private ownership.

The North West Region of England extends from the national border with Scotland in the north to the national border with Wales in the south and covers approximately 220 km of the coastline in the northeast section of the Irish Sea. It is one of eight regions of the National Rivers Authority for England & Wales covering the seven English regions and the Welsh region. This arrangement has operated without material change in the data collection procedures from 1994 and, as such, the annual reports on fishery catch statistics have been collected and published in a comparable standard format over the last 18 years. As noted above for the Scottish Solway Rivers (Section 2.1.2), responsibility for the regulation of sea trout and salmon fisheries on the Scottish Border Esk which flows through both countries is devolved to the Environment Agency and managed as part of the

North West Region. Consequently, catch statistics for this important cross-border river have been collected and reported in the same way as other rivers in the North West Region.

2.1.3.2 General Background

Fishery Features

There are 14 principal rivers in the region sustaining locally significant rod fisheries for sea trout and salmon (Figure 2.1.10). Some of these also sustain commercial net fisheries in their estuaries or at specific locations around the coastline.

The main river lengths (source to upper tidal limit) and total catchment areas of the 14 principle sea trout fisheries in the Region, in order of decreasing size are shown in Table 2.1.13.

Table 2.1.13 Main channel lengths (km) and catchment area for 14 major sea trout fisheries in the Northwest Region

River	Eden	Ribble	Lune	Derwent	Border Esk	Wyre	Kent
Length (km)	137	119	91	72	88	57	46
Area (km^2)	2,339	1,861	1,101	679	688	433	468
River	**Leven**	**Ehen**	**Ellen**	**Cumbrian Esk**	**Duddon**	**Irt**	**Calder**
Length (km)	44	39	38	27	26	30	17
Area (km^2)	305	155	130	109	115	115	45

Other small rivers producing occasional rod caught sea trout each year are all less than 30 km in length (Keer, Annas, Bela, and Wampool).

Several of these rivers originate in the high rainfall area of the English ‘Lake District’ and include one or more natural lakes and reservoirs within their catchments, on either the main river or its tributaries. Some of these lakes are relatively large and deep and some are used as natural water supply reservoirs while artificial reservoirs have been constructed in other catchments where water is also abstracted for domestic and industrial use. These include: 1) Derwent (Bassenthwaite), 2) Irt (Wastwater), 3) Leven (Windermere), 4) Crake (Conniston). 5) Eden (Ullswater, Haweswater and the Howden, Derwent and Ladybower reservoirs) and 6) Ehen (Buttermere).

With the notable exception of the Rivers Mersey, Weaver and Douglas in the heavily industrialised and populated south of the region which lost their runs of migratory salmonids during the 19th century, natural self-sustaining stocks of wild sea trout and salmon occur in all significant river systems and most minor coastal streams throughout the area. However, stocks in some rivers, such as the Ribble and Wyre, remain depleted and have yet to fully recover from the negative effects of historical pollution, the construction of impassable or semi-impassable weirs to divert water for industrial purposes, reservoir impoundments and residual pollution from mining for minerals and coal.

Rod Fisheries

There are 14 named rivers supporting significant rod-fisheries for sea trout and salmon in the region where annual rod catch statistics for each river were published on a consistent and regular basis since 1994. These are listed in Table 2.1.14 and are ranked in order of importance based on the average numbers of sea trout and salmon caught over the most recent 5-year period from 2007-2011.

Figure 2.1.10 Principal Rivers of the Northwest Region of England.

Table 2.1.14 Mean Rod Catch of Salmon and Sea Trout and Importance Ranking for the 14 Principal Rod Fisheries in the Northwest Region (2007-2011).

River	5-Year Mean Catch		Ranking (1-14)	
	Sea Trout	Salmon	Sea Trout	Salmon
Calder	12	46	*14*	*11*
Derwent	236	1,156	*7*	*2*
Duddon	172	79	*8*	*10*
Eden	275	1,376	*6*	*1*
Ehen	353	383	*5*	*7*
Ellen	75	24	*11*	*12*
Border Esk	1,068	980	*2*	*5*
Cumbrian Esk	144	86	*9 =*	*9*
Irt	144	110	*9 =*	*8*
Kent	470	483	*4*	*6*
Leven	60	66	*12*	*12*
Lune	1,071	1,112	*3*	*4*
Ribble	1,250	1,149	*1*	*3*
Wyre	35	14	*13*	*14*

The three most important sea trout rivers in terms of total catch are clearly the Ribble, Border Esk and Lune all with an average annual catch in excess of 1,000 fish. The remaining 11 rivers all had an average sea trout catch of less than 500 fish. By contrast, four rivers had an annual salmon catch in excess of 1,000 fish, the Eden, Derwent, Ribble and Lune. While the average sea trout catch only exceeded the salmon catch on the Lune by a narrow margin, catches were roughly equal on the Ribble and Border Esk. The Rivers Derwent and Eden, as two of the more important salmon rivers, were ranked poorly for sea trout by a large margin of around 1,000 fish: equivalent to 20 % of the salmon catch. Several other minor rivers producing a mean annual catch of less than 35 sea trout or with a nil catch in certain years are not included in Table 2.1.14.

In addition to the widespread and abundant native brown trout, which provide important angling opportunities on most rivers and streams, notably the Eden (Nelson, 1922) and the many stocked and unstocked reservoirs and lakes, the region also sustains increasing rare and endangered, relic populations of two land-locked salmonid species, Arctic charr and whitefish. The Arctic charr (*Salvelinus alpinus*) is the more widely distributed and is still found in several lakes, notably Windermere and Conniston Water. The whitefish is rarer and more localised, and is represented by two sub-species, the Schelly, (*Coregonus lavaretus*) found only in Lakes Haweswater, Ullswater and Red Tarn (River Eden Catchment) and the Vendace (*Coregonus albula*) found only in Lakes Derwentwater and Bassenthwaite (River Derwent catchment) and in a few locations in Southern Scotland. In addition to the grayling (*Thymallus thymallus*), a wide range of coarse fish species were introduced to the region over the last century and now provide important angling opportunities to anglers on some of the large river fisheries, such as the Ribble, Eden and Lune.

With a very few notable exceptions, fishing rights in non-tidal waters are private property and every angler requires a grant of permission to fish from the owner to obtain lawful access to the fishery. Much of the fishing on most of the smaller streams and on many sections of the larger rivers is owned or otherwise controlled by angling association who issue permits to the public. On the larger rivers (Lune and Ribble), several clubs may control different sections the fishing. Elsewhere, on other rivers such as the Eden, sections of the fishing are rented to small syndicates for all or part of the season, while on the Derwent, and a few other rivers such as the Irt and Crake, a small number of time-share ownership schemes now operate.

Commercial Net Fisheries

Every person fishing commercially for salmon and sea trout must possess an annual fishing licence. The number of licences available for a particular type of fishing instrument within a defined area is fixed at maximum number in any one year under the terms of local Net Limitation Orders within the Region.

Grimble (1913) describes the nature and extent of commercial fishing for sea trout and salmon within the region in 19th and early 20th centuries. Fishing then was largely uncontrolled and unregulated throughout the regions and practiced with a range of different nets, fixed engines and fishing weirs. Illegal fishing was widespread. Many of the forms of fishing then described have since been made unlawful in the North West Region (e.g. stake nets, coop nets) and fishing is now restricted to the use of a fixed number of seine nets, haaf nets, lave nets and fixed engines in specified locations.

The widespread decline in the commercial fishing for migratory salmonids in other parts of the UK and Ireland is also evident in the Northwest of England. Table 2.1.15 compares the number of different types of commercial fishing instruments licensed in the Region over the 26- year period from 1985 – 2011. A total of 306 licences were issued in 1985 for 7 types of fishing gear at 11 locations compared with only 105 licences for 5 different types of fishing gear at 7 locations in 2011. The greatest reduction over the period was 187 for the haaf net licences: which decreased from 236 to 64 in the Solway District, from 26 to 12 on the Lune, and from 1 to zero on the Ellen.

Table 2.1.15 Number and Location of Available Licences for Different Types of Commercial Fishing Gear in Northwest England (1985 - 2011).

River, Estuary or Coastal Zone	Type of Fishing Gear	No. of Licencees	
		1985	**2011**
Solway District *[1]	Haaf Nets	236	64
Ellen	Haaf Nets	1	-
Eden	Seine Nets	1	-
	Coops	2	3
Derwent	Coop	1	-
SW Cumbria	Fishing Baulk	1	-
Cumbria	Drift Nets	4	5
Ribble	Drift Nets	6	5
Lune	Haaf Nets	26	12
	Drift Nets	10	7
	Seine Nets	1	-
Duddon	Seine Nets	3	-
Kent	Lave Nets	8	7
Leven	Lave Nets	6	2
Regional Total - All Gears		**306**	**105**

[1] = Eden & Border Esk

2.1.3.3 Fishery Rules & Regulations

Fishing rights in non-tidal waters in England and Wales are subject to private ownership and may be bought and sold on the open market. However, unlike Scotland (see Section 2.2.1), this right of private ownership does not extend to fishing in tidal water (estuaries and the sea) in England. Every angler and netsmen fishing for sea trout and salmon in England and Wales must possess a licence and must submit a mandatory return of catch at the end of each season. Unlike Scotland, there is no ban on fishing for sea trout and salmon on a Sunday.

Measures to protect sea trout and salmon stocks from over-exploitation by the rod and net fisheries extend to a range of statutory regulations imposed by management agencies and other voluntary rules adopted by the owners of the private fishing rights on inland (non-tidal) waters.

In general terms the statutory regulations (byelaws) relating the rod and commercial nets fisheries have been in place in broad generic terms since the 1923 Salmon & Freshwater Fisheries Act and periodically reviewed and amended when necessary every 10 years or earlier if an exceptional need arises. Although some minor modifications have been made to the rod-fishing byelaws over the 18-year review period for the historical record of catches, such changes have been to make minor adjustments to the start and end dates of the rod-fishing season and to increase angler catch-and-release rates on some rivers.

Rod Fishing

The current (2011) fishing season for sea trout and salmon differ by a few weeks, with the sea trout season starting on 1st April and ending on 31st October on all rivers in the region. The salmon season starts earlier and ends later; it is 1st February for all rivers except the Eden where it extends from 15th January to 14th October. The only river with a bag limit for sea trout is the Border Esk, where anglers may retain (harvest) a maximum of 2 fish per day until 20th September and must release any sea trout caught after this date. The only maximum bag limits applying to salmon are on the Ribble (2 fish per season) and Lune (4 fish per season). Salmon angling on the Leven and Crake is currently subject to mandatory catch-and-release for the entire season.

Commercial Net Fishing

The introduction of the National Spring Salmon Fishery Byelaws in 1997 to protect declining stocks of early running ‘spring’ salmon resulted in a delay to the start of the annual net fishing season by some 10 – 14 weeks. The current (2011) commercial net fishing season now starts on 1st June and ends on 31st August for all fishing gears except the Solway haaf nets where it ends on 9th September. The weekly close-time (when all nets must not fish) extends from 06.00 hours on a Saturday to 06.00 hours on a Monday for all gears except the Solway haaf nets where it extends from 22.00 hours on a Friday to 10.00 hours on a Monday. A further added restriction on the Solway haaf nets is prohibition on fishing (at night) between 22.00 hours and 10.00 hours the next day. These regulations apply to both sea trout and salmon.

2.1.3.4 Historical Catch Records

It is only since the formation of the Environment Agency in 1994 that catch records for salmon and sea trout were collected in a standard format throughout England & Wales. Although catch statistics for the region were published in various formats by predecessor management agencies (i.e. National Rivers Authority, Regional Water Authority, River Boards), there was no consistent or comparable approach within and between these former agencies.

The historical record of catches for the rod and net fisheries in England & Wales as published by various agencies over the period 1951- 1990 has been reviewed (Russell et al., 1995). This provides a comprehensive digest of the catch data for the North West Region from 19 named river systems and a further ‘unknown’ group of small rivers where catches were very low or infrequently recorded. From 1994, when annual reports of regional catch statistics were first published in a common format, catch data for 14 named rivers, and an aggregated group listed as 'other rivers', has been routinely included over the eighteen years to 2011. These 14 named rivers are shown in Table 2.1.14 along with their mean rod catch of sea trout and salmon for the most recent 5-year period (2007-2011) and their ranked order (1- 14) based on their respective mean catches of sea trout and salmon.

2.1.3.5 Data Collection Methods

The same standard catch return form for obtaining catch data from every licensed angler and commercial net fisherman has been used throughout the region since 1994. The catch return form is issued at the same time as the licence. A return of catch is mandatory. The rod-catch return must be submitted within 7 days of the end of the fishing season (full season licences) or within 7 days of the expiry of a licence (weekly and day licences). The commercial fishing return must be submitted at the end of each month of the fishing season.

The following information is required from every individual angler for each season:

- The name of each main river fished.
- Number of days/part-days fished on each named river.

Then for each named river,

- Number of sea trout and salmon caught in each river.
- The month of capture of each fish.
- The total number of small sea trout (whitling or herling) of less than 1lb weight caught in each month.

In addition, for all other sea trout over 1lb in weight:

- Date of capture.
- The weight (in kgs or lbs) of each individual fish.
- The method of capture of each fish (fly, spinner or bait).
- Whether each fish was retained (harvested) or released after capture.

The information required from each Commercial licence holder is,

- The number of tides fished in each month.
- The number of sea trout and salmon caught each month
- The weight of each fish (in kgs or lbs)

And, since the introduction of the scheme of carcass tagging in 2007

- The unique number of the tag attached to each fish

Each licensed netsman receives a personal logbook at the start of the season for recording catch data and must submit a monthly return of catch. Unlike a similar scheme in Ireland from 2001, supplementary information the method of disposal of tagged fish via the market place is not required at this time.

2.1.3.6 Fishery Performance

Catch Returns

The number of anglers who obtained rod licences to fish for salmon and sea trout in each year and the number and proportion of catch returns subsequently submitted in each year from 1994 – 2011 is shown in Table 2.1.16.

The general decline in angler participation in recreational rod fisheries throughout the UK and Ireland in recent years is also evident in the Northwest region. Sales of rod licences (all categories) fell rapidly from a peak of 9,259 in 1994 to a low of 4,872 in 2001 but have since increased steadily in subsequent years. The significant decline in sales in 2001 may be linked to the epidemic outbreak of Foot-and-Mouth Disease that restricted public access to large areas of the countryside and river fisheries from January to August of that year. Figure 2.1.11 illustrates the pattern of catch returns submitted by anglers over the period. A standard rod-licence structure and mandatory catch return system was first introduced throughout the region in 1974 and has operated without change over the last 18 years. Although the response rate has ranged between 51.7% and 75.8% over the period, the overall trend has been relatively stable about the long-term mean of 64.8%.

Table 2.1.16 Annual Number of Rod Licences Issued and Catch Returns Received for the Northwest Region (1994-2011).

Rod Fishing Season	Number Licences Issued	Catch Returns Received	
		No.	%
1994	9,259	5,773	62.4
1995	8,714	5,415	62.1
1996	8,854	5,107	57.7
1997	7,681	5,345	69.6
1998	7,299	5,532	75.8
1999	6,922	4,715	68.1
2000	7,055	4,273	60.6
2001	4,872	2,520	51.7
2002	6,561	4,528	69.0
2003	5,916	4,169	70.5
2004	6,745	4,724	70.0
2005	7,123	4,440	62.3
2006	6,745	3,924	58.2
2007	6,678	4,171	62.5
2008	7,136	4,998	70.0
2009	7,493	4,851	64.7
2010	7,698	4,935	64.1
2011	7,864	5,208	66.2
Mean	**7,256**	**4,702**	**64.8**

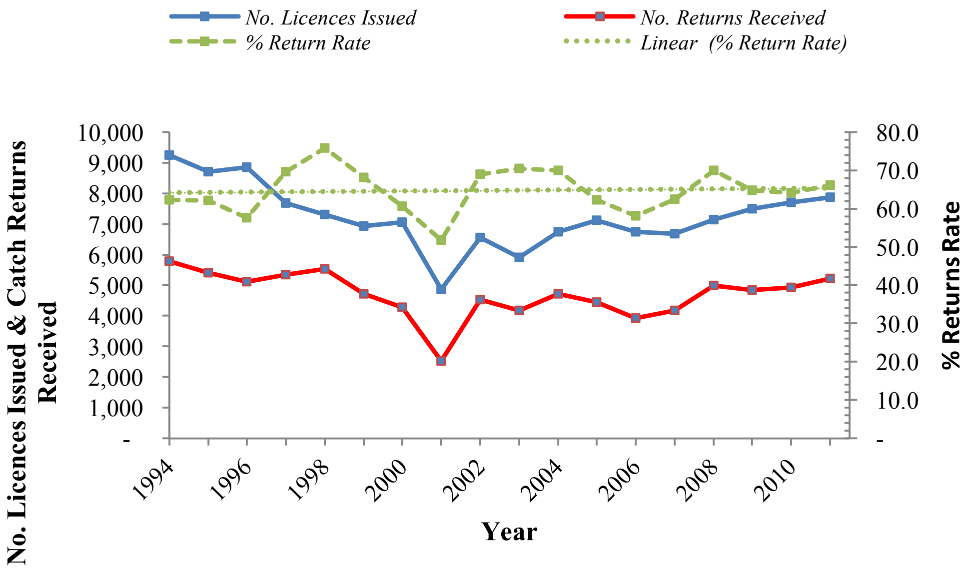


Figure 2.1.11 The Number and Proportion of Catch Returns Submitted by Rod Licence Holders in the Northwest Region (1994-2011).

Number of Fish Caught

Rod Catch

Table 2.1.17 shows the numbers of sea trout and salmon reported from both the recreational rod and the commercial net fisheries from 1994. The annual rod catch of sea trout has ranged from 10,345 fish in 2000 and 3,863 in 2006 with a long-term mean catch of 6,416.fish. Salmon catches have ranged from 10,022 fish in 2004 to 4,141 in 1997 about a long-term mean of 6,465 fish. While both means are very similar, the pattern of annual catches (Figure 2.1.12) shows wide fluctuations in their relative relationship in different years. Greater numbers of sea trout were caught in 9 of the eighteen years, principally between 1996 and 2003, while the salmon catch was dominant in the other 9 years (principally from 2004).

The pattern of rod catches (Figure 2.1.12) exhibits no direct relationship between sea trout and salmon other than from 1997-2001. There has been a slow but steady decrease in the sea trout catch over the period compared with similar increase in the catch of salmon.

Commercial Net Fishing

The dramatic decline in the nature and extent of commercial fishing within the region (Table 2.1.15) presents difficulties in interpreting the pattern of commercial catches in Table 2.1.17 and Figure 2.1.13 and any relationship with the rod catch over the same period. The net catch of sea trout has varied from 3,343 fish in 1994 to 291 fish in 2011 with a long-term mean of 1,480 fish over the period. The comparable long-term mean for salmon was 3,223 fish and ranged from 6,143 fish in 1,004 to 915 fish in 2011. The net catch of salmon exceeded the sea trout catch in all years. The overall pattern of catches exhibited a marked decline for both species. The peak in the commercial salmon catch from 2004-2006 was present in the commercial catch of sea trout but was not apparent with the rod catch of salmon (Figure 2.1.13).

Table 2.1.17 Reported Catch of Sea Trout & Salmon from the Rod and the Net Fisheries in the Northwest Region of England (1994-2011).

Year of Capture	Reported Rod Catch		Reported Net Catch	
	Sea Trout	Salmon	Sea Trout	Salmon
	No.	No.	No.	No.
1994	6,295	8,834	3,343	6,143
1995	5,968	6,352	3,430	5,566
1996	5,767	5,712	1,828	4,464
1997	5,249	4,141	1,152	3,161
1998	9,184	6,359	1,154	1,778
1999	7,265	4,133	1,953	2,387
2000	10,345	6,814	1,315	3,496
2001	4,463	4,209	2,201	3,310
2002	8,245	5,532	851	3,318
2003	7,893	3,547	1,225	2,801
2004	6,176	10,022	1,339	2,477
2005	6,691	8,446	1,027	5,178
2006	3,863	6,771	589	3,977
2007	5,182	7,151	413	2,324
2008	4,541	8,065	679	981
2009	5,608	5,535	935	846
2010	6,229	8,074	1,433	1,665
2011	6,517	6,672	291	915
Mean	**6,416**	**6,465**	**1,480**	**3,223**

Weight of Fish Caught

Rods

Table 2.1.18 gives the total weight and mean fish weight of sea trout and salmon reported annually from the rod fisheries in the region. The total weight of the rod catch fluctuated annually between years but was relatively stable over the period and is reflected in the total weight and mean weight of the reported catch for both species. The total aggregated weight of rod-caught sea trout ranged about a mean of 11,424 kg from 16,160 kg in 2002 to 7,150 kg in 2001 while that for salmon has ranged more widely about a mean of 23,951 kg from 37,657 kg in 2004 to 14,579 kg in 1997.

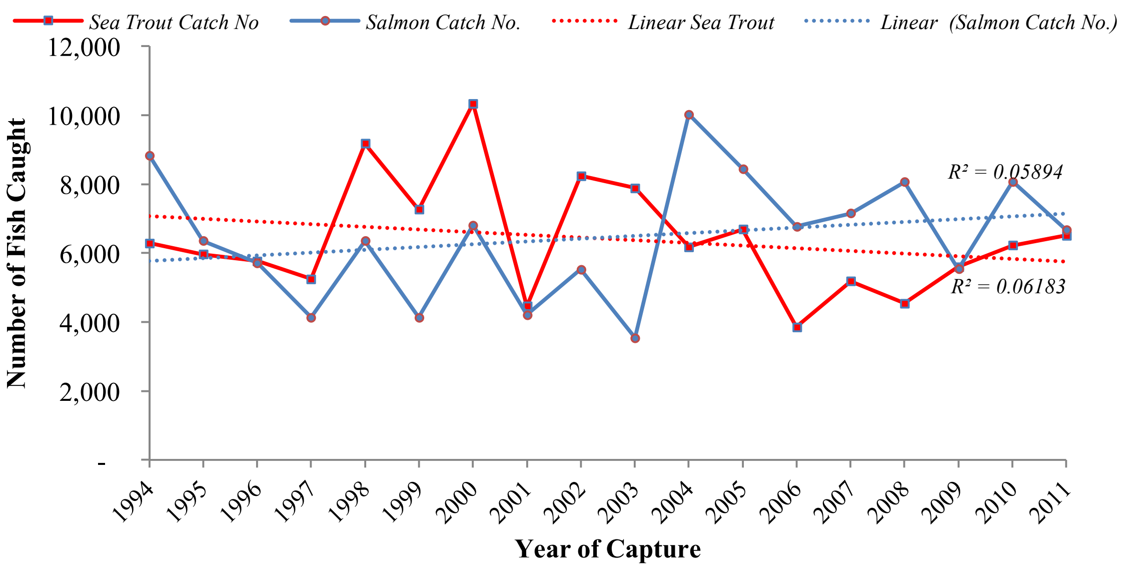


Figure 2.1.12 Pattern of Rod Catches of Sea Trout & Salmon in the Northwest Region of England (1994-2011).

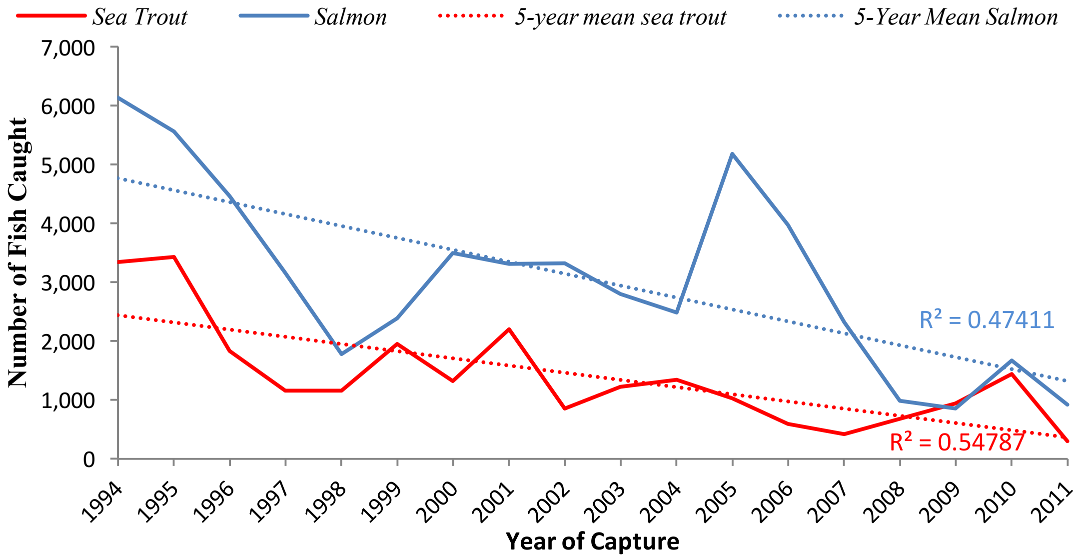


Figure 2.1.13 Pattern of Catches of Sea Trout & Salmon for Commercial Net Fisheries (all methods) in the Northwest Region of England (1994-2011).

Annual fluctuations in the mean weight of individual fish related to adult growth rate, general condition (K factor) and changes in the abundance in different components of the available stock between years. The weight of individual sea trout averaged 0.81 kg (range 0.94 kg in 2002 to 0.74 kg in 1998). The mean weight of individual salmon was 3.7k and ranged from 4.0 kg in 2004 and 3.2 kg in 1998. The long-term mean weight of individual sea trout of sea trout at 0.81 kg (1.78 lbs) was 23.5% of the mean weight of salmon at 3.7 kg (8.14 lbs): a difference of 2.89 kg (6.4 lbs).

Table 2.1.18 Total Weight and Mean Weight of each fish for Rod-Caught Sea Trout & Salmon in the Northwest of England (1994-2011).

Year of Capture	Sea Trout			Salmon		
	No Fish Caught	Total Catch Weight (kg)	Mean Weight (kg)	No Fish Caught	Total Catch Weight (kg)	Mean Weight (kg)
1994	6,295	11,455	*0.83*	8,834	34,504	*3.9*
1995	5,968	10,014	*0.76*	6,352	22,163	*3.5*
1996	5,767	9,994	*0.79*	5,712	21,602	*3.8*
1997	5,249	9,250	*0.80*	4,141	14,579	*3.5*
1998	9,184	14,995	*0.74*	6,359	20,486	*3.2*
1999	7,265	14,000	*0.88*	4,133	15,905	*3.8*
2000	10,345	18,264	*0.80*	6,814	24,941	*3.7*
2001	4,463	7,150	*0.73*	4,209	15,860	*3.8*
2002	8,245	16,160	*0.89*	5,532	20,745	*3.7*
2003	7,893	14,258	*0.82*	3,547	14,227	*4.0*
2004	6,176	11,540	*0.85*	10,022	37,657	*3.8*
2005	6,691	10,869	*0.74*	8,446	31,982	*3.8*
2006	3,863	6,690	*0.79*	6,771	23,371	*3.5*
2007	5,182	8,982	*0.79*	7,151	25,595	*3.6*
2008	4,541	8,648	*0.87*	8,065	29,328	*3.6*
2009	5,608	11,594	*0.94*	5,535	21,833	*3.9*
2010	6,229	10,666	*0.78*	8,074	28,259	*3.5*
2011	6,517	11,111	*0.77*	6,672	28,085	*4.2*
Mean	**6,416**	**11,424**	***0.81***	**6,465**	**23,951**	***3.7***

Commercial Nets

Table 2.1.19 and Figure 2.1.14 show the total weight of catch and mean weight of each fish reported by all methods of commercial fishing. The total weight of the sea trout catch fell by 90% from a peak of 4,898 kg in 1995 to 434 kg in 2011 while the salmon catch reduced by 83% from 22,987 kg in 1994 to 3,864 kg in 2011. It is likely that this overall reduction in the total weight of fish caught by the commercial nets over the review period is closely linked to the reduction in fishing effort and its effect on the number of fish caught each year rather than any significant trend of decline in the local availability or general condition of the fish.

Any breakdown of the catches for the different type of fishing gears would be largely academic in view of the many changes over the period. However, the haaf nets on the Lune and the Eden/Esk area of the upper Solway remain the most numerous fishing gear in the region. The reduction in the number of haaf nets from 236 in 1985 to 64 in 2011 resulted in the reported catch falling from 3,632 sea trout and 3,346 salmon in 1995 to a reduced catch of 1,293 sea trout and 1,314 salmon in 2011.

The annual mean weight of individual fish was relatively stable for both species over the period: with mean weights of 1.38 kg (3.0 lbs) for sea trout and 3.58 kg (7.8lbs) for salmon. The long-term mean weight of sea trout at 1.38 kg was 2.2 kg less than the mean weight of salmon at 3.58 kg. The mean weight of rod caught sea trout at 0.81 kg was 0.57 kg smaller than net caught sea trout. This difference of 0.57 kg (1.25 lbs) results from the nets fishing selectively for larger sea trout that are unable to pass through the mesh used in the construction of the nets.

Table 2.1.19 The Total Weight and Mean Weight of Sea Trout & Salmon Caught by Commercial Fisheries (all methods) in Northwest England (1994-2011).

Year Caught	**Sea Trout**			**Salmon**		
	No. Caught	**Total Weight (kg)**	**Mean Weight (kg)**	**No. Caught**	**Total Weight (kg)**	**Mean Weight (kg)**
1994	3,343	4,512	1.35	6,143	22,987	3.74
1995	3,430	4,898	1.43	5,566	18,722	3.36
1996	1,828	2,918	1.60	4,464	16,819	3.77
1997	1,152	1,826	1.59	3,161	10,472	3.31
1998	1,154	1,776	1.54	1,778	6,015	3.38
1999	1,953	2,910	1.49	2,387	9,215	3.86
2000	1,315	2,036	1.55	3,496	12,799	3.66
2001	2,201	3,028	1.38	3,310	12,481	3.77
2002	851	1,246	1.46	3,318	12,726	3.84
2003	1,225	1,376	1.12	2,801	10,791	3.85
2004	1,339	1,925	1.44	2,477	8,504	3.43
2005	1,027	1,197	1.17	5,178	17,410	3.36
2006	589	781	1.33	3,977	12,912	3.25
2007	413	545	1.32	2,324	8,002	3.44
2008	679	966	1.42	981	3,299	3.36
2009	935	1,225	1.31	846	3,375	3.99
2010	1,433	1,222	0.85	1,665	5,839	3.51
2011	291	434	1.49	915	3,864	4.22
Mean	**1,480**	**2,048**	**1.38**	**3,223**	**11,543**	**3.58**

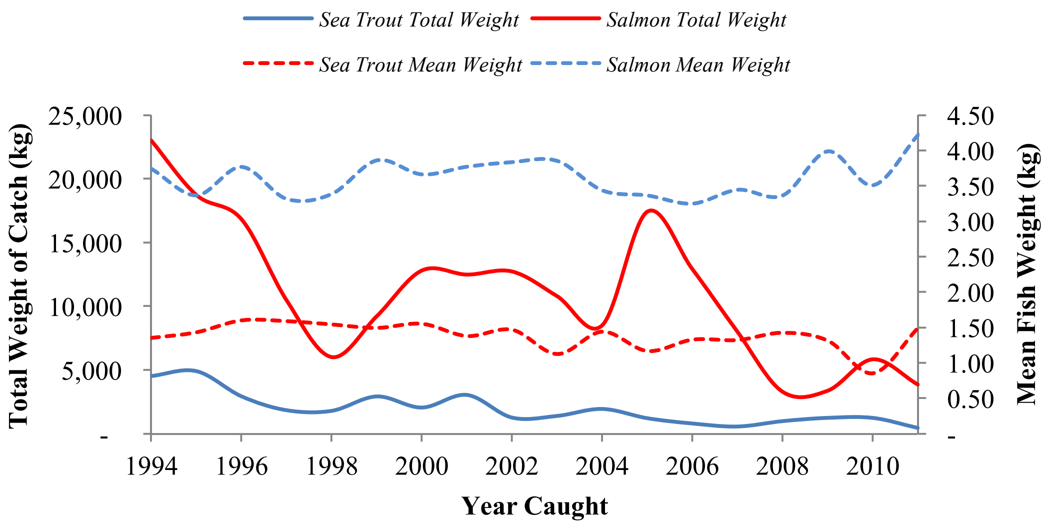


Figure 2.1.14 Total Weight of Catch and Mean Weight of Individual Fish from Commercial Fisheries in the North West of England (1994-2011).

Weight Distribution

Rods

Information on the weight of each rod caught sea trout has been included in the catch returns for all regions of England and Wales since 1994, but no summary on the weight distribution of the catch across a range of different size groups is provided in the Annual Fishery Reports. However a detailed breakdown has been abstracted from the historical database. This is given in Table 2.1.20 where the number of fish in each of 6 weight-class interval is shown over the range of reported weight from < 1 lb to >20 lbs.

The weight distribution of the long-term annual mean catch of 6,416 fish declined rapidly as size increased: with 59% weighing >2 lbs, 33% weighing 2-4 lbs and only 8% weighing between 4–20 lbs. The Northwest region, unlike Wales, does not have a reputation for producing very large sea trout. Nevertheless, 0.7% (46 fish) of the mean annual catch of 6,416 fish weighed more than 10 lbs with 13 fish (0.2%) in the 12 – 20 lb weight class. Figure 2.14 shows the percentage of weight distribution in 4 principal weight classes. [Note that the >6lbs weight class combines small numbers of fish in the larger weight-classes shown in Table 2.1.20]

Figure 2.1.15 Sea Trout Weight Class Distribution (n = 6,415fish)

Table 2.1.20 Weight-Class Distribution (lbs) of Rod-Caught Sea Trout in the Northwest of England (1994-2011)

Year Caught	No. Returns with Data	Weight Class Interval (lbs).							Total Rod Catch
		<2	>2 - <4	>4 - <6	>6 - <8	>8 - <10	>10 - <12	>12 - 20+	
1994	**1,253**	3,472	2,314	364	85	34	34	13	6,295
1995	**1,151**	3,498	2,085	311	56	14	14	1	5,968
1996	**1,206**	3,413	1,880	360	79	21	21	6	5,767
1997	**1,121**	3,007	1,797	320	93	19	19	7	5,249
1998	**1,544**	5,717	2,842	447	110	41	41	8	9,184
1999	**1,334**	3,510	3,104	507	92	31	31	10	7,265
2000	**1,457**	6,031	3,495	628	128	35	35	12	10,345
2001	**702**	2,987	1,206	183	53	28	28	-	4,463
2002	**1,431**	4,155	3,257	604	146	56	56	10	8,245
2003	**1,238**	4,448	2,810	447	122	44	44	10	7,893
2004	**1,198**	3,688	1,892	375	107	55	55	35	6,176
2005	**1,310**	4,239	2,081	279	56	19	19	10	6,691
2006	**913**	2,420	1,161	167	58	35	35	12	3,863
2007	**1,064**	3,125	1,699	238	69	24	24	9	5,182
2008	**1,006**	2,567	1,530	279	93	40	40	23	4,541
2009	**1,167**	2,997	1,973	379	114	64	64	42	5,608
2010	**1,229**	3,979	1,787	328	86	24	24	14	6,229
2011	**1,290**	5,360	935	158	38	9	9	10	6,517
Total	**21,614**	**68,613**	**37,848**	**6,374**	**1,585**	**593**	**593**	**232**	**115,481**
Mean	**1,201**	**3,812**	**2,103**	**354**	**88**	**33**	**33**	**13**	**6,416**
% of Mean		***59.41***	***32.77***	***5.52***	***1.37***	***0.51***	***0.51***	***0.20***	***100.00***

Month of Rod Capture

Table 2.1.21 & Table 2.1.22 show the mean number and proportions of sea trout and salmon caught in each month of the annual fishing season from 1994-2011. Figure 2.1.16 compares the cumulative percentage mean catch in each month as the season progresses. Few sea trout are caught in March and April (0.8%). The catch then increases rapidly to a peak between July and September before declining October. The monthly salmon catch increased steadily in each month throughout the season until October; with the highest catches reported in September and October when 70.3% of the mean annual catch was recorded. This compares with 33.5% of the sea trout catch in the same period. The proportion of the salmon catch recorded to the end of June was 7.5% ((479 fish) compared with 17.23% (1,085 fish) while the proportion of salmon caught in June and July was 22.9% (1,459 fish) compared with 41.7% (3084 fish).

Salmon stocks in the Northwest of England are not noted for producing strong runs of early 'spring' salmon or late 'autumn' salmon. Only the Eden has any reputation as an early season salmon fishery but, unlike the neighbouring Solway rivers to the North (Annan and Nith), it is not noted as a late salmon fishery.

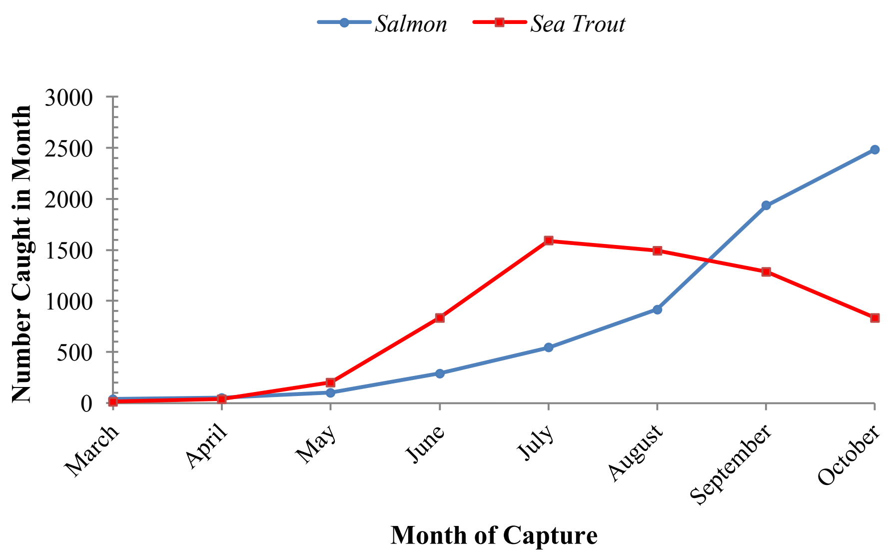


Figure 2.1.16 Month of Angling Capture of Sea Trout & Salmon in Northwest England (1994-2011)

Table 2.1.21 Month of Capture of Rod-Caught Sea Trout in Northwest England (1994-2011).

Year Caught	Number of Sea Trout Caught in Month								Total Number
	March	April	May	June	July	August	September	October	
1994	84	9	170	527	1,350	1,760	1,659	660	6,220
1995	11	30	244	926	1,215	995	1,319	1,178	5,918
1996	10	25	117	706	1,134	1,203	1,373	1,081	5,649
1997	16	25	140	788	976	894	1,615	666	5,121
1998	9	18	171	914	2,548	2,172	1,754	1,109	9,175
1999	10	15	194	1,122	1,887	1,718	1,294	947	7,261
2000	3	26	298	1,566	3,022	2,351	1,862	1,025	10,342
2001	1	3	95	560	1,051	1,244	913	536	4,456
2002	4	32	264	1,227	2,471	2,031	1,152	968	8,240
2003	17	85	283	1,161	2,534	1,734	1,253	734	7,883
2004	6	17	173	690	1,485	1,608	1,100	870	6,164
2005	12	45	132	804	1,426	1,462	1,639	996	6,675
2006	11	37	149	339	671	1,004	924	668	3,862
2007	8	83	195	677	1,225	1,277	1,038	568	5,163
2008	5	24	159	580	1,185	1,120	617	823	4,530
2009	7	71	231	764	1,397	1,337	1,020	701	5,597
2010	6	50	289	605	1,399	1,494	1,441	821	6,226
2011	19	76	322	1,049	1,663	1,471	1,157	660	6,500
Mean	**13**	**37**	**201**	**834**	**1,591**	**1,493**	**1,285**	**834**	**6,289**
%	**0.21**	**0.59**	**3.20**	**13.26**	**25.30**	**23.74**	**20.43**	**13.26**	**100.00**

Table 2.1.22 Month of Capture of Rod-Caught Salmon in Northwest England (1994-2011).

Year Caught	Number of Salmon Caught in Month								Total Number
	March	April	May	June	July	August	September	October	
1994	78	107	148	322	610	1,473	3,162	2,799	8,699
1995	57	108	172	393	528	319	1,555	3,142	6,274
1996	54	71	133	262	392	471	923	3,277	5,583
1997	54	42	78	206	260	336	1,526	1,543	4,045
1998	24	31	62	368	939	1,394	1,472	1,908	6,325
1999	34	34	66	271	460	507	1,163	1,572	4,123
2000	10	18	58	354	750	977	2,281	2,280	6,797
2001	5	25	38	129	282	580	1,415	1,642	4,181
2002	23	33	89	399	683	782	1,241	2,237	5,507
2003	24	29	84	196	369	311	1,037	1,438	3,529
2004	55	51	70	309	685	1,422	3,356	3,917	9,984
2005	68	63	124	328	406	1,075	2,463	3,689	8,377
2006	47	75	146	250	218	660	2,312	2,986	6,736
2007	34	40	101	240	541	1,244	2,454	2,360	7,104
2008	41	65	78	290	663	1,351	2,166	3,325	8,028
2009	17	48	122	248	588	998	1,346	2,083	5,503
2010	32	50	91	225	702	1,257	2,910	2,677	8,030
2011	50	44	137	398	708	1,314	2,070	1,840	6,652
Mean	**39**	**52**	**100**	**288**	**544**	**915**	**1,936**	**2,484**	**6,358**
%	**0.62**	**0.82**	**1.57**	**4.53**	**8.55**	**14.39**	**30.45**	**39.07**	**100.00**

Rod Fishing Effort (CPUE) and Catch Success

Table 2.1.23 gives details of the general relationship between angling fishing effort and catch success expressed as the number of angler days (or part-days) fished and the number of sea trout and salmon caught in each season from 1994 -2011. It shows the number of rod licences issued (i.e. the number of participants in the fisheries) and the number of returns received from each angler with the necessary information on catch and effort to calculate the average number of days fished by each angler and the individual catch-per unit-effort of each angler. This is then expressed as the average catch per angler day and the number of days required by each angler to catch one salmon and one sea trout over the fishing season. Since the rod licence covers both sea trout and salmon, it is not possible to allocate the number of fishing days into separate components targeted at either species. Therefore, it is necessary to assume that angler fishing effort is split equally across both species. However, this assumption is questionable (see Section 2.3.3.3 for further elaboration).

The total number of days fished each year ranged widely about the long-term mean of 51,280 days from 78,176 days in 1994 to 23,213 days in 2001. The average number of days fished by each angler over a single season varied about a mean of 10.2 days from 13.5 days in 1994 to 8.1 days in 2004. The annual daily catch of sea trout ranged about a mean of 0.321 fish from 0.121 and 0.211 fish while the mean daily catch of salmon of 0.132 fish ranged between 0.113 and 0.176 fish.

While it may seem logical to assume a close relationship between licence sales, fishing effort and catch, both effort and catch may vary with river flow conditions and the strength and timing of the annual runs of fish over a season. These two key factors influencing angling success often differ widely between years and between different rivers within a region in the same year. It is inevitable therefore, that the aggregated regional catch and effort data in Table 2.1.23 contains a large degree of spatial and temporal variability.

Figure 2.1.17 illustrates that extensive fluctuations occurred between years and in the general trend for each variable over the period. While licence sales and total fishing effort both exhibited a trend of decline, albeit at different rates, the total combined catch of sea trout and salmon remained remarkably stable over the period.

Figure 2.1.18 shows the relationship between the average number of days fished by each angler and the combined number of sea trout and salmon caught each day. Annual differences between the number of days fished and daily catch showed no close relationship. The number of days fished by each angler showed a trend of decrease while, paradoxically, the trend in angler catch-per-day showed an increase.

Table 2.1.23 Angler Catch-Per-Unit-Effort for Sea Trout & Salmon in Northwest England (1994-2011).

Fishing Season	No. Rod Licences Issued	Returns with Effort Data	Total No. Days Fished	Mean No. Days Fished	Reported Rod Catch		Reported Catch per Day fished		No. Rod Days to Catch One Fish		Species Catch Index *1
					Salmon	Sea Trout					
					No.	No.	Salmon	Sea Trout	Salmon	Sea Trout	
1994	9,256	5,773	78,176	13.5	8,840	6,295	0.113	0.081	8.8	12.4	1.4
1995	8,714	5,415	65,601	12.1	6,348	5,968	0.097	0.091	10.3	11.0	1.1
1996	8,854	5,107	64,454	12.6	5,720	5,769	0.089	0.090	11.3	11.2	1.0
1997	7,681	5,345	70,222	12.5	4,144	5,251	0.059	0.075	16.9	13.4	0.8
1998	7,299	5,532	64,443	11.3	6,359	9,184	0.099	0.143	10.1	7.0	0.7
1999	6,922	4,715	50,409	9.6	4,133	7,265	0.082	0.144	12.2	6.9	0.6
2000	7,055	4,273	48,940	11.4	6,814	10,345	0.139	0.211	7.2	4.7	0.7
2001	4,872	2,520	23,213	9.0	4,209	4,463	0.181	0.192	5.5	5.2	0.9
2002	6,561	4,528	43,027	9.3	5,532	8,245	0.129	0.192	7.8	5.2	0.7
2003	5,916	4,169	37,347	8.5	3,547	7,893	0.095	0.211	10.5	4.7	0.4
2004	6,745	4,724	47,978	8.1	10,022	6,176	0.209	0.129	4.8	7.8	1.6
2005	7,123	4,440	49,513	9.5	8,446	6,691	0.171	0.135	5.9	7.4	1.3
2006	6,745	3,924	40,632	9.9	6,771	3,863	0.167	0.095	6.0	10.5	1.8
2007	6,678	4,171	40,704	9.2	7,151	5,182	0.176	0.127	5.7	7.9	1.4
2008	7,136	4,998	46,464	9.0	8,065	4,541	0.174	0.098	5.8	10.2	1.8
2009	7,493	4,851	47,330	8.2	5,532	5,608	0.117	0.118	8.6	8.4	1.0
2010	7,698	4,935	51,511	10.4	8,074	6,229	0.157	0.121	6.4	8.3	1.3
2011	7,864	5,208	53,081	10.1	6,672	6,517	0.126	0.123	8.0	8.1	1.0
Mean	**7,256**	**4,702**	**51,280**	**10.2**	**6,466**	**6,416**	**0.132**	**0.132**	**7.6**	**7.6**	**1.0**

*1 = Average number of sea trout caught by each angler in one day for each salmon caught in one day.

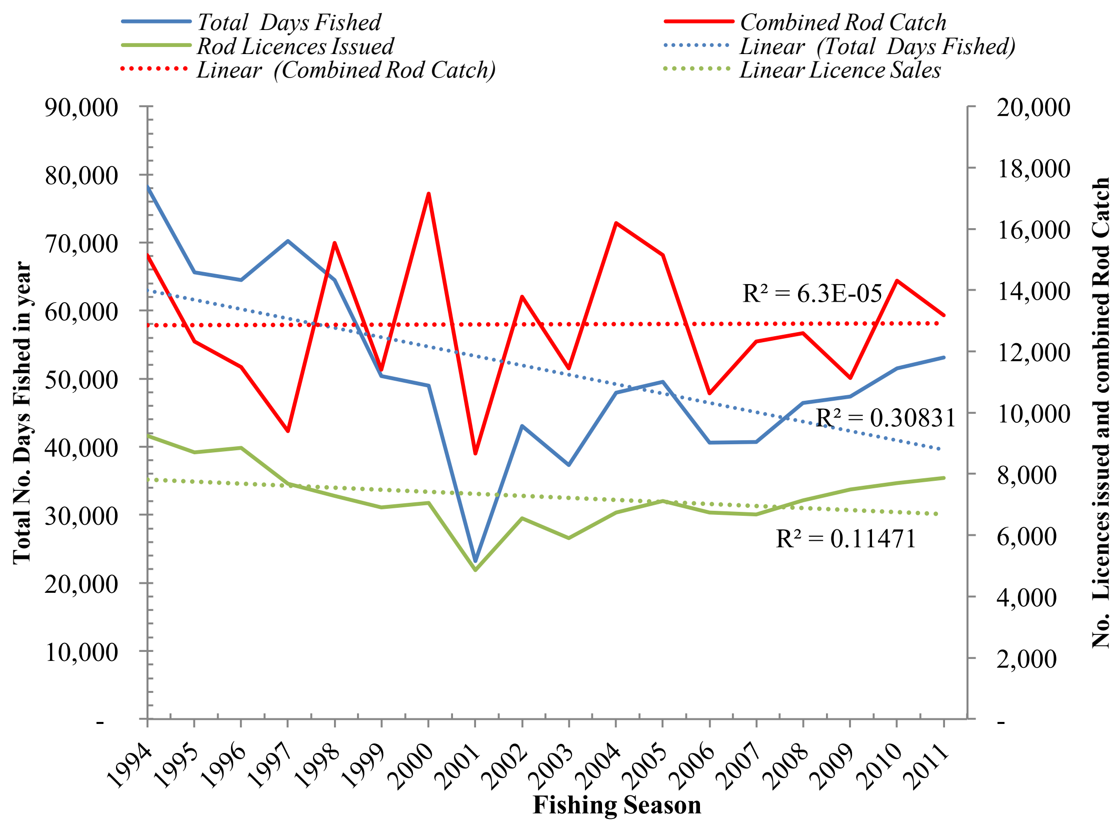


Figure 2.1.17 Number of Rod Licences Sold, Total (Combined) Catch and Total Number of Days Fished for Salmon & Sea Trout in Northwest England (1994 – 2011).

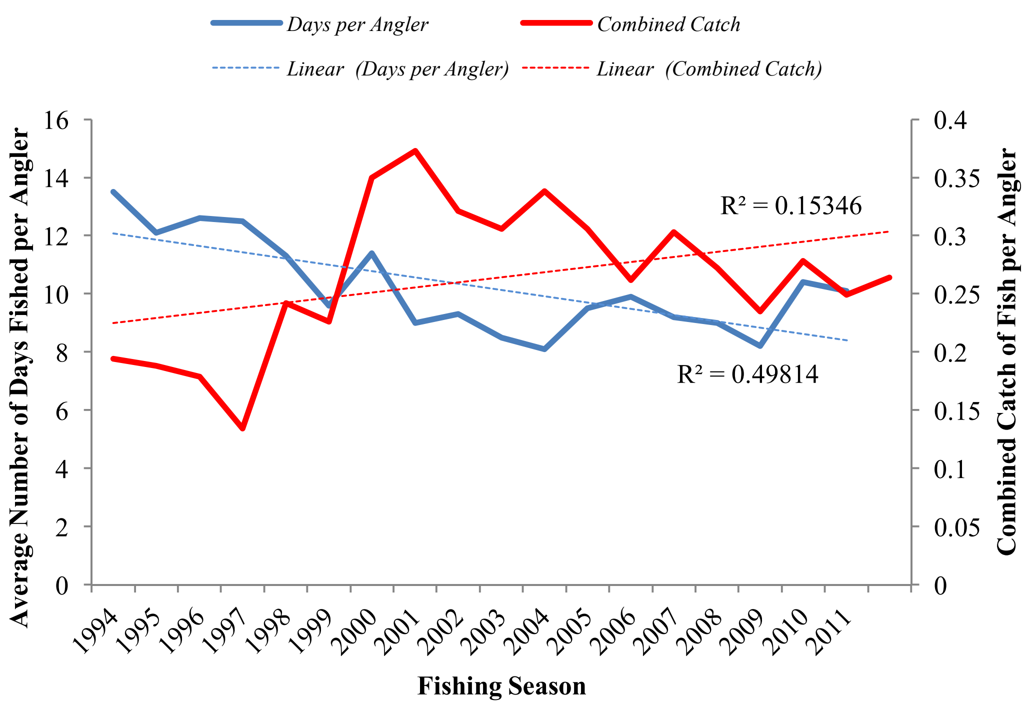


Figure 2.1.18 The Number of Days Fished and the Combined Number of Sea Trout & Salmon Caught by Each Angler in Northwest England (1994 -2011).

Angler Catch-and- Release

The number and proportion of sea trout and salmon returned alive to the water immediately after capture by anglers in each year, as opposed to being harvested (retained) by their captor, is shown in Table 2.1.24 and in Figure 2.1.19.

Table 2.1.24 Number of Sea Trout & Salmon Caught & Released by Anglers in the Northwest of England (1994-2011).

Year of capture	No. Returns with Data	SALMON			SEA TROUT		
		Caught	Released		Caught	Released	
		No.	No.	%	No.	No.	%
1994	5,773	8,834	1,274	14.4	6,295	2,754	43.7
1995	5,415	6,348	1,393	21.9	5,968	2,847	47.7
1996	5,107	5,720	1,332	23.3	5,769	2,923	50.7
1997	5,345	4,144	1,311	31.6	5,251	2,665	50.8
1998	5,532	6,359	2,019	31.8	9,184	5,438	59.2
1999	4,715	4,131	1,795	43.5	7,265	3,910	53.8
2000	4,273	6,814	2,816	41.3	10,345	6,263	60.5
2001	2,520	4,209	1,779	42.3	4,463	2,949	66.1
2002	4,528	5,532	2,534	45.8	8,245	4,563	55.3
2003	4,169	3,547	1,859	52.4	7,893	5,145	65.2
2004	4,724	10,022	4,672	46.6	6,176	3,973	64.3
2005	4,440	8,446	4,376	51.8	6,691	4,712	70.4
2006	3,924	6,771	3,450	51.0	3,863	2,843	73.6
2007	4,171	7,151	3,838	53.7	5,182	3,521	67.9
2008	4,998	8,065	4,360	54.1	4,541	3,129	68.9
2009	4,851	5,532	3,236	58.5	5,608	3,894	69.4
2010	4,935	8,074	4,807	59.5	6,229	4,729	75.9
2011	5,208	6,672	3,904	58.5	6,517	5,108	78.4
Mean	**4,702**	**6,465**	**2,820**	**43.4**	**6,416**	**3,965**	**62.3**

The proportion of fish released has increased steadily over the period for both sea trout and salmon irrespective of the number of fish caught each year (Figure 2.1.19). Return rates for sea trout have ranged about a long-term mean of 62.7% from 43.7% in 1994) to 78.4% in 2011. This compares with a long-term mean return rate for salmon of 43.4% and a range of 14.4% in 1994 t0 59.5% in 2010.

Several reasons may explain the higher return rates achieved over the period. These include: a) the introduction of statutory regulations from 2007 for the mandatory release of all salmon caught before 16th June, b) an increase in the number of fisheries imposing local fishery rules on bag limits and catch-and-release fishing for all or part of the season and c) increased acceptance by anglers of catch-and-release as a voluntary code of conduct. Other factors have been the introduction of statutory regulations imposing bag limits. This currently applies to salmon angling on the Crake and Leven, where catch-and-release -only fishing applies to salmon throughout the season, and on the Eden, Lune and Ribble, where anglers may retain only 2 fish over the season. The only restriction on harvesting sea trout occurs on the Border Esk where there is a bag limit of 2 fish a day.

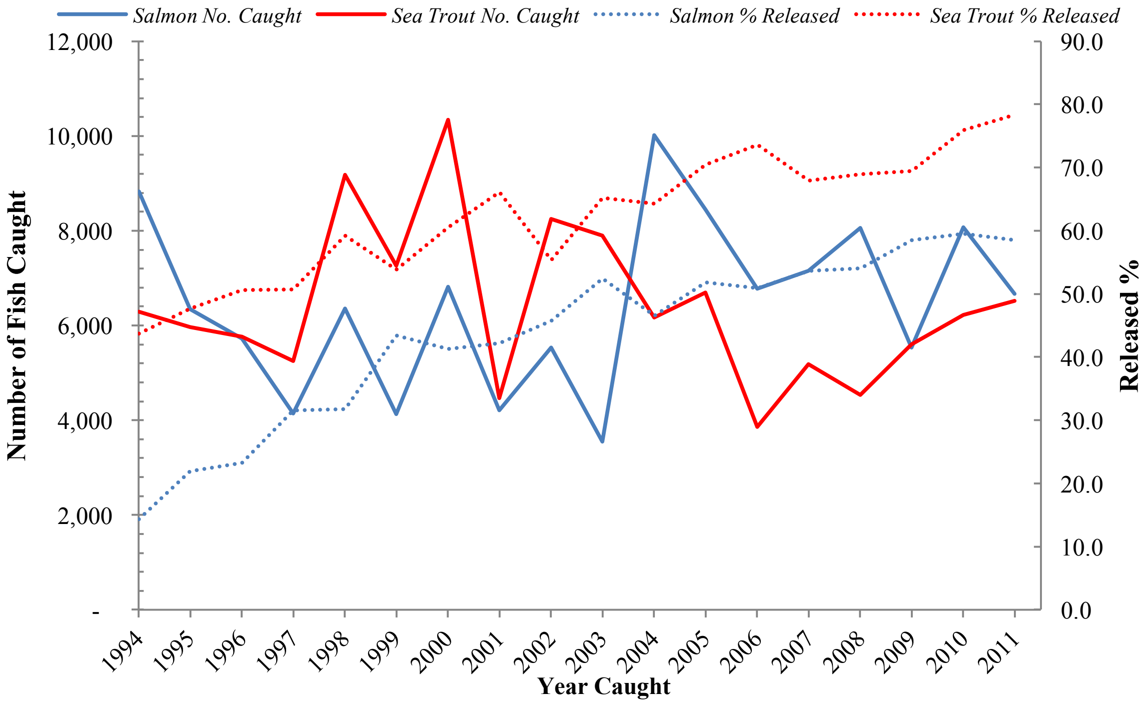


Figure 2.1.19 Number and Proportion of Sea Trout & Salmon Caught-&-Released in Northwest England (1994-2011).

Method of Angling Capture

Lawful methods of angling are restricted to fishing with a fly, spinner or bait throughout England & Wales by longstanding primary legislation and then further restricted by local fishery rules that may then restrict or prohibit certain methods at various times and locations throughout the region.

The number and proportions of fish caught by the three different methods of angling for all rivers throughout the Northwest of England from 1994-2011 are given in Table 2.1.25 and Figure 2.1.20. [Note that bait fishing includes the use of earthworm, prawn and shrimp.]

The long-term proportions of sea trout caught by each method were 69.5% on fly, 15.4% on spinner and 15.3 % on bait. Comparable figures for salmon were 32.5% on fly, 38.4% on spinner and 29.2% on bait. While fly-fishing for salmon and sea trout can occur in daylight with any method, fly fishing during the hours of darkness is restricted to sea trout. This method of sea trout fishing is generally more successful than daylight fly-fishing. It is widely practiced on many rivers and, as such, is probably the main reason for the higher proportion of sea trout than salmon caught by this method.

Much of the annual variation in the number of fish caught by different methods is likely to reflect the prevailing water conditions over any season. This key factor largely determines the choice of a particular method of fishing and can vary widely between seasons and between different rivers during the same season. Fly-fishing is impracticable under flood conditions of high coloured water when spinning and bait fishing become most productive as the most widely used fishing methods.

Table 2.1.25 Number and Proportion of Sea Trout & Salmon Caught by Different Fishing Methods in the Northwest of England (1994-2011)

Year of Capture	No. Returns with Data	Method of Angling Capture							
		SALMON				SEA TROUT			
		Fly	Spin	Bait	Total	Fly	Spin	Bait	Total
1994	3,634	2,802	3,305	2,514	8,621	4,315	956	952	6,223
1995	3,147	1,941	2,484	1,786	6,211	4,124	837	925	5,886
1996	3,247	1,510	2,504	1,449	5,463	3,788	1,142	647	5,577
1997	2,714	1,301	1,597	1,171	4,069	3,357	1,014	775	5,146
1998	3,557	1,742	2,545	1,763	6,050	5,199	1,974	1,337	8,510
1999	2,886	1,422	1,592	977	3,991	5,122	1,242	685	7,049
2000	3,338	1,977	3,218	1,403	6,598	6,849	2,036	1,251	10,136
2001	1,925	1,447	2,038	656	4,141	3,089	996	354	4,439
2002	3,195	1,848	2,330	1,183	5,361	5,281	1,732	971	7,984
2003	2,596	1,394	1,298	777	3,469	5,954	1,014	759	7,727
2004	3,606	3,340	4,944	1,538	9,822	4,005	1,267	592	5,864
2005	3,699	2,947	3,737	1,421	8,105	4,490	1,173	797	6,460
2006	2,976	2,587	2,692	1,313	6,592	2,604	658	503	3,765
2007	3,082	3,493	2,187	1,335	7,015	3,001	1,322	731	5,054
2008	3,166	2,770	3,568	1,527	7,865	2,451	1,245	757	4,453
2009	3,063	2,443	1,963	1,030	5,436	3,317	1,509	700	5,526
2010	3,397	3,207	2,862	1,741	7,810	3,931	1,361	863	6,155
2011	3,347	2,931	2,391	1,224	6,546	4,233	1,346	875	6,454
Mean	**3,143**	**2,283**	**2,625**	**1,378**	**6,287**	**4,173**	**1,268**	**804**	**6,245**
% of Mean		**32.5**	**38.3**	**29.2**	**100.0**	**69.3**	**15.4**	**15.3**	**100.0**

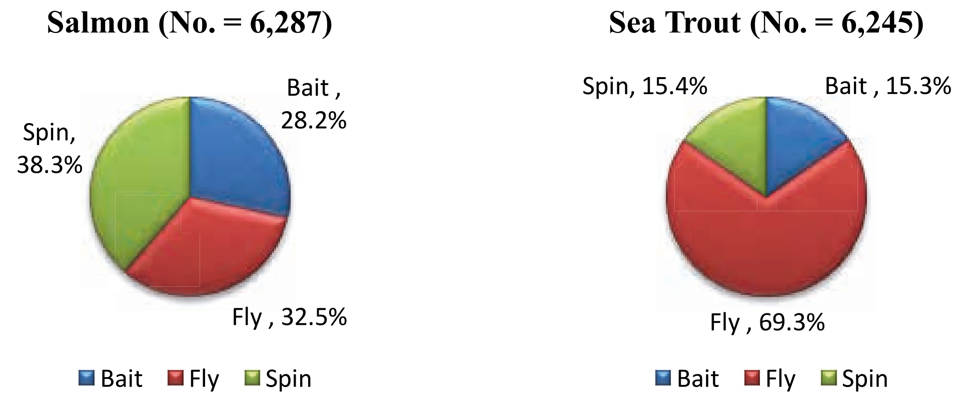


Figure 2.1.20 Proportions of Sea Trout & Salmon Caught by Different Angling Methods in Northwest England (1994-2011).

2.1.3.7 Regional Stock Assessments

The most recent annual assessment by the Environment Agency of the general health and sustainable status of the sea trout and salmon fisheries in Northwest of England was in 2012 and is summarised in Table 2.1.26.

Table 2.1.26 Annual 'Health Assessment' of Stock Status of Principal Sea Trout & Salmon Rivers in Northwest England (2012).

River Name	Level of Risk Assessment	
	Sea Trout	Salmon
Ribble	Probably Not At Risk	Probably At Risk
Lune	Probably At Risk	Probably Not at Risk
Kent	Probably Not at Risk	Probably Not at Risk
Leven	Probably at Risk	Probably At Risk
Duddon	Probably At Risk	Not At Risk
Cumbrian Esk	Not At Risk	Probably At Risk
Irt	Not At Risk	Probably Not at Risk
Ehen	At Risk	Not At Risk
Derwent	Probably Not at Risk	Probably Not At Risk
Ellen	Probably Not at Risk	Probably Not at Risk
Eden	Probably At Risk	Probably At Risk
Border Esk	Probably At Risk	Probably Not at Risk
Wyre	Not Assessed	At Risk
Crake	Not Assessed	Probably At Risk
Calder	Not Assessed	Probably Not At Risk

Only 7 of the 12 rivers exhibited comparable assessments for both sea trout and salmon, albeit at different levels of health status. The Ehen was At Risk for sea trout but Not at Risk for salmon and only the Cumberland Esk and Irt were judged to be Not At Risk for sea trout. Only the River Ehen was Not At Risk for both sea trout and salmon. The status of the 6 major sea trout fisheries differed, with the Ribble, Kent and Derwent appearing reasonably healthy (i.e. Not at Risk) while sea trout stock status on the Lune, Eden and Border Esk was assessed as less favourable (i.e. Probably at Risk)

Fish Traps & Counters

Fish Counting Stations

Two permanent fish counting stations have operated in the North West of England to provide routine information the numerical abundance of the annual upstream runs of sea trout and salmon. They are: (1) a fixed trap on the River Lune and (2) a fish counter on the River Kent.

The Lune Fish Trap

This consists of a fixed trap located in the fish pass on Forge Weir some 4 km above the tideway. It is operated on a regular monthly basis to provide a consistent annual estimate of run strength for salmon and sea trout from 1994 based on a programme of stratified closure (sampling) days in each month of the year. The actual count of fish handled through the trap is adjusted to allow for frequency of operation and variable trap efficiency between species. The spacing between the upstream grids of the trap allows the smallest sizes of whitling sea trout to pass upstream and the actual trap count has therefore underestimated the strength of the 0SW whitling component of the annual run of sea trout.

The adjusted numbers of fish recorded through the trap over the 18 years from 1994-2011 are given in Table 2.1.27 and Figure 2.1.21. There is no run estimate for salmon in 1998.

Table 2.1.27 Annual Numbers of Sea Trout & Salmon Recorded from Forge Weir Fish Trap on the River Lune (1994 – 2011).

Year of Operation	All Salmon	All Sea Trout
1994	5,970	17,032
1995	4,437	12,099
1996	4,605	10,249
1997	3,121	17,773
1998	n/d	8,862
1999	4,846	11,858
2000	8,262	11,129
2001	6,195	12,191
2002	7,603	11,186
2003	6,895	11,851
2004	12,863	8,373
2005	9,824	10,344
2006	7,443	7,668
2007	11,166	8,130
2008	9,420	9,201
2009	8,289	8,097
2010	8,315	9,665
2011	6,318	5,246
Mean	**7,387**	**10,609**

n/d = no count for year

Sea trout numbers varied widely about the long-term mean of 10,609 fish from a peak of 17,773 fish in 1997 to an all-time low of 5,246 fish in 2011, Salmon numbers varied less extensively about a mean of 7,387, with a peak of 12,863 fish in 2004 and a low of 3,121 fish in 1997. The annual run strength of sea trout was greater than salmon in 12 of the 17 years with comparable data, often by a large margin over the earlier part of the record to 2004. This disparity was particularly evident in 1997 when the numbers of sea trout and salmon were respectively at their lowest and highest and when 14,652 more sea trout than salmon passed upstream. By contrast, 4,490 more salmon than sea trout were recorded in 2004.

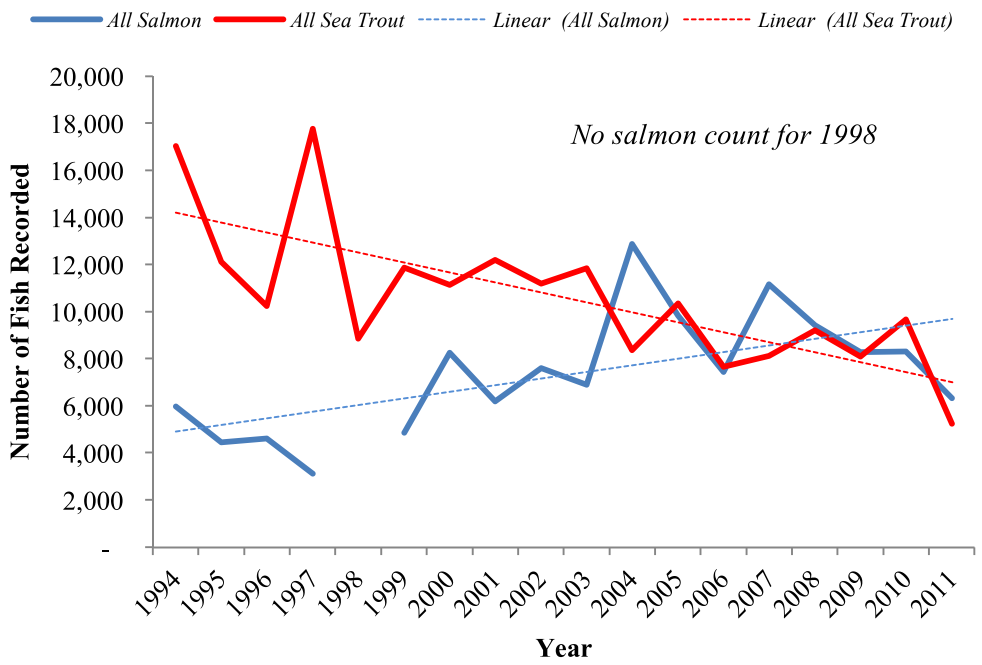


Figure 2.1.21 Annual Numbers of Sea Trout & Salmon Recorded from Forge Weir Fish Trap on the River Lune (1994-2011).

The annual pattern of run strength (Figure 2.1.21) shows a steady decline in sea trout numbers over the period. This contrasts with a less marked but steady increase in salmon numbers. Any pattern of synchronized increase and decrease in the annual number of sea trout and salmon is not evident, with the all-time peak for sea trout in 1997 coinciding with the all-time low for that same year.

Kent Fish Counter

This consists of a resistivity counter located on a Crump gauging weir at Basinghyll some 5 km above the tideway. It is thought to provide a reliable total count of all fish passing upstream that includes both the smaller 0SW whitling run component of sea trout returning for the first time as maiden fish in the same year that they migrated as smolts and the larger sea trout. This allows the sea trout run to be broken down into both 0SW and older (> 0SW stock components.). No adjustment is made for uncounted fish that can bypass the facility. Validation of counts for the separate species employed a combination of different means over the years: using: a) size split (1997-1998), b) information extrapolated from Forge trap (1999-2000) and c) video recording (2001-2004). The trap has operated continuously from 1994-2009 for salmon and from 1997-2009 for sea trout.

Run-Strength

The upstream run counts of sea trout and salmon recorded from the counter are shown in Table 2.1.28 and Figure 2.1.22. The total sea trout count is also given as 0SW whitling, older >0SW fish. The annual count of sea trout ranged between 2,616 fish in 2009 and 7,693 fish in 1998, with a long-term mean of 3,949 fish over the period. The runs of both the 0SW whitling and the older group of sea trout have remained relatively stable from 2002, but the overall trend in run strength shows a general decline. By contrast, the salmon count has remained generally stable over the period about a long-term mean of 2,323 fish and a range between 1,147 fish in 2009 and 3,246 fish in 1996.

The mean annual run of 0SW whitling of 1,134 fish represents 28.7% of the total run of 3,949 sea trout, while the mean run of 2,323 salmon represented 58.8% of the mean run of 3,949 sea trout. The sea trout count was greater than the salmon count in all years from 1997-2009.

Table 2.1.28 Recorded Counts of Sea Trout and Salmon through Basinghyll Fish Counter on River Kent (1994-2009).

Year of Count	0SW Whitling	Older Sea Trout	All Sea Trout	All Salmon
1994	nd	nd	nd	2,072
1995	nd	nd	nd	2,762
1996	nd	nd	nd	3,246
1997	336	2,280	2,616	1,473
1998	1,671	6,022	7,693	2,166
1999	613	3,543	4,156	1,023
2000	3,061	1,827	4,888	2,354
2001	1,688	3,097	4,785	2,882
2002	1,003	3,163	4,166	3,149
2003	1,024	2,812	3,836	2,741
2004	1,018	2,607	3,625	2,982
2005	755	2,430	3,185	3,082
2006	789	2,118	2,907	2,625
2007	935	2,106	3,041	2,304
2008	806	2,231	3,037	1,147
2009	1,043	2,358	3,401	1,156
Mean	**1,134**	**2,815**	**3,949**	**2,323**

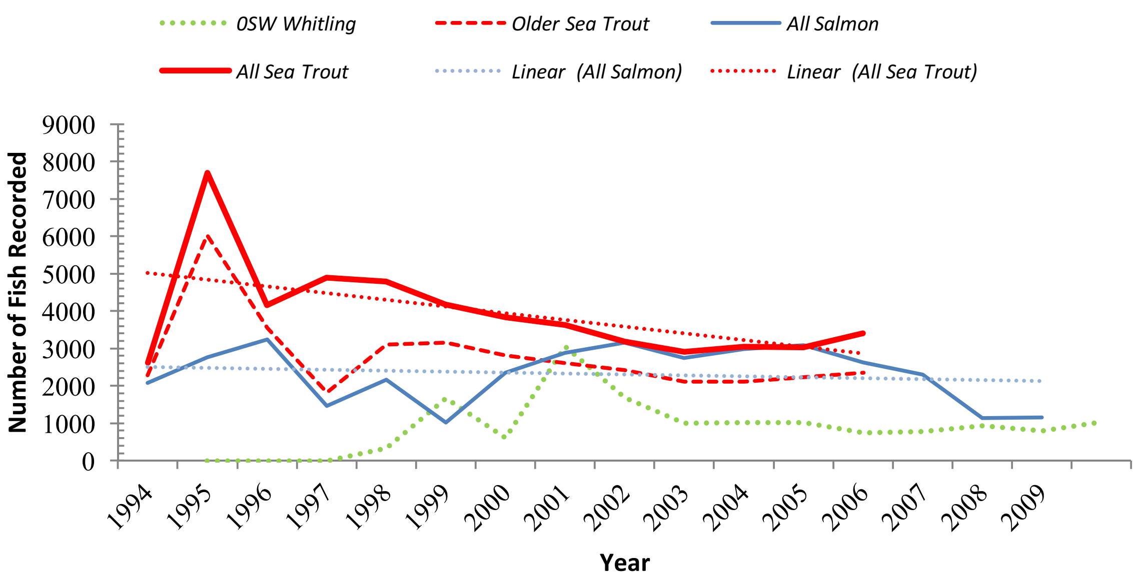


Figure 2.1.22 Recorded Counts of Sea Trout and Salmon through Basinghyll Fish Counter on River Kent (1994-2009).

Run Timing

The mean monthly pattern of upstream fish movements over the 16 years study period is summarised in Table 2.1.29 and Figure 2.1.23. The main run of sea trout starts from May and increases rapidly to peak in July before decreasing steadily until December. The whitling run appears a month later, peaking in July and then declining over the following months. The runs of both 0SW and older >0SW show a slight increase in October.

The main run of salmon also appears in May and increases at a slower rate than sea trout to peak in October. Small numbers of 0SW whitling were recorded between January and May. Fish of this size are unlikely to result from the downstream migrating smolts of the same year and may indicate the occurrence of an autumn run of smolts from the preceding year. Figure 2.1.24 shows the monthly cumulative percentage of fish running upstream over the year. Whereas 53.7% of the annual run of sea trout entered the river before August, only 23.8% of the salmon run occurred over the same period.

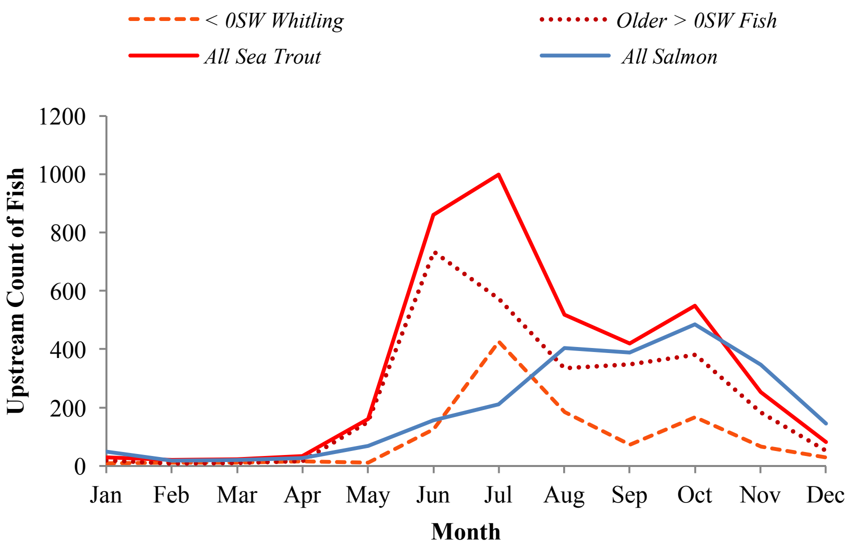


Figure 2.1.23 Mean Counts of Sea Trout & Salmon Recorded Monthly through Basinghyll Fish Counter on River Kent (1994/97 -2009)

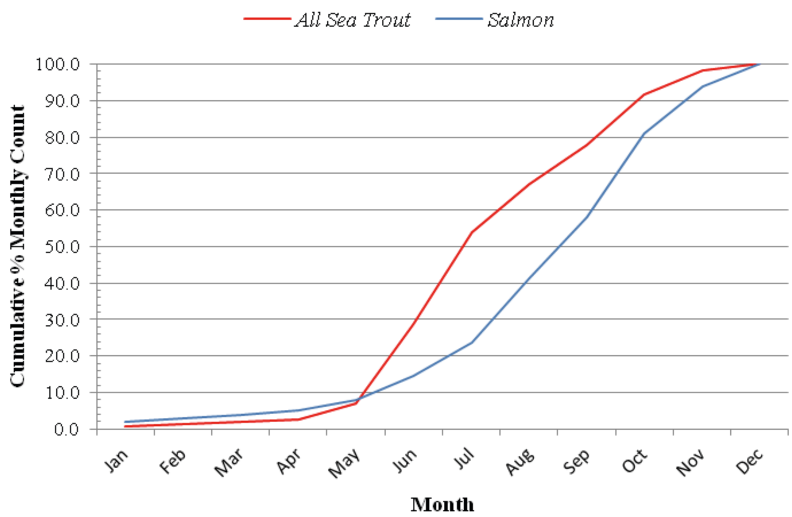


Figure 2.1.24 Cumulative Monthly Proportions of Sea Trout & Salmon through Basinghyll Counter on River Kent (1994/97 – 2009).

Table 2.1.29 Aggregated Mean Monthly Counts and Proportions of Salmon, 0SW Whitling, Older Sea Trout and All Sea Trout Recorded at Basinghyll Counter on River Kent: 1994- 2009 (Salmon) and 1997-2009 (Sea Trout).

Species and Sea Trout Sea-age Class	Aggregated Mean Number of Fish Recorded in Month												Aggregated Mean Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
< 0SW Whitling	**10**	**12**	**12**	**16**	**11**	**126**	**427**	**184**	**72**	**168**	**68**	**29**	**1,134**
%	0.9	1.0	1.1	1.4	1.0	11.1	37.6	16.2	6.4	14.8	6.0	2.5	100.0
Cum %	0.9	1.9	3.0	4.4	5.4	16.5	54.1	70.3	76.7	91.5	97.5	100.0	
Older > 0SW Sea Trout	**20**	**9**	**11**	**18**	**150**	**734**	**571**	**335**	**347**	**382**	**184**	**53**	**2,815**
%	0.7	0.3	0.4	0.6	5.3	26.1	20.3	11.9	12.3	13.6	6.6	1.9	100.0
Cum %	0.7	1.0	1.4	2.0	7.3	33.4	53.7	65.6	77.9	91.5	98.1	100.0	
All Sea Trout	**30**	**21**	**23**	**35**	**161**	**860**	**998**	**519**	**420**	**550**	**252**	**82**	**3,949**
%	0.7	0.5	0.6	0.9	4.1	21.8	25.3	13.1	10.6	13.9	6.4	2.1	100.0
Cum %	0.8	1.3	1.9	2.8	7.0	28.8	54.0	67.2	77.8	91.8	98.1	100.2	
All Salmon	**49**	**19**	**20**	**28**	**68**	**157**	**211**	**404**	**389**	**485**	**347**	**146**	**2,323**
%	2.1	0.8	0.9	1.2	2.9	6.8	9.1	17.4	16.7	20.9	14.9	6.3	100.0
Cum %	0.8	1.3	1.9	2.8	7.0	28.8	54.0	67.2	77.8	91.8	98.1	100.2	

2.1.4 The Welsh Region

2.1.4.1 Introduction

The Welsh Region is one of eight administrative regions of the Environment Agency in England & Wales. As such, it shares several common features with the Northwest Region of England in respect of fishery legislation, licence requirements for rod and net fisheries and the submission of a mandatory annual return of catch. In this latter respect, the catch records for both regions are directly comparable since 1994 when the same standard format was applied to all regions. (See Section 2.2.2.1).

The Welsh Region borders the southwest section of the Irish Sea (Figure 2.1.25) and covers about 750 kilometres of coastline extending from Chester in the northeast to Newport on the southeast. It contains three large cross-border rivers (the Dee, Wye and Severn) that originate in Wales and then flow through England before entering the sea via the Severn Estuary. Historically, the Welsh Region has managed the fisheries of the Dee and Wye catchments on an integrated basis while the Severn catchment has been managed as one of the English regions.

Although the geographical scope of the Celtic Sea Trout Project excludes the Wye, Usk and several rivers of South Wales 'Coal-Field Belt' between Newport and Swansea (principally the Tawe, Loughor, Neath and Dau Gendraeth), they are included in the regional description of Welsh sea trout fisheries and when making comparisons with other parts of the UK and Ireland. This is partly because it is impracticable to separate the historical catch data for these rivers from the aggregated National catch for Wales and partly because sea trout from this region contribute to the feeding stocks of sea trout in the Irish Sea.

Catch statistics for the rod and net fisheries in Wales have been collected using the same standard approach throughout the region since 1976. This approach was subsequently adopted and adapted for all regions in England and Wales from 1989 without significant amendment other than to record rod fishing effort as the number of days (or part-days) fished over the season as an improvement on the earlier approach in Wales where rod-effort was expressed as the number of licences issued to anglers.

2.1.4.2 General Background

Fishery Features

Almost every watercourse with unobstructed access from the sea now contains a natural, self-sustaining stock of sea trout and salmon; albeit at different levels of abundance and importance in sustaining recreational rod fisheries and (where present) commercial net fisheries. Runs of migratory fish on several rivers were eradicated or severely depleted by an historic environmental degradation following the Industrial Revolution from the start of the 19th Century. However, the massive investment since the 1970s in overcoming gross pollution from domestic and industrial sources and in removing impassable weirs to upstream migration and spawning have seen significant improvements in their performance as rod fisheries. The once fishless rivers Taff, where a series of impassable barriers, combined with gross pollution and abstraction to cause the extinction of salmon and sea trout runs until the 1980s (Mawle, 1995), and the Rheidol and Ystwyth in Mid Wales, where residual pollution from lead and zinc mining eradicated migratory fish stocks until the 1960s (Jones & Howells, 1975), now yield annual catches of several hundred sea trout and salmon each year.

In very general terms, most Welsh rivers can be characterised as small spate streams with a main channel length of less than 50 kilometres from source to sea. Notable exceptions are the Wye (122 km), Usk (111 km), Dee (110 km), and Teifi (103 km). Apart from the Tywi (82 km) and Clwyd (50 km) all other rivers are less than 50 Km in length. The Taff (49 km), Dyfi (44 km) and Conway (42 km) representing the medium length rivers. The remaining 20 or so significant sea trout and salmon rivers have lengths of between 39 km (Taf) to 10 km (Llyfni). (It should be noted that the rivers Taff (Southeast Wales) and Taf (Southwest Wales) are different rivers).

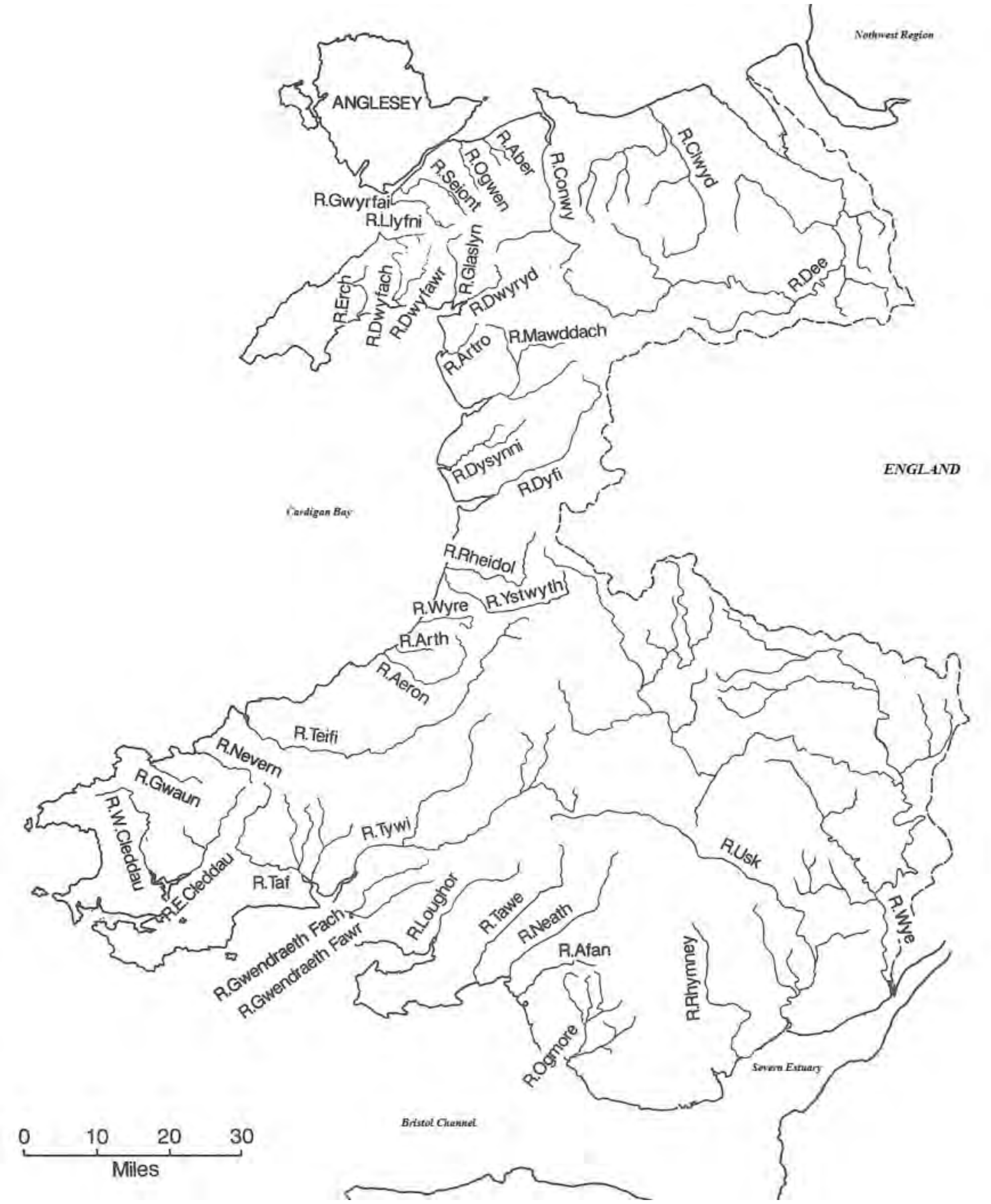


Figure 2.1.25 Principal Sea Trout & Salmon Rivers of the Welsh Region.

Unlike parts of Ireland and Scotland, the only major sea trout rivers in Wales with natural lakes that are accessible to migratory salmonids are the Dee, Glaslyn, Dysynni, Seiont and Gwyrfai. They produce the occasional sea trout or salmon to the rod fishery. Several rivers remain adversely affected by the construction of large reservoir impoundments for water supply purposes and some are heavily abstracted and regulated during dry summer periods. Large reservoir schemes that have inundated previously accessible spawning and nursery grounds have been constructed in the headwater streams of the Wye, Dee, Usk, Tywi, and Eastern Cleddau and water is directly abstracted from natural lakes in several catchments that are either accessible (Gwyrfai) or inaccessible (Teifi, Taff) to migratory fish. Hydroelectric power generating schemes entailing reservoir impoundments operate on the Rheidol, Dwyryd and Seiont (pumped-storage) while large amenity barrage schemes have been constructed on the Tawe (semi-tidal) and Taff (total exclusion) estuaries. The tidal sluices to control flooding on the lower Glaslyn delay the natural seaward migration of sea trout smolts and kelts into the estuary and have created an unnatural and productive 'early' sea trout fishery in the spring months (Brassington, 1982).

Rod Fisheries

One of the most significant features of the recreational rod-and-line fisheries of Wales is their widespread availability to the public. With the notable exception of the three major salmon rivers (Wye, Usk and Dee), much of the attractive and worthwhile fishing on other rivers is owned or otherwise controlled (leased or licensed) to locally based angling associations who grant permits to both local and visiting anglers alike for all or part of the season. There are over 250 angling clubs throughout Wales. Of these, some control almost all of the fishing on a single river, others may have fishing on several rivers and, there may be several different clubs with sections of fishing on the some of the longer rivers. Many of these clubs have more than 200 full members and a few have between 500-1,000 members. A waiting list for membership may still exist on some of the better known sections of fishing, but many clubs report a decline in membership over the last decade. Elsewhere on water not controlled by angling associations, most fishery owners now issue angling permits, either directly or through hotels and other agents or by letting fishing linked to accommodation. A few owners operate limited syndication schemes on a day-week season or full season basis.

The annual reports on inland fishery statistics for Wales from 1994 have included rod and net catches for the 30 most significant sea trout and salmon rivers listed in Table 2.1.30. This also shows the average yearly catch of each species over the most recent 5-year period (2007-2011) and their ranked order of importance (1-30) based on greatest number of fish caught over the period. A small number of other rivers producing a mean catch of less than 40 sea trout have been excluded (e.g. Rhymney, Artro, Gwyrfai, Erch and Soch).

The aggregated 5-year mean annual catches for all 30 rivers were 15,038 sea trout and 4,856 salmon. The Usk Wye and Dee are the longest rivers with the largest catchment areas in the region. Their combined catch of 2,234 salmon represented 46% of the total annual mean catch of salmon whereas their combined sea trout catch of just 502 fish represented only 3.6% of the total sea trout catch of all 30 rivers. The three most important sea trout rivers were the Tywi, Teifi and Dyfi. Their combined total mean catch of sea trout of 7,094 fish represented 47% of the total for all rivers.

Welsh rivers can be described as 'sea trout rivers with some salmon: as opposed to 'salmon rivers with some sea trout'. Only the Tywi, Teifi, Dyfi and Conwy ranked highly in most recent years for both species. The sea trout catch outnumbered the salmon catch by a large margin on all other 27 rivers except for the Usk, Wye and Dee. Many of the smaller rivers with a reasonable average catch of sea trout (e.g. Aeron. Dysynni, Lyfni, Nevern and Ystwyth) reported a mean salmon catch of < 10 fish a year and in some seasons a 'nil' annual catch of salmon was recorded for several minor rivers.

Table 2.1.30 5-Year Mean Rod Catch & Ranking of the Principal Sea Trout & Salmon Rivers in Wales (2007-2011).

River Name	5-Year Mean Catch		Ranked Order (1-30)	
	Sea Trout	Salmon	Sea Trout	Salmon
Aeron	165	2	22	29
Afan	139	11	24	23
Cleddau	557	75	7	13
Clwyd	1005	154	4	9
Conwy	484	205	10	6
Dee	330	732	15	2
Dwyfach	82	3	26	26=
Dwyfawr	328	15	16	22
Dwyryd	47	10	29	24
Dyfi	1768	159	3	8
Dysynni	396	3	13	26=
Glaslyn	648	29	5	20
Gwendraeth	56	1	28	30
Llyfni	154	3	23	26=
Loughor	258	44	18	17
Mawddach	578	105	8	11
Neath	447	73	11	14
Nevern	566	33	9	19
Ogmore	418	67	12	15
Ogwen	185	98	21	12
Rheidol	321	32	17	19
Seiont	62	28	27	21
Taf	346	109	14	10
Taff	89	42	25	18
Tawe	250	166	19	7
Teifi	2153	583	2	4
Tywi	2813	683	1	3
Usk	130	819	23	1
Wye	42	566	29	5
Ystwyth	224	8	20	25

Wales is widely acclaimed for the overall quality of its sea trout fisheries in terms of their numerical abundance, larger than average weight of individual fish and their innate potential to reach a very large size in excess of 5 kg or more. Jones (2006) claimed that there are now probably more 'salmon-sized' sea trout in most Welsh rivers than actual salmon. The Dyfi and Tywi consistently yield very large sea trout in excess of 15 lbs every year. The Dyfi periodically yields fish of 20+ lbs to the rod and net fisheries and several other rivers, including the shorter sea trout rivers such as the Taf and Dysynni have produced the occasional fish of 15 lbs+ in recent years.

An unprecedented number of scale reading studies have described the structure and composition of sea trout stocks in Wales following a pioneer investigation on the Dyfi by Nall (1933). Solomon (1995) reviewed and summarised the information in published and unpublished reports by various workers on 13 named rivers and subsequent studies by Evans (1994) and Harris (2002) have since supplemented the available data.

Harris (2002) categorised Welsh sea trout as representatives of a type that was 'long-lived' and 'fast-growing'. They grew more rapidly in the sea and attained a larger size than most other regions in England & Wales by spending up to 2 complete years at sea before returning to spawn for the first time as maiden fish and then surviving multiple repeat spawning in successive years, returning to sea and increasing in size between each spawning visit. The largest 'authenticated' Welsh sea trout was a fish of 241/2 lbs from the River Dyfi. It was 11 + years old when caught and had migrated to sea as a 2-year old smolt, returned to spawn for the first time after 2 complete years feeding at sea and then spawned in 7 successive years. (Scale formula = 2.2+7SM+). The main run of sea trout into Welsh Rivers occurs between June and September. Very few fresh sea trout enter the river in the spring or autumn, but the Tywi has reputation as an early fishery, with some remarkable sea trout in the 8 lb+ weight class being caught in late March and April: including several fish well into 'double-figures' each year.

The general decline in stocks of MSW salmon throughout the UK and Ireland since the 1970s has resulted in the structure of the annual run of salmon into Welsh rivers becoming increasingly dependent on the runs of 1SW grilse that enter freshwater from June/July to September in most seasons. Unlike the rivers of the Solway Region, there are no significant late 'autumn' runs of MSW in October/November. However, most of the larger rivers still maintain a small run of early MSW 'spring' salmon at the start of the year. A breakdown of the rod catch of 3,369 salmon from 13 Welsh rivers for the 2009 season into its constituent 1SW grilse and larger MSW salmon components (based on age-weight data from the trap on the River Dee) gave a split of 72% grilse and 28% MSW fish. However, the grilse component increased with decreasing river length and ranged from 88% on the shortest river (Ogwen) to 37% on the longest river (Wye).

Commercial Net Fisheries

Unlike Scotland, the right to fish for migratory salmonids in estuaries and near coastal waters cannot be privately owned unless the crown granted that right prior to 1187. Such private rights of ownership in tidal waters are very rare in Wales and only known to exist in parts of the Severn Estuary and at two locations on the Conway. Their owners no longer exercise these rights apart from the occasional use of the ancient fish trap at Tanrallt on the upper river. Elsewhere throughout the remainder of Wales, there is a public right of fishing in tidal waters which, while largely uncontrolled and unrestricted until the 1860s, has now been progressively derogated and much reduced by subsequent legislation to limit the levels of exploitation and protect spawning stocks: particularly over the last 50 years.

Jenkins (1974) described the background and history of commercial fishing salmon and sea trout in Welsh waters over the 100 years between the middle of the 19th and 20th centuries. [This also contains less detailed reference to the Northwest of England.] Many of the different types of fishing gear and locations listed by Jenkins (loc.cit) have ceased operate and no longer exist: (e.g. Stop boat fishing, putcheons and putcher ranks in the Wye and Usk, drift nets in the Dee and Usk, trammel nets (a form of drift net) in the Clwyd and fish traps in the Dysynni and Conway estuaries. Some of the fishing gears still operating in Southwest Wales, namely compass nets on the Cleddau and coracle nets on the Teifi, Tywi and Taf, remain unique to Wales and are now accepted as part of the cultural heritage of the Welsh Nation.

The history of commercial exploitation illustrated the dramatic reduction in overall fishing effort over the last 30 years in Welsh waters. Table 2.1.31 compares the number of different types of commercial fishing licence available in 1976 compared with those available in 2006. It shows an overall reduction from 178 licences for 12 different types of fishing gear at 21 locations in 1976 to 47 licences for 7 different types of gear at 10 different locations in 2010. The declared catch for 1976 was 7,729 salmon and 9,066 sea trout compared with just 237 salmon and 2,074 sea trout in 2010.

The principal causes for this reduction were:

1) A positive shift towards phasing out all interceptory and mixed stock fisheries in accordance with the 'Headland Principle' by the introduction of 'Reducing NLOs' that fix the number of licences available in any year to a lower number when existing licence allocations are not taken up or when an existing fisherman relinquishes a licence.

2) Voluntary buy-outs, where private fishery owners agree to pay netsman to relinquish their licence in perpetuity or to cease fishing for a period of years. Those netsmen who choose to continue fishing are free to do so, but when a licence is relinquished, the number available under terms of the local NLO is reduced accordingly the following year. Some netsmen who take out a licence but do not fish or fish only occasional over a season, either in anticipation of a future buy-out or simply to maintain a local heritage as a living tradition.

3) The growth of commercial salmon farming and the low price obtained for wild fish.

Table 2.1.31 Comparison of the Number, Type & Location of Commercial Salmon Fishing Licences Issued in the Welsh Region for the 1976 and 2010 Fishing Seasons

Name of Main River or District	Type of Authorised Fishing Gear	1976 Season			2010 Season		
		Licences Issued	Reported Catch		Licences Issued	Reported Catch	
			Salmon	Sea Trout		Salmon	Sea Trout
Dee	Trammel	4	297	45	*Fishery Closed*		
	Draft	30	2,505	61	*Fishery Closed*		
Clwyd	Sling	8	919	698	*Fishery Closed*		
Dyfi	Seine	6	172	1,527	3	2	75
Dysynni	Seine	2	34	311	1	0	16
Mawddach	Seine	3	39	72	2	0	0
Dwyryd	Seine	1	30	9	*Fishery Closed*		
Glaslyn	Seine	2	73	239	*Fishery Closed*		
S. Caerns -Dwyfor	Seine	2	66	481	*Fishery Closed*		
S. Caerns -Daron	Seine	2	20	20	*Fishery Closed*		
N. Caerns	Seine	2	2	0	*Fishery Closed*		
Seiont/Gwyrfai	Seine	4	147	280	*Fishery Closed*		
N. Angelsey	Seine	2	0	26	*Fishery Closed*		
Ogwen/Aber	Seine	2	72	87	*Fishery Closed*		
Conwy	Seine	6	154	88	3	7	3
	Basket	1	5	0	1	*Not Fished*	
Teifi	Seine	5	298	428	2	56	222
	Coracle	12	86	717	11	78	786
Nevern	Seine	*No applicants: 1 licence available*			1	0	6
Tywi	Seine	9	181	1720	3	20	311
	Coracle	11	119	1,779	7	40	655
Daucleddua	Compass	8	80	8	6	13	0
Three-Rivers	Coastal Seine	15	80	192	*Fishery Closed*		
	Coastal Wade	12	19	48	*Fishery Closed*		
Taf	Wade	1	0	0	1	*Not Fished*	
	Coracle	2	9	147	1	*Not Fished*	
Usk	Drift	8	871	48	*Fishery Closed*		
	Putcher Rank	2	350	35	*Fishery Closed*		
Wye	Tuck	1	147	0	*Fishery Closed*		
	Stop	6	868	0	*Fishery Closed*		
	Lave	9	86	0	6	21	0
ALL METHODS TOTAL		**178**	**7,729**	**9,066**	**47**	**237**	**2,074**

2.1.4.3 *Fishery Rules & Regulations*

Rod Fishing

Various minor local adjustments to start and end of the rod-fishing season have occurred over the 18-year study period from 1994 that reduced the length of the fishing season. The current byelaw fixes a common closing date of 17th October for all rivers for both sea trout and salmon. However starting dates vary by several weeks - from 3rd March on the Usk and Wye, 20th March for all rivers in South and North Wales and 1st April for rivers in South West Wales. (Unlike Scotland, there is no prohibition on rod-and-line fishing for sea trout and salmon on a Sunday).

A complex array of other, river specific, local byelaws currently operate to prohibit bait fishing altogether (Wye), or to variously prohibit spinning and bait fishing at either or both the start and end of the season. Several rivers Conwy, Dwyryd, Dyfi and Seiont) have recently been granted an extended season until 31st October that is subject to mandatory catch-and release and fly-fishing only restrictions from 18th October. Bag limit restrictions apply only to 7 rivers in Southwest Wales where anglers may retain (harvest) a maximum of 4 sea trout and 2 salmon a day and a maximum of 5 salmon a week. No weekly or season bag limits apply to sea trout and there is no season bag limit for salmon. A ban on the sale of rod-caught sea trout and salmon was introduced from the start of the 2007 fishing season.

Commercial Net Fishing

All commercial fishing in Wales has been subject to a system of licensing since 1865. However, the principal statutory regulations to control the nature and extent of the commercial fishery are: a) Net Limitation Orders and b) Local Net Fishing Byelaws.

- **Net Limitation Orders (NLOs).** These powers are used to fix the maximum number of licences that may be issued in any year for different types of fishing gear at a specified location. Each NLO may operate for a maximum period of ten years and, unless it is reconfirmed or amended, the number of available licences becomes unlimited.

- **Local Fishery Byelaws.** The provisions of local byelaws are extensively used to specify the different types of fishing gear that may be licensed in any named location, the dates and duration of the fishing season, their precise location and manner of operation. They also specify the dimensions of any net and the materials to be used in its construction and, where appropriate, the time of any weekly closed period within the season when nets may not operate. They may also require each licence holder to submit an annual return of catch and stipulate the information to be included in that return.

These regulations have been supplemented recently by two other statutory measures:

- **Spring Salmon Byelaws.** Introduced in 1997, these byelaws delay the start of the salmon fishing season to 1st June for the commercial fishery (and to 16th June for the rod fishery) in order to conserve early running multi-sea winter component of the salmon stock in all Welsh rivers. They did not apply to rod-fishing for sea trout or to net fishing for sea trout on the Tywi and Teifi provided any salmon taken before 1st June were released immediately on capture.

- **Carcass Tagging.** In 2007, a new byelaw was introduced prohibiting the sale of rod caught fish and requiring an opercula (jaw) tag to be fixed to all salmon and sea trout harvested (killed) by licensed commercial netsmen. While there was no limit to the number of tags issued to fishermen over a season, each tag was uniquely numbered and traceable back through the market to each licence holder. This scheme, intended to restrict the market for the sale of illegally caught fish, was accompanied by a' logbook recording scheme' requiring each netsman to submit a monthly return of the number, weight and date of capture and tag number of each individual fish.

The only significant change in the net fishing regulations over the 18-year study period is a delay in the start of the fishing season from 1st February (Wye), 1st March (Usk) or 14th March (others rivers) until 1st June following the introduction of the 1997 byelaw to protect stocks of early running MSW spring salmon. The current fishing season (2011) is from 1st June to 31st August on all rivers except those with early runs of sea trout where a special dispensation was granted for an earlier start to the season: namely Tywi and Taf (1st March to 31st July) and the Teifi (1st April to 31st August). Any salmon caught on these three rivers before 1st June must be returned to the water. The weekly closed-time when all netting shall cease is now 06.00 hours on a Saturday until 06.00 hours on a Monday except on the West Wales rivers where the weekend closure extend to 12.00 hours on a Monday.

2.1.4.4 Fishery Performance

Catch Return Rates

Rod Fishing

The number of rod licences issued to salmon and sea trout anglers and the number of mandatory catch returns submitted each year in Wales from 1994 – 2011 is shown in Table 2.1.32. A general decline in rod licence sales is evident over the 18 year period, from 9,900 in 1994 to 7,196 in 2011. The number of catch returns submitted each year shows only a loose relationship with licence sales, but this is less apparent with the annual return rate (expressed as a percentage of sales), with the highest rates of 94% occurring in 2003 and 2004 when licence sales were lowest (Figure 2.1.26).

The mean catch return rate of 80.7% now represents a significant improvement over the rates of 26% before reminders and then 58% after reminders achieved in 1978 shortly after the new catch return system was first introduced in Wales. This indicates a heightened awareness by anglers of the importance of submitting an annual return of catch.

It should be noted that the rod catch data used in this section are 'as declared' by respondents and that no adjustment have been made by applying a 'raising factor' (Small, 1991) to include fish that may have been caught by anglers who failed to submit a catch return after receiving the two annual reminder notices. The Environment Agency now considers that the reported rod catch represents approximately 80% of the true catch over the period (Anon, 2009). It is also important to note that a variable proportion of anglers submitting an annual catch return may fail to provide complete details on effort, month of capture, method of capture, and weight of each fish caught. For this reason, the number of fish caught is based on those returns received with the relevant data and, as such, may differ in some of the following tables where the reported catch is linked to the number of returns with the relevant data.

Table 2.1.32 Annual Number of Welsh Rod Licences Issued & Number of Catch Returns Submitted (1994-2011).

Year	Number of Rod Licences Issued	Catch Returns Submitted	
		No.	%
1994	9,904	8,687	87.7
1995	9,455	6,852	72.5
1996	8,904	6,314	70.9
1997	8,900	7,407	83.2
1998	7,921	7,026	88.7
1999	7,885	5,961	75.6
2000	8,266	5,630	68.1
2001	6,612	5,379	81.4
2002	7,821	6,327	80.9
2003	6,720	6,324	94.1
2004	6,817	6,417	94.1
2005	7,505	6,190	82.5
2006	6,982	4,540	65.0
2007	7,402	5,737	77.5
2008	7,568	6,668	88.1
2009	7,815	5,802	74.2
2010	7,122	6,131	86.1
2011	7,196	6,162	85.6
Mean	7,822	6,309	80.7

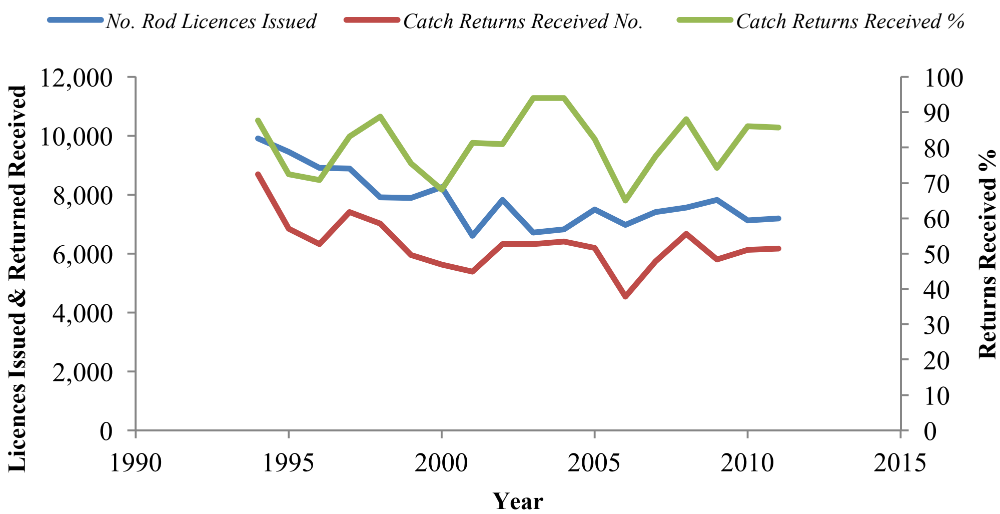


Figure 2.1.26 Annual Number of Welsh Rod Licences Issued & Number and Proportion of Catch Returns Submitted (1994-2011).

Commercial Net Fishing

Following the introduction and enforcement of a standard catch return and reporting system for the net fishery in Wales from 1976, catch return rates approximated 90%: although there was evidence of significant under-reporting of catches until the introduction of the mandatory scheme of carcass tagging and monthly reporting through the log-book scheme in 2007. Return rates of almost 100% are now achieved; with an unprecedented level of reporting of the true catch.

Detailed and reliable information on the number of net licences issued each year was impossible to obtain from the paper records for the early part of the period. This was because it is difficult to distinguish in any year between a) the number of licences available for issue, b) the number of licences actually taken out by netsmen and c) the number of licensed netsmen who did not fish. The available data, however, shows that the number of net licenses issued in the first 5 years from 1976 - 1980 ranged from 161- 175 with a mean of 168 over the 5-year period at the start of the record. This compares with a range of 44- 54 licences with a mean of 50 over the last 5 years of the record from 2007 – 2011: an overall reduction of almost 70% over the 36-year period.

Number of Fish Caught

The historical record of rod catches of sea trout and salmon for the Welsh region is based on a consistent and comparable system of rod licensing and mandatory catch returns from individual anglers that now spans a 36-year period from 1976 – 2011 (Table 2.1.33). However, the rod catch data for the 1992 and 1993 seasons is considered inaccurate because the impracticability of issuing catch return reminders in those two years following the introduction of a new 'universal' licence structure which merged the originally separate licences for salmon and sea trout with the licences for non-migratory trout and coarse fish. This hiatus was remedied from 1994 when a separate licence and catch return reminder system for migratory fish was reintroduced. For this reason, the data for 1992 and 1993 is excluded from the annual catch data when calculating the long-term mean rod catch. A separate returns system operated for the commercial net fisheries and the catch record for 1992 & 1993 remained unaffected.

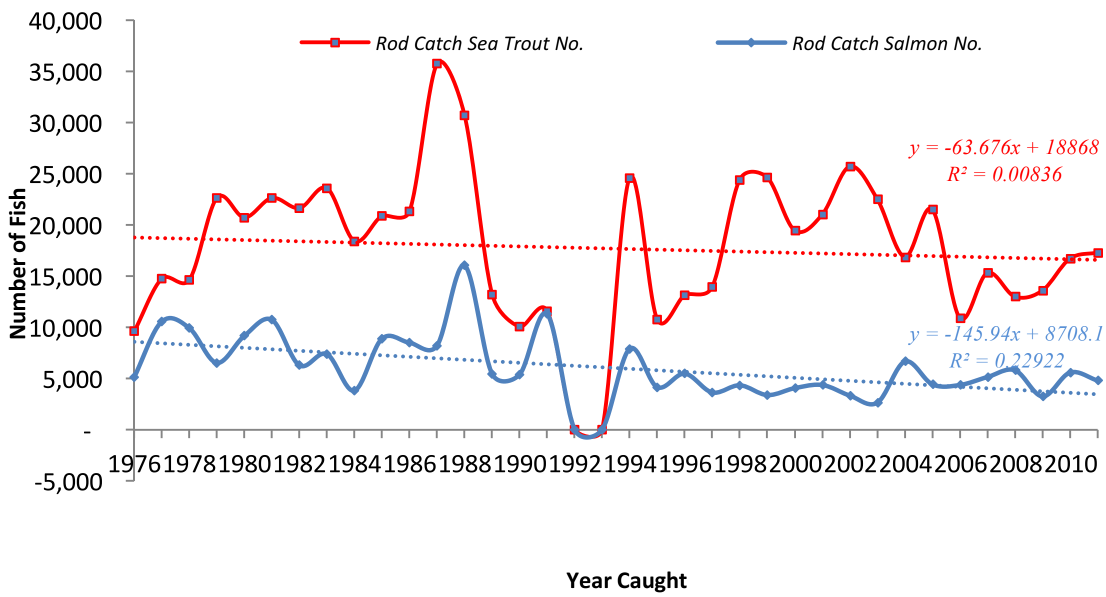


Figure 2.1.27 Number of Rod Caught Sea Trout & Salmon in Wales (1976-2011).

Table 2.1.33 Number of Sea Trout and Salmon Caught by the Rod & Net Fisheries in Wales (1976 – 2011).

Year of Capture	Reported Rod Catch		Reported Net Catch	
	Sea Trout	Salmon	Sea Trout	Salmon
	Number	Number	Number	Number
1976	9,601	5,097	9,146	7,712
1977	14,736	10,546	6,957	6,492
1978	14,623	9,937	6,589	7,426
1979	22,621	6,520	10,518	4,552
1980	20,700	9,152	12,407	6,880
1981	22,612	10,734	9,854	9,050
1982	21,621	6,285	7,820	4,481
1983	23,561	7,381	8,566	4,834
1984	18,386	3,802	10,937	3,947
1985	20,868	8,876	5,097	3,465
1986	21,308	8,498	5,098	5,031
1987	35,727	8,193	4,878	4,535
1988	30,681	16,043	6,591	5,010
1989	13,203	5,454	6,440	5,058
1990	10,030	5,370	3,588	4,377
1991	11,586	3,783	2,705	3,044
1992*1	4,634	1,279	1,647	2,927
1993*1	13,350	4,080	1,684	3,324
1994	24,585	7,901	3,019	4,995
1995	10,754	4,146	2,426	3,039
1996	13,123	5,468	1,608	2,931
1997	13,914	3,622	1,322	2,628
1998	24,401	4,325	1,192	2,300
1999	24,616	3,369	1,978	2,347
2000	19,439	4,049	1,942	1,004
2001	20,991	4,351	2,334	997
2002	25,689	3,312	1,943	1,275
2003	22,503	2,632	1,964	975
2004	16,836	6,652	1,337	970
2005	21,477	4,408	1,442	1,121
2006	10,885	4,355	695	679
2007	15,290	5,136	936	613
2008	12,970	5,789	1,022	160
2009	13,556	3,235	1,480	93
2010	16,674	5,573	2,074	223
2011	17,274	4,784	1,906	230

*1 No catch return reminders were issued to anglers in 1992 & 1993.

Rod Catches

The annual rod catch of sea trout for the periods 1976-1991and 1994 – 2011 varied widely about the long-term mean of 18,362 fish and ranged from a peak of 35,727 in 1987 to a low of 9,601 in 1976. This compares with a mean salmon catch of 6,362 with a peak of 16,043 in 1998 and a low of 2,632 in 2003 over the same 34 -year period. The significant declines in catches of both salmon and sea trout in 1989 and 1990 may be explained by the impact on fishing effort and angling success caused by the extended droughts and exceptional low river flows that occurred in those two years.

Figure 2.1.27 illustrates the pattern of catches over the study period. The 5-year running mean suggests that the long-term rod catch of sea trout fluctuates about two clear peaks in 1988 and 2002 but exhibits no general decline in catch. By contrast, the salmon rod catch shows a steady and consistent downward trend from the peak catch in 1988.

Commercial Net Catches

It is difficult to interpret the long-term record of catches for the commercial fishery shown in Table 2.1.33 and Figure 2.1.28 because of the dramatic decrease in the number of licences issued each year and, the consequent reduction in the overall reduction in fishing effort between the start and end of the 36- year period. The reported commercial catch of sea trout peaked at 12,407 in 1980, declined progressively to an all time low of 695 fish in 2006 and has been less than 2,000 fish in 9 of the last 10 years. Similarly, the salmon net catch peaked at 9,050 in 1981, reached an all-time low in 2009 when only 93 fish were recorded. It and has been less than 1,300 fish in the last 10 years and below 1,000 fish in 9 of those 10 years.

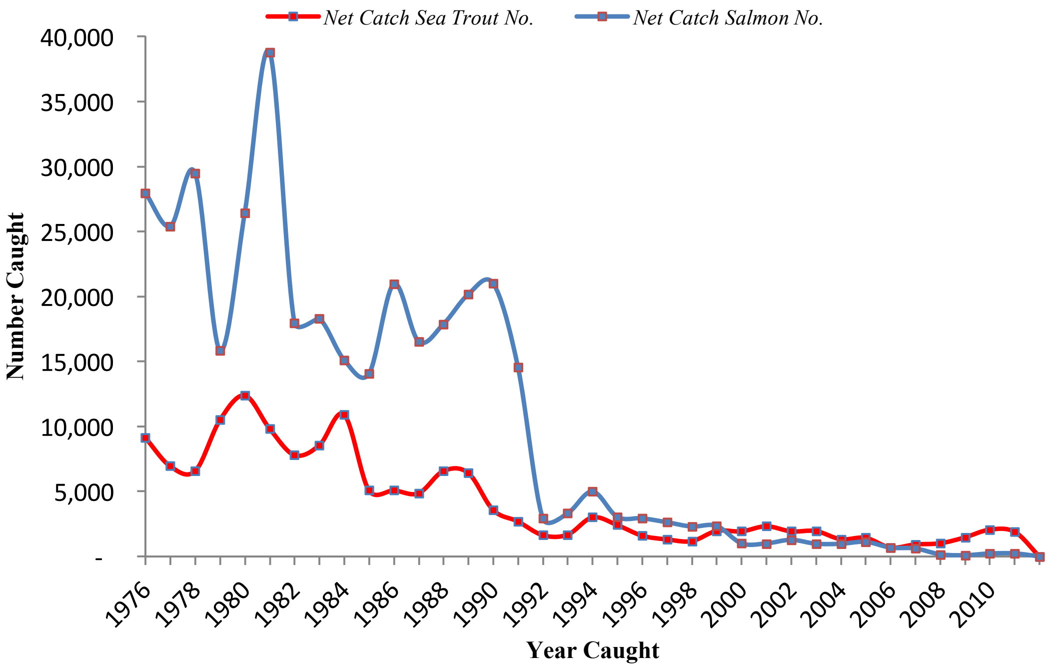


Figure 2.1.28 Number of Net Caught Sea Trout & Salmon in Wales (1976-2011).

The general impact of the overall reduction in net fishing in most recent years (Table 2.1.34) is that only three rivers in the Region (Teifi, Tywi and Dyfi) have been regularly fished each year to any significant extent. Elsewhere, not all the licences available in any year were taken out, not all of the licences issued were fished and, even when nets were operated, fishing effort was intermittent, infrequent and largely recreational between seasons. Nevertheless, commercial fishing is still a significant regular feature on the Teifi and Tywi (seine and coracle) nets and on the Dyfi (Seine nets). The reported net catches for these three rivers over the 11 -year period from 2001-2011 are shown in Table 2.1.34 for sea trout and salmon. Figure 2.1.29 illustrates the combined catch for the coracle and seine nets on the Tywi and Teifi.

The mean annual sea trout catch for the three rivers of 1,474 sea trout was significantly greater than the mean catch of 119 salmon. The sea trout catch exceeded the salmon catch in all years for both the seine nets and coracle nets on the Tywi and Teifi. However, dispensation for an earlier start to the fishing season in March on the Tywi compared with April for the Teifi and the presence of an earlier run of sea trout on the Tywi resulted in greater catches by the Tywi seines and coracles than for these instruments on the Teifi.

The decline in net fishing on other rivers has seen a marked shift in the proportion of sea trout and salmon taken on these three rivers relative to all other rivers in Wales. In 2001, when the 4 Dee trammel nets and 8 seine nets were operating (and reported a catch of 750 salmon but only 26 sea trout) the proportion of net caught fish on the three rivers was a remarkable 93% for sea trout and 14% for salmon. By 2011, when the Dee net fishery had closed and fishing on all other rivers was at a very low level of effort, these proportions had changed to 99% for sea trout and 84% for salmon.

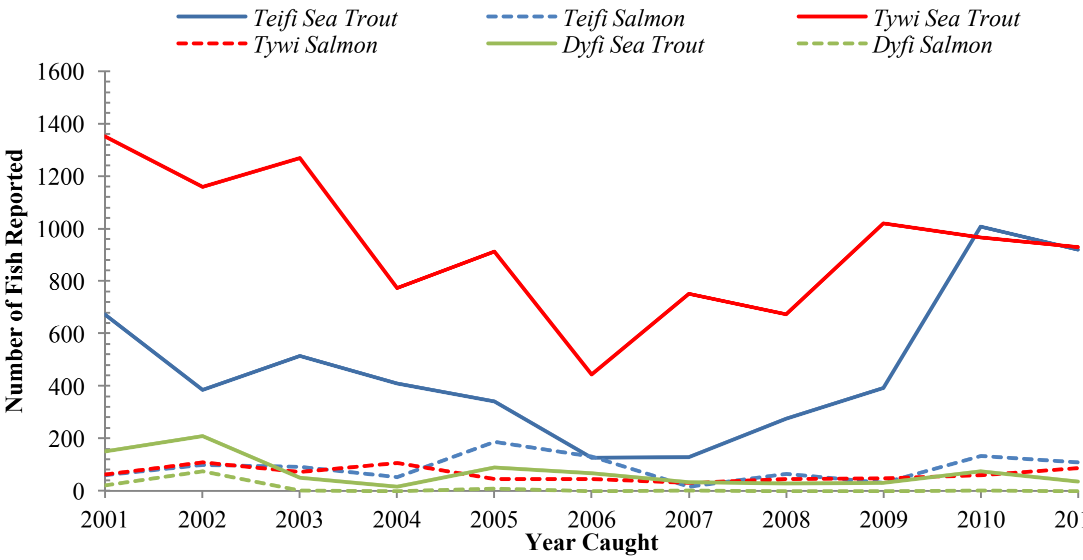


Figure 2.1.29 Number of Sea Trout & Salmon Caught by Seine and Coracle Nets on the Afonau Tywi and Teifi (2001-2011).

Weight of Catch

Table 2.1.35 and Figure 2.1.30 show the total weight of salmon and sea trout caught by the rod and commercial net fisheries in Wales and the average weight of individual fish in each year from 1994-2011.

Rods

The total annual weight of the rod catch of sea trout ranged about a mean of 33,070 lbs from 20,315 lbs in 2006 to 47,036 lbs in 2001. This compares with a mean annual catch for salmon of 36,488 lbs with a range between 23,126 lbs in 2003 and 59,046 lbs in 1944. It is relevant to note that the total weight of the sea trout catch exceeded that of the salmon catch over the 6-year period from 1998-2003 and that the long-term mean catches of sea trout and salmon at 33,070 lbs and 36,488 lbs respectively were similar.

The mean weight of individual rod-caught sea trout was 0.84 kg and ranged from 0.72 kg in 1998 and 2001 to 0.94 kg in 2008 and 2009. The mean weight of individual salmon at 3.8 kg ranged between 3.32 kg in 2010 to 4.2 kg in 2003. The mean weight of each sea trout and salmon has been fairly constant with no marked increase or decrease over the period (Figure 2.1.30).

Table 2.1.34 Annual Catch of Sea Trout & Salmon from the Coracle and Seine Net Fisheries on the Afonydd Teifi, Tywi & Dyfi Compared with the Total Net Catch for the Welsh Region (2001-2011).

SEA TROUT													
River	**Gear**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**Mean**
Teifi	Seines	170	7	15	13	79	13	38	80	94	222	224	87
	Coracles	502	378	500	396	263	112	90	194	299	786	696	383
	Teifi Total	**672**	**385**	**515**	**409**	**342**	**125**	**128**	**274**	**393**	**1,008**	**920**	**470**
Tywi	Seines	613	604	504	567	589	247	400	306	383	311	336	442
	Coracles	738	555	766	205	324	197	351	367	637	655	594	490
	Tywi Total	**1,351**	**1,159**	**1,270**	**772**	**913**	**444**	**751**	**673**	**1,020**	**966**	**930**	**932**
Dyfi	Seines	151	210	51	16	90	67	33	29	31	*75*	36	**72**
3-Rivers Total		**2,174**	**1,754**	**1,836**	**1,197**	**1,345**	**636**	**912**	**976**	**1,444**	**2,049**	**1,886**	**1474**
All Wales Total		**2,334**	**1,943**	**1,964**	**1,337**	**1,442**	**695**	**936**	**1,022**	**1,480**	**2,074**	**1,906**	**1,558**

SALMON													
River	**Gear**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**Mean**
Teifi	Seines	0	17	4	1	103	85	1	41	13	56	39	**33**
	Coracles	60	82	88	51	85	45	15	24	17	78	69	**35**
	Teifi Total	**60**	**99**	**92**	**52**	**188**	**130**	**16**	**65**	**30**	**134**	**108**	**66**
Tywi	Seines	16	45	32	71	26	20	16	16	8	20	29	**19**
	Coracles	46	63	41	35	20	25	16	29	40	40	57	**24**
	Tywi Total	**62**	**108**	**73**	**106**	**46**	**45**	**32**	**45**	**48**	**60**	**86**	**43**
Dyfi	Seines	21	75	1	0	8	0	2	0	0	2	0	**10**
3-Rivers Total		**143**	**282**	**166**	**158**	**242**	**175**	**50**	**110**	**78**	**196**	**194**	**119**
All Wales Total		**997**	**1275**	**975**	**970**	**1121**	**679**	**613**	**160**	**93**	**223**	**230**	**667**

Table 2.1.35 The Number, Total Annual Weight of Catch and Mean Fish Weight (kg) for Salmon & Sea Trout Caught by Rods in Wales (1994-2011).

Year Caught	**SEA TROUT (kg)**			**SALMON (kg)**		
	No.	***Weight***	***Mean***	***No.***	***Weight***	***Mean***
1994	24,562	20,818	0.85	7,196	26,847	3.73
1995	10,754	9,755	0.91	3,882	14,660	3.78
1996	13,123	9,853	0.75	4,788	18,960	3.96
1997	13,914	11,862	0.85	3,371	12,150	3.60
1998	24,401	17,506	0.72	4,208	13,964	3.32
1999	24,629	21,114	0.86	3,139	12,714	4.05
2000	19,439	17,541	0.90	3,796	13,777	3.63
2001	20,991	15,718	0.75	4,165	15,590	3.74
2002	25,689	21,380	0.83	3,282	12,367	3.77
2003	22,503	18,667	0.83	2,503	10,512	4.20
2004	16,836	14,810	0.88	6,387	23,948	3.75
2005	21,477	16,417	0.76	4,239	16,466	3.88
2006	10,885	9,234	0.85	4,214	15,581	3.70
2007	15,290	13,450	0.88	4,971	18,199	3.66
2008	12,970	12,164	0.94	5,789	22,147	3.83
2009	13,556	12,789	0.94	3,235	12,885	3.98
2010	16,674	13,729	0.82	5,573	18,519	3.32
2011	17,274	13,768	0.80	4,784	19,252	4.02
Mean	**18,054**	**15,032**	**0.84**	**4,418**	**16,585**	**3.77**

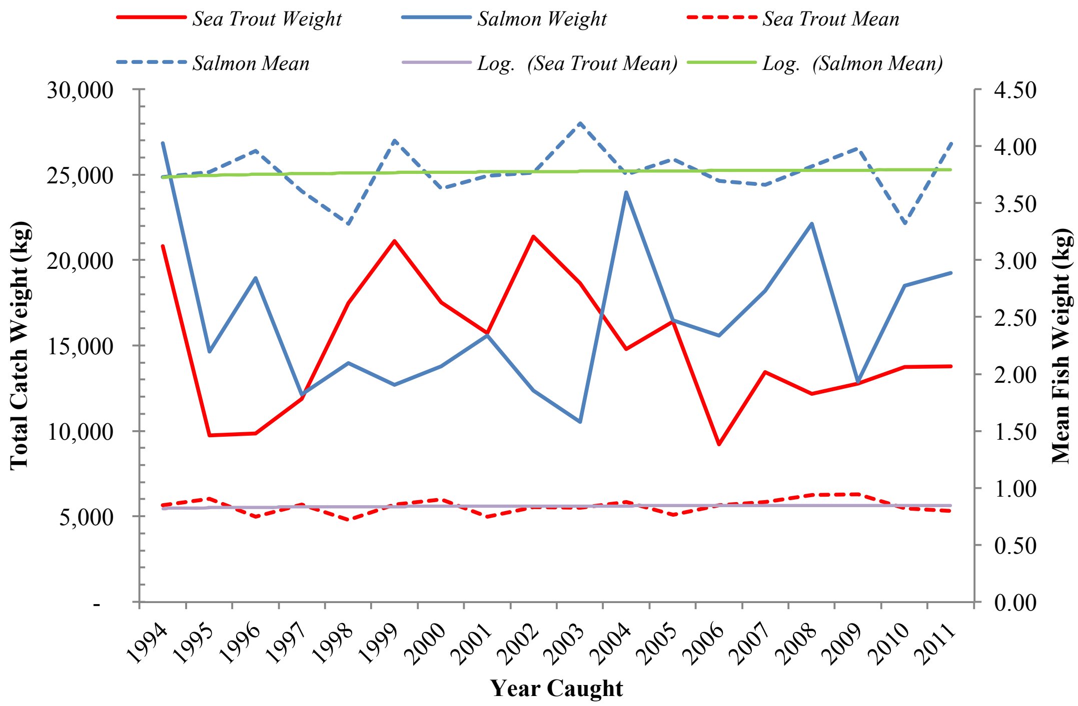


Figure 2.1.30 Total Catch Weight & Mean Individual Fish Weight of Rod Caught Salmon and Sea Trout in Wales (1994 – 2011).

Nets

Parallel information on the total annual weight of fish caught and the average weight of each fish for the net fishery is shown in Table 2.1.36 and Figure 2.1.31. The marked decline in the total weight of the catch of sea trout and salmon largely reflects the significant decrease in the number of fish caught as a consequence of the significant reduction in netting licences and fishing effort over the 18-year period of the record.

Apart from decline in the total annual weight of the net catch of sea trout and salmon, a significant feature of the record is that the weight of the annual sea trout catch exceeded that of salmon for the first time in 2000 and was greater than the salmon catch in each of the last 5 years. Consequently, the importance of sea trout contributing to the livelihood of the netsmen in the Welsh Region is now greater than that of salmon.

The weight of individual sea trout with a mean of 2.1 lbs and a range of 1.7 lbs – 2.5 lbs, has been relatively constant over the study period (Figure 2.1.31) with no long-term trend of increase or decrease. The mean weight of 3.8 lbs for salmon and a range of 3.2 lbs – 4.8 lbs has shown greater variability and a modest trend of decrease over the period. This which may reflect the reduction of netting effort on rivers such as the Dee, Usk and Wye where a major proportion of the salmon catch consisted of large MSW salmon.

The long-term mean weight of individual net caught fish was 1.95 kg for sea trout (range 1.5 – 2.49 kg). For salmon, the mean fish weight was 3.91 kg (range 3.22-4.50 kg). While the trend in annual mean weight of sea trout (Figure 2.1.31) appears to show a slight increase from the late 1980s, the trendline for salmon indicates a steady decrease in the mean weight of individual fish.

Table 2.1.36 Total Weight and Mean Weight of Net Caught Salmon & Sea Trout in Wales (1994-2011).

Year Caught	SEA TROUT			SALMON		
	No.	*Weight*	*Mean*	*No.*	*Weight*	*Mean*
1994	3,019	7,231	2.4	4,995	21,397	4.3
1995	2,426	6,010	2.5	3,039	14,586	4.8
1996	1,608	3,213	2.0	2,931	11,026	3.8
1997	1,322	2,532	1.9	2,628	8,961	3.4
1998	1,192	2,400	2.0	2,300	8,360	3.6
1999	1,978	3,774	1.9	2,347	9,397	4.0
2000	1,942	3,622	1.9	1,004	3,565	3.6
2001	2,334	4,031	1.7	997	3,594	3.6
2002	1,943	4,222	2.2	1,275	5,211	4.1
2003	1,964	3,781	1.9	975	3,783	3.9
2004	1,337	3,012	2.3	970	3,653	3.8
2005	1,442	3,152	2.2	1,121	3,970	3.5
2006	695	1,633	2.3	679	2,852	4.2
2007	936	2,032	2.2	613	2,022	3.3
2008	1,022	2,026	2.0	160	561	3.5
2009	1,480	3,214	2.2	93	390	4.2
2010	2,074	3,213	1.5	223	718	3.2
2011	1,906	3,980	2.1	230	901	3.9
Mean	**1,701**	**3,504**	**2.1**	**1,477**	**5,830**	**3.8**

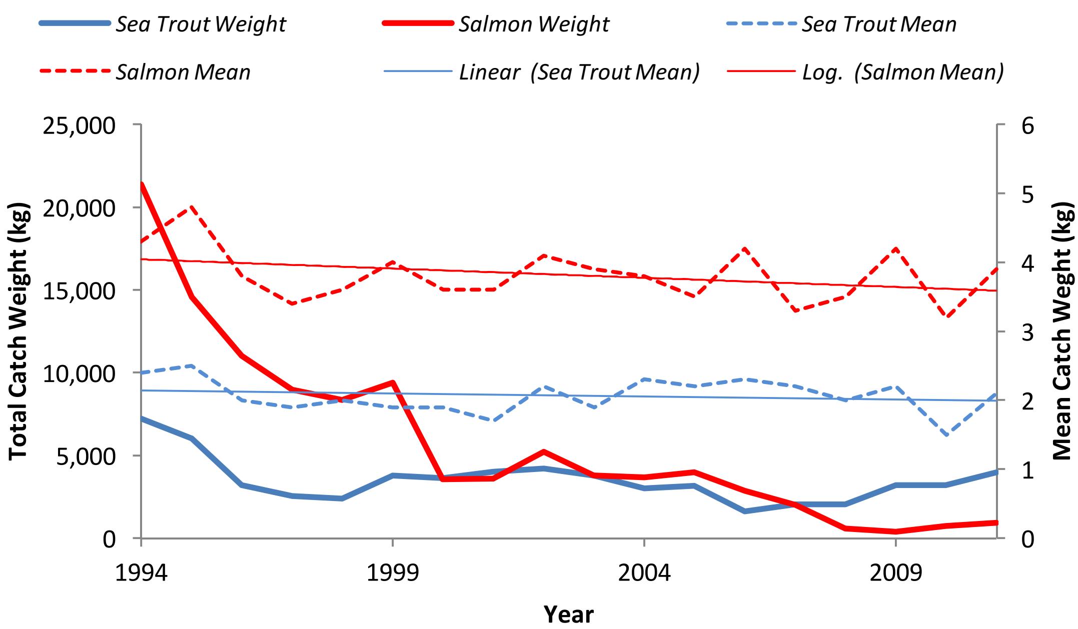


Figure 2.1.31 Total Annual Weight and Mean Weight of Net Caught Salmon & Sea Trout in Wales (1994–2011).

Weight Distribution of Sea Trout

Wales was the first region of the UK and Ireland to incorporate a basic breakdown of the weight of individual sea trout caught by anglers in the annual statistical reports at various times from 1976. However, reporting was not throughout the study period from 1994. It only recommenced in 2006 when the annual rod catch was broken down into three weight classes as: a) 1lb or less, b) 1 – 4 lbs and c) more than 4lbs. As such, this analysis fails to describe effectively the wide range of larger weights attained by Welsh sea trout.

In an attempt to fill this important gap in any description of the overall quality of Welsh sea trout fisheries, unpublished data has been sourced from the central data-base from 1994-2011 (Table 2.1.37). This shows show the number of fish caught in each of the separate weight class intervals of 1 lb across the range of weights attained by Welsh sea trout.

It is evident that the number of the smallest whitling sea trout of less than 1 lb weight was underestimated since this immature component of the returning annual run is the largest single component of the stock in Welsh rivers and is often caught in very large numbers on most fisheries. This anomaly is thought to result from the way anglers record the weight of their catch of small fish (which are invariably returned after capture, with the weight guessed at 1lb or more) and the way that the data is abstracted from the catch return forms and incorporated into the database.

The annual mean number and proportion of fish in each weight class declines rapidly with decreasing size from more than half the catch at 59.5% (3,812 fish) weighing less than 2 lbs, 32.8% (2,103 fish) weighing between 2-4 lbs, 5. 6% (16 fish1) weighing between 4-6 lbs, 1.4% (88 fish) weighing between 6- 8 lbs and 0.8% (59 fish) weighing from 8-20 lbs. These data are shown in Table 2.1.38 and Figure 2.1.32 where the two smallest weight classes of less than 2lbs and the 8 largest weight classes from 13-20+ lbs have been aggregated.

Aggregation of the larger weight classes to show the annual mean catch tends to underestimate the important 'cachet value' of these very large 'trophy' or 'specimen' sea trout to a region. The number of sea trout caught over the 18 -year period shown in Table 2.1.37 in excess of 10 lbs was 1,925 and in excess of 15 lbs was 163, of which 10 fish weighed in excess of 20 lbs. The current Welsh record sea trout came from the Dyfi in 1952 and weighed 241/2 lbs. Most Welsh sea trout rivers have produced large 'specimen' sea trout in the past, even the smaller, minor rivers such as the Dwyryd and Dwyfawr, (Harris 1972) , but the most notable rivers for consistently producing fish in excess of 15 lbs weight are the Dyfi and Tywi.

Table 2.1.37 Mean Annual Weight Class Distribution for Rod-Caught Sea Trout in Welsh Region (1994 – 2011).

Year Caught	No. Returns with Data	Sea Trout Weight Class Interval (lbs)															Total Catch
		<1	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+	13+	14-20+	
1994	**1,253**	47	3,425	1,609	705	272	92	55	30	17	17	9	4	3	3	7	6,295
1995	**1,151**	88	3,410	1,505	580	217	94	41	15	9	5	1	2	-	-	1	5,968
1996	**1,206**	100	3,313	1,330	550	266	94	49	30	16	5	5	3	4	-	2	5,767
1997	**1,121**	149	2,858	1,272	525	222	98	64	29	16	3	4	2	4	1	2	5,249
1998	**1,544**	527	5,190	1,989	853	320	127	68	42	28	13	9	10	2	3	3	9,184
1999	**1,334**	54	3,456	2,006	1,098	392	115	61	31	17	14	6	5	3	2	5	7,265
2000	**1,457**	73	5,958	2,316	1,179	446	182	85	43	18	17	11	5	6	3	3	10,345
2001	**702**	8	2,979	857	349	132	51	30	23	26	2	6	-	-	-	-	4,463
2002	**1,431**	30	4,125	2,048	1,209	413	191	99	47	35	21	13	4	4	3	3	8,245
2003	**1,238**	31	4,417	1,909	901	328	119	72	50	32	12	10	2	3	2	5	7,893
2004	**1,198**	49	3,639	1,256	636	262	113	59	48	34	21	15	9	15	9	11	6,176
2005	**1,310**	112	4,127	1,440	641	203	76	32	24	11	8	5	2	2	1	7	6,691
2006	**913**	55	2,365	817	344	106	61	30	28	27	8	8	2	3	2	7	3,863
2007	**1,064**	34	3,091	1,193	506	161	77	41	28	21	3	11	7	4	-	5	5,182
2008	**1,006**	8	2,559	1,052	478	181	98	55	38	30	10	9	-	12	1	10	4,541
2009	**1,167**	-	2,997	1,255	718	240	139	73	41	42	22	18	21	12	6	24	5,608
2010	**1,229**	1	3,978	1,145	642	221	107	58	28	19	5	10	1	5	3	6	6,229
2011	**1,290**	4,076	1,284	717	218	101	57	30	8	5	4	2	5	1	4	5	6,517
Total	**21,614**	**5,442**	**63,171**	**25,716**	**12,132**	**4,483**	**1,891**	**1,002**	**583**	**403**	**190**	**152**	**84**	**83**	**43**	**106**	115,481
Mean	**1,201**	**302**	**3,510**	**1,429**	**674**	**249**	**105**	**56**	**32**	**22**	**11**	**8**	**5**	**5**	**2**	**6**	6,416
% of Annual Mean		4.71	54.70	22.27	10.51	3.88	1.64	0.87	0.50	0.35	0.16	0.13	0.07	0.07	0.04	0.09	100.00

Table 2.1.38 Mean Weight Class Distribution of Rod-Caught Sea Trout For Welsh Region (1994 – 2011).

Year of Capture	Weight Class Interval (lbs)							Annual Total
	<2	>2 - <4	>4 - <6	>6 - <8	>8 - <10	>10 - <12	>12 - 20+	
1994	3472	2,314	364	85	34	13	13	6,295
1995	3498	2,085	311	56	14	3	1	5,968
1996	3413	1,880	360	79	21	8	6	5,767
1997	3007	1,797	320	93	19	6	7	5,249
1998	5717	2,842	447	110	41	19	8	9,184
1999	3510	3,104	507	92	31	11	10	7,265
2000	6031	3,495	628	128	35	16	12	10,345
2001	2987	1,206	183	53	28	6	-	4,463
2002	4155	3,257	604	146	56	17	10	8,245
2003	4448	2,810	447	122	44	12	10	7,893
2004	3688	1,892	375	107	55	24	35	6,176
2005	4239	2,081	279	56	19	7	10	6,691
2006	2420	1,161	167	58	35	10	12	3,863
2007	3125	1,699	238	69	24	18	9	5,182
2008	2567	1,530	279	93	40	9	23	4,541
2009	2997	1,973	379	114	64	39	42	5,608
2010	3979	1,787	328	86	24	11	14	6,229
2011	5360	935	158	38	9	7	10	6,517
Total	68,613	37,848	6,374	1,585	593	236	232	**115,481**
Mean	3,812	2,103	354	88	33	13	13	**6,416**
%	59.4	32.8	5.5	1.4	0.5	0.2	0.2	**100.00**

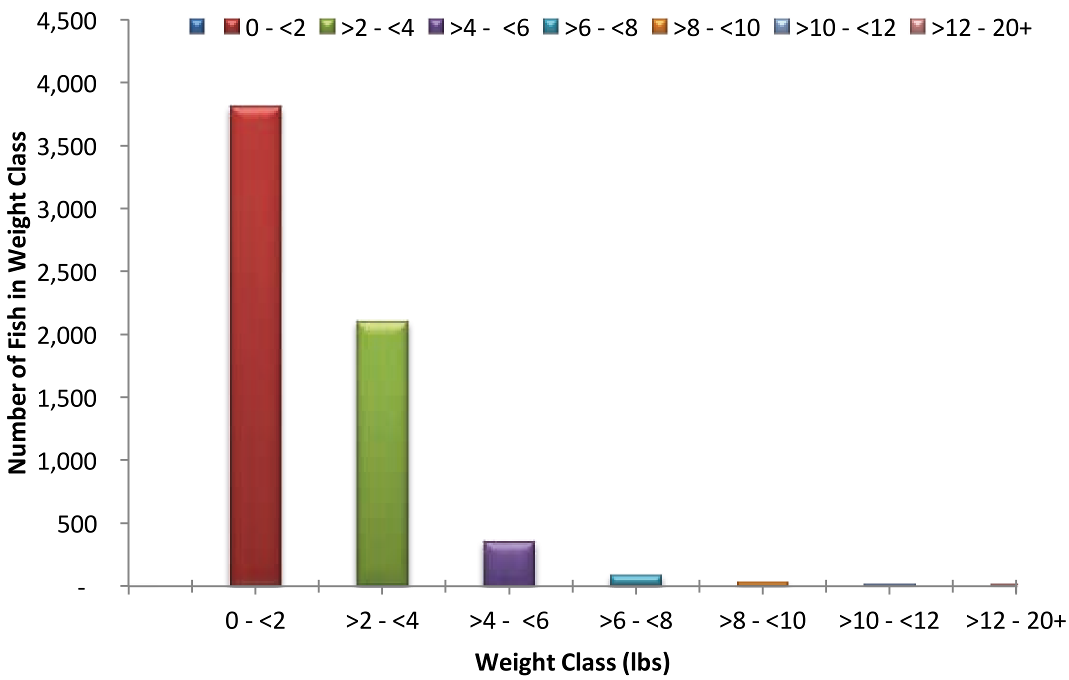


Figure 2.1.32 Mean Weight Class Distribution of Rod-Caught Sea Trout For Welsh Region (1994 – 2011).

Month of Rod Capture

The aggregated annual number of fish caught in each month of the rod fishing season in each year from 1994-2011 is given in Table 2.1.39 & Table 2.1.40 for sea trout and salmon respectively and shown in Figure 2.1.33. (Note that the fishing season ended on 17th October on most rivers over much of the period and that the reported catches are for part of the month only). The introduction of the National Spring Salmon Byelaws in 1999 requiring the release of all rod-caught salmon before 16th June may have reduced salmon fishing effort and catches in the early month of the year.

Sea trout catches built up slowly between March and May and then increased rapidly through June and July to a peak in August before tailing off during the last few weeks of the season in September and October. Relatively few salmon were caught in March and April. They then increased steadily from May to August, reached a peak in September before decreasing in October (part-month).

Figure 2.1.33 shows the proportions of fish caught in each month and the cumulative percentage of fish caught as the season progresses. The proportion of the mean catch of sea trout caught before June was 6.3% (1,098 fish) compared with 8.4% (363 fish) for salmon. The mean catch of sea trout caught from June to August was 68.9% (11,943 fish compared with 35% (1,932 fish) for salmon. While 46.5% of salmon (2,000 fish were caught in September and October compared with 24.7% (4,279 fish) for Sea Trout. On average, more sea trout were caught in each month of the season than salmon and, significantly, the mean catch of sea trout in each of the two months of July (4,871 fish) and August (4,373 fish) exceeded the total mean catch of salmon for the whole year (4,294 fish).

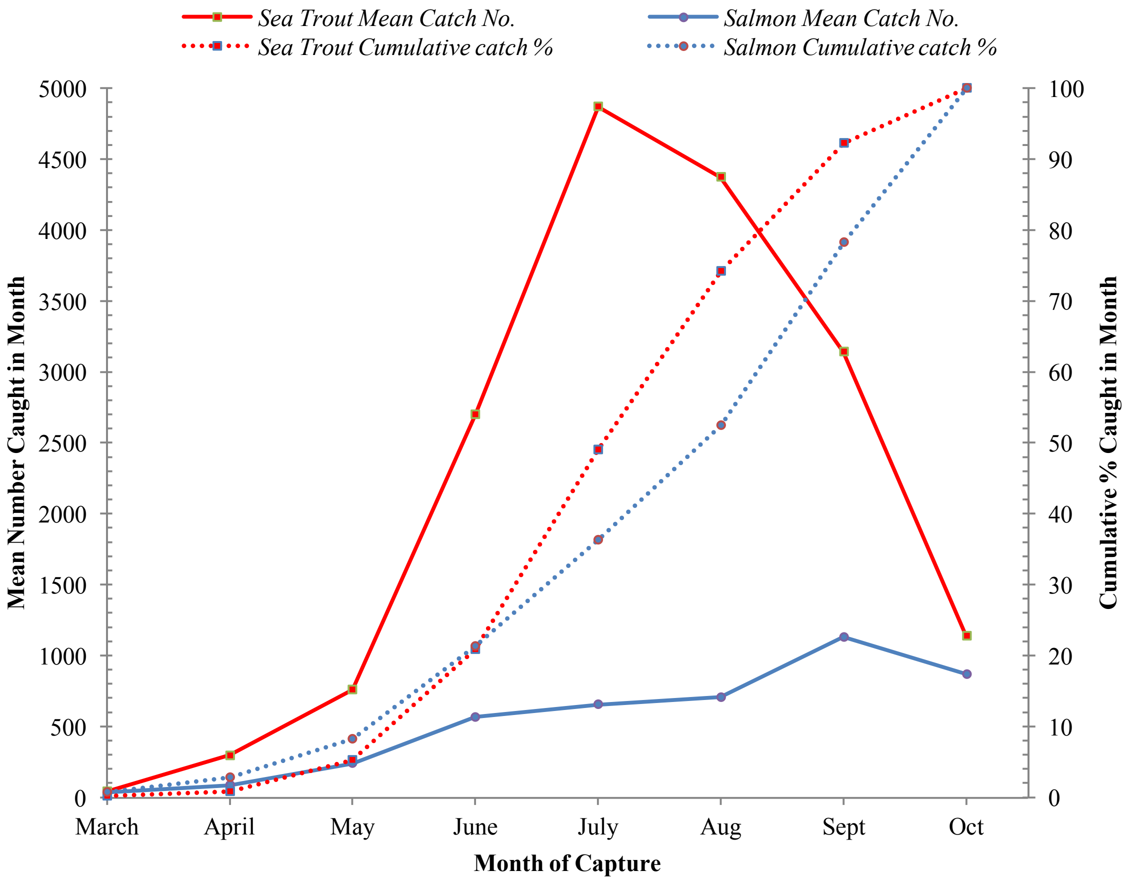


Figure 2.1.33 Mean Number and Cumulative Proportion of Sea Trout & Salmon Caught by Rods in Welsh Region for Each Month of Annual Fishing Season (1994 -2011).

Table 2.1.39 Number of Sea Trout Caught by Anglers in Each Month of the Fishing Season in the Welsh Region (1994-2011).

Year Caught	Number of Sea Trout Caught in Month								Total Number
	March	April	May	June	July	Aug	Sept	Oct	
1994	45	413	920	3,322	6,249	6,477	5,029	1,294	23,749
1995	31	192	499	1,559	2,432	1,764	2,731	1,327	10,535
1996	58	204	462	1,433	2,564	3,608	3,035	1,457	12,821
1997	10	221	734	2,375	3,284	3,366	2,652	796	13,438
1998	45	269	554	3,337	6,570	6,492	4,272	986	22,525
1999	15	422	1,160	4,186	5,829	5,977	4,211	1,644	23,444
2000	28	345	943	3,610	5,582	4,192	3,010	1,020	18,730
2001	5	36	254	2,169	6,221	6,292	3,727	1,207	19,911
2002	33	438	1,108	4,284	7,371	6,013	3,689	1,520	24,456
2003	35	265	1,286	3,977	7,504	5,049	2,948	1,120	22,184
2004	15	240	667	2,227	4,372	4,315	3,124	1,194	16,154
2005	92	350	724	3,197	5,889	4,692	3,480	1,956	20,380
2006	18	252	585	1,543	2,309	2,353	2,310	1,177	10,547
2007	50	330	838	2,464	4,250	3,612	2,540	722	14,806
2008	20	285	552	1,768	3,909	3,267	2,075	805	12,681
2009	88	351	829	2,267	3,781	3,230	1,912	659	13,117
2010	72	344	705	1,730	4,574	4,376	3,238	916	15,955
2011	76	387	854	3,139	4,980	3,631	2,555	686	16,308
Mean	**41**	**297**	**760**	**2,699**	**4,871**	**4,373**	**3,141**	**1,138**	**17,319**
% Mean	**0.2**	**1.7**	**4.4**	**15.6**	**28.1**	**25.2**	**18.1**	**6.6**	**100.00**

Table 2.1.40 Number of Salmon Caught by Anglers in Each Month of the Fishing Season in the Welsh Region (1994-2011).

Month Caught	Number of Salmon Caught in Month								Total Number
	March	April	May	June	July	Aug	Sept	Oct	
1994	63	246	615	815	925	963	2,449	907	6,983
1995	52	116	308	679	422	263	948	1,035	3,823
1996	53	121	497	854	415	686	879	1,202	4,707
1997	40	63	200	591	478	409	827	615	3,223
1998	19	30	122	464	768	845	1,151	582	3,981
1999	20	46	211	447	415	503	665	764	3,071
2000	14	40	177	488	728	600	913	717	3,677
2001	2	18	104	452	692	957	991	821	4,037
2002	10	35	195	631	575	528	512	644	3,130
2003	17	60	229	439	505	345	443	426	2,464
2004	71	101	254	486	713	1,066	1,973	1,556	6,220
2005	65	114	263	498	538	512	819	1,238	4,047
2006	18	144	250	544	323	464	1,046	1,355	4,144
2007	30	71	189	533	1,007	1,048	1,316	708	4,902
2008	31	123	227	793	967	1,097	1,401	1,070	5,709
2009	43	76	184	435	639	618	680	459	3,134
2010	43	74	106	368	902	1,117	1,821	946	5,377
2011	48	67	214	701	799	717	1,519	602	4,667
Mean	**36**	**86**	**241**	**568**	**656**	**708**	**1,131**	**869**	**4,294**
% Mean	**0.8**	**2.0**	**5.6**	**13.2**	**15.3**	**16.5**	**26.3**	**20.2**	**100.00**

Angler Catch-and-Release

The number and proportion of sea trout and salmon that were released after capture by anglers in the Welsh region in each year from 1994 - 2011 is shown in Table 2.1.41 and Figure 2.1.34 (sea trout) & Figure 2.1.35 (salmon). It is evident that there was progressive and steady increase in annual release rates for both species over the period, with higher return rates for sea trout than salmon in every year.

The long-term mean return rate for sea trout was 52.7% and ranged from a low of 11.1% in 1994 to a peak of 52.7% in 2011. Over that period, the mean catch of sea trout was 18,053 fish of which 9,410 were returned to their respective rivers. Over the same period, salmon release rates ranged about a mean of 36.7%, from a low of 11.1% in 1994 to a peak of 57.8% in 2011 and the mean catch of salmon was 4,603 fish of which 1,668 (36.2%) were returned.

There appears to be little direct relationship between the annual number of fish caught and then released (Figure 2.1.34 & Figure 2.1.35) or with the numbers of days fished in each year (Table 2.1.41).

Table 2.1.41 Number and Proportion of Sea Trout & Salmon Caught and Released in the Welsh Region (1994 – 2011).

Year of Capture	No. Returns with Effort Data	Total No. Days Fished	SALMON			SEA TROUT		
			Caught	Released		Caught	Released	
			No.	No.	%	No.	No.	%
1994	8,687	118,862	7,196	800	11.1	24,562	8,776	35.7
1995	6,852	85,107	4,146	593	14.3	10,754	4,647	43.2
1996	6,314	84,922	5,468	684	12.5	13,123	6,117	46.6
1997	7,407	102,930	3,622	480	13.3	13,914	6,305	45.3
1998	7,026	87,801	4,325	979	22.6	24,401	12,233	50.1
1999	5,961	70,424	3,369	1,216	36.1	24,616	11,988	48.7
2000	5,630	65,965	4,049	1,264	31.2	19,439	9,321	47.9
2001	5,379	58,895	4,351	1,347	31.0	20,991	11,283	53.8
2002	6,327	67,653	3,312	1,346	40.6	25,689	12,618	49.1
2003	6,324	70,400	2,632	1,172	44.5	22,503	11,005	48.9
2004	6,417	72,346	6,648	2,487	37.4	16,840	8,793	52.2
2005	6,190	66,820	4,408	2,310	52.4	21,477	12,150	56.6
2006	4,540	52,919	4,355	2,285	52.5	10,885	6,283	57.7
2007	5,737	64,386	5,136	2,517	49.0	15,290	8,609	56.3
2008	6,668	56,042	6,122	3,153	51.5	12,970	7,411	57.1
2009	5,802	68,668	3,356	1,736	51.7	13,556	7,808	57.6
2010	6,131	69,615	5,573	2,880	51.7	16,674	11,505	69.0
2011	6,162	68,453	4,784	2,766	57.8	17,274	12,519	72.5
Mean	***6,309***	***74,012***	***4,603***	***1,668***	**36.7**	***18,053***	***9,410***	**52.7**

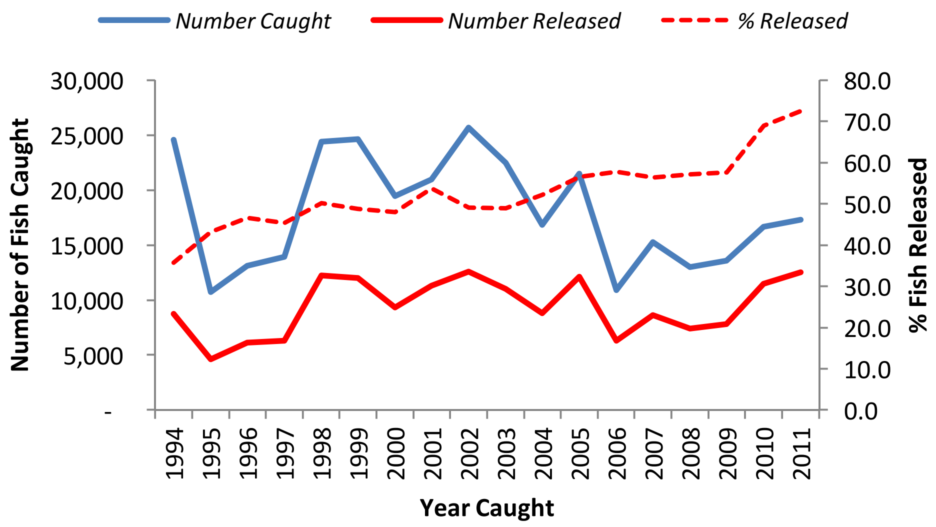


Figure 2.1.34 The Number & Proportion of Sea Trout Caught and Released by Anglers in the Welsh Region (1994-2011).

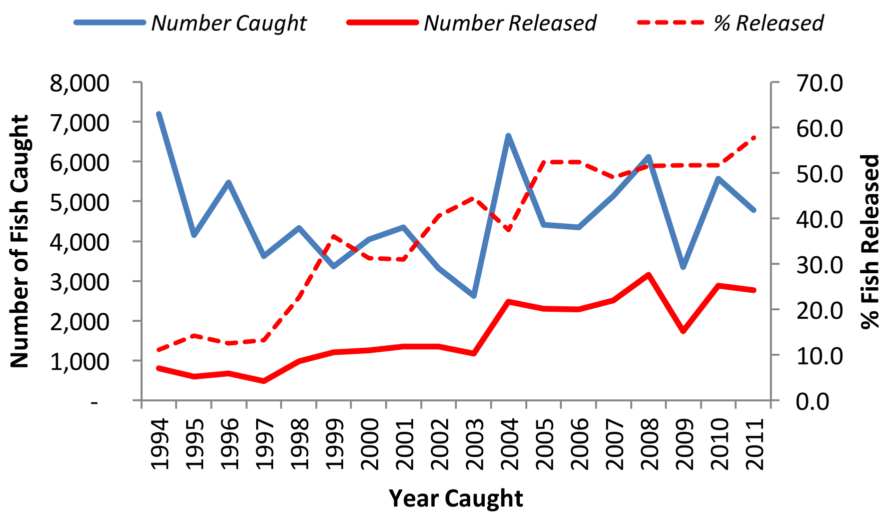


Figure 2.1.35 The Number & Proportion of Salmon Caught and Released by Anglers in the Welsh Region (1994-2011).

The introduction of a National byelaw in 1999 requiring the release of all salmon (but not sea trout) caught before 16th June and certain local byelaws imposing mandatory catch and release for both species in the latter weeks of the season may have resulted in a greater proportion of fish being released over the period. However, much of the increase in release rates has resulted from the extensive promotion of catch-and release angling as a general 'Code of Conduct' within the game angling community and the increasing number of fishery owners adopting their own voluntary measures to increase the number of fish released back into their river catchments after capture by anglers fishing their waters.

In addition to the subsequent survival rates of released fish, the practical benefits of catch-and release in increasing escapement into the spawning population in any year will be a product of several factors; principally the actual number of fish released, their individual size, sex ratio and fecundity.

The annual fishery statistics produced by the Environment Agency discontinued reporting the weight of released sea trout in 1997, but data has been obtained (Table 2.1.42) for the most recent 6-year period from 2006 – 2011 that shows important differences in return rates for different sizes of fish.

Table 2.1.42 Release Rates for Different Weight Groups of Rod Caught Sea Trout in Wales (2006-2010).

Weight Group	Fish Caught	Fish Released	Fish Retained	Release %
<1 lb	7,138	5,486	1,652	76.9
>1 - <2 lb	2,408	1,163	1,245	48.3
>2 - <4 lb	2,653	1,005	1,648	37.9
>4 - <8 lb	1,271	441	830	34.7
>8 - < 12 lb	206	87	119	42.3
> 12 lb	44	20	24	45.0
Total	**13,720**	**8,202**	**5,518**	**59.8**

Release rates are highest at 76.9% for the smaller weight class of 0SW whitling weighing 1lb or less. They then decreased steadily to 34.7% as weight groups increased in size before increasing again to more than 40% for the two largest weight classes greater than 8lb: reflecting the encouraging tendency for anglers to release the larger ‘specimen or trophy’ sea trout to maintain the quality of a fishery.

Method of Capture

The only lawful methods of angling for sea trout and salmon in Wales are fly-fishing, spinning and bait fishing and local byelaws may impose further local restrictions on angling methods within the fishing season at certain periods of the fishing season on a number of rivers.

The use of prawn as a bait is prohibited throughout the region and the use of the earthworms is prohibited in the early months of the season to June 16 for salmon (but not sea trout) under the byelaw to protect early runs of MSW salmon. Local byelaws in West Wales prohibit bait fishing for salmon and sea trout after October 7th until the end of the season on 17th October and spinning is currently banned between different dates during the season on several rivers and mandatory catch-and-release fishing restrictions apply on all rivers in West Wales from 10th – 17th October.

In addition to these statutory byelaw restrictions, many fishery owners and tenants have introduced a wide range of voluntary measures to protect stocks from overfishing by restricting spinning and bait fishing to certain weeks of the season and by imposing catch-and release fishing at different periods in the autumn over the last few weeks of the season. This may include fly-only fishing on low river flows and/or catch-and release fishing for both sea trout and salmon in some catchments over the last weeks of the season. Table 2.1.43 gives details of the number of sea trout and salmon caught on fly, spinner, or bait in the Welsh Region in each year from 1994 -2011. Figure 2.1.36 shows the proportions of fish caught by each method after subtracting those fish for which the method was not stated (= ‘unknown’). The proportion of sea trout caught by each method were 54% with fly, 24.8% with spinner and 21.2% with bait. Comparable proportions for salmon were 27.8% with fly, 47.8% with spinner and 24.8% with bait. Salmon, unlike sea trout, are rarely fished for or caught between dusk and dawn, but fly-fishing at night on low river level during the summer months for sea trout can be highly productive and has a strong tradition in Wales. The higher proportion of sea trout taken on the fly (54%) when compared with the much lower figure for salmon of (27.8%) will include a large number of fish taken at night.

This aggregated data for all Welsh Rivers masks large differences between different rod fisheries in the region that reflects their physical characteristics. On many of the spate streams with narrow rocky channels and heavily wooded banks, fly fishing, and and/or spinning is difficult if not impossible and the majority of angling is by bait fishing. That apart, local tradition in conjunction with local fishery regulations will also affect the number of fish caught by different methods over the season.

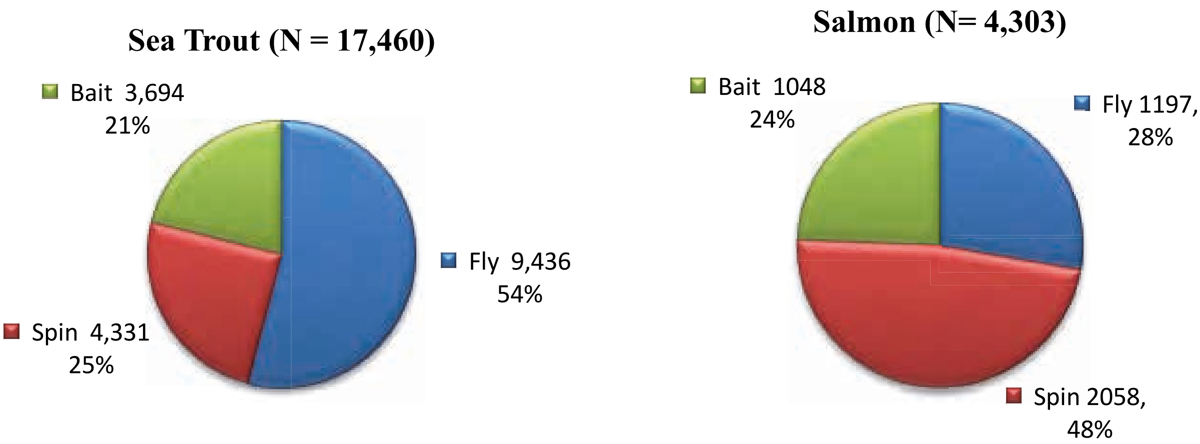


Figure 2.1.36 Method of Capture of Rod-Caught Sea Trout and Salmon in the Welsh Region (1994 – 2011).

Table 2.1.43 Method of Capture of Rod-Caught Salmon and Sea trout in the Welsh Region (1994 – 2011).

Year of Capture	No. of Returns with Data	Method of Capture					Method of Capture				
		SALMON					SEA TROUT				
		Fly	Spin	Bait	Unknown	Total	Fly	Spin	Bait	Unknown	Total
1994	5,485	1,454	3,293	2,345	104	7,196	12,923	5,335	6,116	188	24,562
1995	3,557	1,064	1,743	1,009	66	3,882	6,279	1,895	2,482	109	10,765
1996	4,047	1,216	1,956	1,501	115	4,788	7,650	2,213	2,879	381	13,123
1997	3,798	774	1,578	986	33	3,371	6,645	3,557	3,559	153	13,914
1998	4,442	1,166	1,814	1,031	197	4,208	11,468	5,764	4,976	2,193	24,401
1999	3,987	843	1,516	672	108	3,139	13,022	5,577	4,824	1,206	24,629
2000	3,969	912	1,885	912	87	3,796	10,088	4,963	3,894	494	19,439
2001	3,869	943	1,986	1,190	46	4,165	11,795	4,798	4,003	395	20,991
2002	4,132	951	1,337	897	97	3,282	14,812	4,915	4,856	1,106	25,689
2003	3,897	691	1,071	704	37	2,503	13,050	4,461	4,585	407	22,503
2004	4,522	1,485	3,599	1,093	210	6,387	8,686	4,441	2,965	744	16,836
2005	4,358	1,378	2,018	640	203	4,239	12,723	4,214	3,370	1,170	21,477
2006	3,411	1,296	1,873	887	158	4,214	5,927	2,433	1,994	531	10,885
2007	3,997	1,591	2,159	1,078	143	4,971	6,544	4,858	3,500	388	15,290
2008	4,077	1,812	2,820	1,070	87	5,789	5,151	4,901	2,723	195	12,970
2009	3,698	931	1,534	683	87	3,235	6,237	4,236	2,717	366	13,556
2010	4,254	1,442	2,641	1,306	184	5,573	8,055	4,494	3,795	330	16,674
2011	3,965	1,591	2,227	864	102	4,784	8,791	4,898	3,249	336	17,274
TOTAL	**73,465**	**21,540**	**37,050**	**18,868**	**2,064**	**79,522**	**169,846**	**77,953**	**66,487**	**10,692**	**324,978**
MEAN	**4,081.389**	**1,196.6667**	**2,058.333**	**1,048.222**	**114.6667**	**4,417.89**	**9,435.8889**	**4,330.722**	**3,693.72**	**594**	**18,054.333**
Mean %		27.086844	46.59088	23.72677	2.595508	100	52.263846	23.98716	20.4589	3.290069	100

2.1.4.5 Regional Stock Assessment

The most recent annual assessment by the Environment Agency of the general health status of the sea trout and salmon stocks and their associated fisheries in Wales was completed in 2012 and is summarised in Table 2.1.44. Although these assessments are 'science-based', two different approaches are used for salmon and sea trout. Both utilise rod catch as a major input but the methodology adopted for sea trout is still in the early stages of development and is very dependent on the basic catch and effort data obtained from the anglers.

Comparable stock assessments for salmon were undertaken on 23 of the 29 rivers listed. Only the Dwyryd was "At Risk" and only the Ogwen was "Not at Risk" for both species. The Usk, Loughor and Ogwen were "Not at Risk" for sea trout while 9 rivers, the Dee, Dysynni, Rheidol, Nevern, Dau Cleddau, Tawe, Ogmore. Taff and Usk were "At Risk" for salmon. There were 15 sea trout and 9 salmon rivers in the two intermediate categories of "Probably at Risk/Probably Not at Risk". Three of the 5 most productive sea trout rivers (Mawddach, Dyfi and Clwyd) were "Not at Risk" while the other 2 rivers (Tywi and Teifi) were" Probably at Risk".

Table 2.1.44 Annual Assessment of Stock Status for the Principal Sea Trout & Salmon Rivers in Wales (2012)

River Name	Level of Risk Assessment	
	Sea Trout	**Salmon**
Wye	*Not Assessed*	At Risk
Usk	At Risk	Probably Not at Risk
Taff	Probably Not at Risk	At Risk
Ogmore	Not at Risk	At Risk
Tawe	*Not Assessed*	At Risk
Afan	Probably Not at Risk	*Not Assessed*
Neath	Not at Risk	*Not Assessed*
Tawe	Probably Not at Risk	At Risk
Loughor	At Risk	*Not Assessed*
Taf	Probably at Risk	Probably at Risk
Tywi	Probably at Risk	Probably at Risk
Dau Cleddau	Probably at Risk	At Risk
Nevern	Probably Not at Risk	At Risk
Teifi	Probably Not at Risk	Probably at Risk
Aeron	Probably at Risk	*Not Assessed*
Ystwyth	Probably at Risk	*Not Assessed*
Rheidol	Probably at Risk	At Risk
Dyfi	Not at Risk	Probably at Risk
Dysynni	Not at Risk	At Risk
Mawddach	Not at Risk	Probably Not at Risk
Dwyryd	At Risk	At Risk
Glaslyn	Not at Risk	Probably at Risk
Dwyfawr	Probably Not at Risk	At Risk
Llyfni	Probably Not at Risk	*Not Assessed*
Seiont	Probably at Risk	Probably at Risk
Ogwen	Not at Risk	Not at Risk
Conwy	Probably at Risk	Not at Risk
Clwyd	Not at Risk	Probably Not at Risk
Dee	Not at Risk	At Risk

Traps and Counters

Fish Traps & Counters

No fish counting stations are currently in routine operation in the Welsh region. However, sea trout and salmon stocks of the River Dee were comprehensively monitored since 1991 in connection with the River Dee Stock Assessment Programme and its subsequent adoption as part of the network of European Index Rivers for assessing the status of stocks in the North Atlantic (Davidson et al., 1996; Environment Agency, 2012). An integral part of this monitoring programme includes trapping and tagging upstream migrating adults in the lower estuary to provide an annual estimate of run strength along with information on age, length and weight and other biological information.

The Dee Trap

The fixed trapping station is located in the fish pass on a large weir near the head of the tide at Chester. The trap is operated in each month throughout the entire year for between 60-70% of the time. For this reason, and because fish can by-pass the trap over the weir at certain states of the tide and river flows, it provides a partial count only. A proportion of the monthly trap catch is tagged (Visual Implant and Floy tags). An estimate of the total run is then calculated statistically from the reported capture of tagged fish from the upstream rod fishery and from the ratio of tagged to untagged fish recorded from the trap (and from the commercial net fishery until it was phased out in 1997) in subsequent years. The installation of fine mesh screens (20 x 20 cm) on the upstream grids of the trap in 1994 in the peaks months of the 0SW whitling run in July and August has resulted in the capture of the smallest sizes of sea trout and improved the reliability of the sea trout run estimate.

Estimated Run Strength

The estimated numbers of salmon and sea trout entering the River Dee in each year from 1994 - 2011 are shown in Table 2.1.45 and Figure 2.1.37. Note that the total run of all sea trout run is also shown for the separate stock components of 0SW whitling and older >0SW fish.

Table 2.1.45 Estimated Annual Run-Strength of Sea Trout & Salmon in River Dee (1994-2011).

Year	Annual Run Strength Estimate			
	All Salmon	Sea Trout		
		0SW	>0SW	Total
1994	5,285	3,897	1,838	5,735
1995	5,703	6,673	2,653	9,326
1996	4,931	4,645	1,450	6,095
1997	5,496	5,509	1,731	7,240
1998	6,661	7,877	2,560	10,437
1999	3,664	6,763	1,424	8,187
2000	3,751	7,502	2,092	9,594
2001	4,766	14,680	2,182	16,862
2002	7,216	11,505	2,641	14,146
2003	4,915	10,251	2,377	12,628
2004	7,123	11,542	1,387	12,929
2005	5,435	11,191	1,325	12,516
2006	5,663	7,754	1,487	9,241
2007	5,839	10,718	1,166	11,884
2008	5,707	6,204	1,472	7,676
2009	5,006	7,191	860	8,051
2010	5,615	12,455	1,421	13,876
2011	4,831	n/a	n/a	n/a
Mean	**5,422.611**	**8,609.235**	**1,768.588**	**10,377.82**

n/a = not available

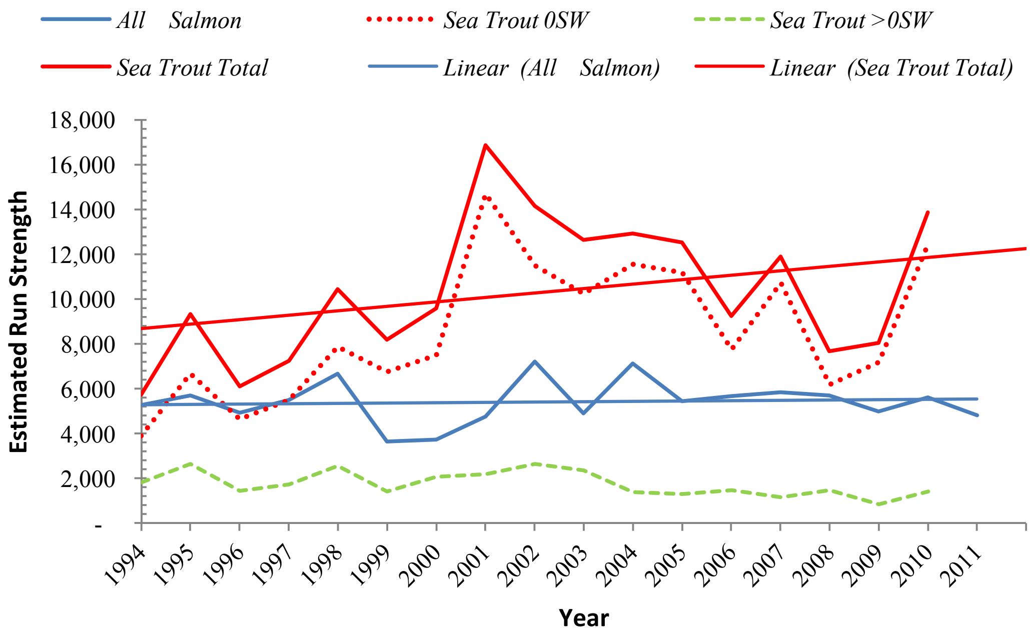


Figure 2.1.37 Estimated Annual Run-Strength of Sea Trout & Salmon for River Dee (1994-2011).

The annual run of salmon has remained relatively stable over the period and ranged about long-term mean of 5,423 fish from a low of 3,664 fish in 1999 to a peak of 7,216 in 2002. By contrast, the sea trout run has fluctuated widely about a long -term mean of 10,378 fish from a low of 5.735 fish in 1994 to a peak of 16,862 fish in 2001. However, much of the variability in total sea trout run strength is a direct result of fluctuations in the abundance of 0SW whitling that ranged widely about the long-term mean of 8,609 fish from a low of 3,897 fish in 1994 to a peak of 14,680 fish in 2001. The estimated number of older >0SW has remained relatively stable about a long-term mean of 1,789 fish and ranged from 1,166 fish in 1994 to 2,641 fish in 2002. It is apparent that fluctuations in run-strength of 0SW whitling in any one year do not appear to have any discernible impact on the numbers of older sea trout returning in subsequent years. When expressed as a proportion of the total run of all sea trout, the 0SW whitling component has varied about the long-term mean of 82.9% from 67.9% in 1994 to 90.2% in 2007.

Run-Timing

Table 2.1.46, Table 2.1.47 and Figure 2.1.38 show the estimated mean number of sea trout and salmon entering the Dee in each month of the year over the 18- year period. Very few sea trout (all sizes) entered the river from January to April but numbers then increased rapidly from May to a peak in July before declining from August, with few fish running over the remainder of the year. Runs of salmon began to increase more slowly from May to a peak in September before decreasing in October to December. The sea trout run peaked two months earlier than salmon (Figure 2.1.39) with 84% of the run appearing by July compared with only 25% for salmon that same month.

Sea Trout Weight Distribution

Table 2.1.48 & Figure 2.1.40 show the weight-class distribution of sea trout taken in the trap in each year over the study period based on a subsample fish taken by the trap. The 0SW whitling component of fish less than 0.5 kg represented 32% of the sample and 83% weighed less than 2 kg. While the number of fish in excess of 2 kg was relatively small at 13% of the sample, some very large specimen fish in excess of 5 kg were recorded: the largest taken in each year ranging from 5.2 to 8.80 kg.

The Dee Rod Fishery

While recognised as one of the top three recreational rod fisheries for salmon in Wales, the Dee, unlike the neighbouring River Clwyd, was never viewed as a significant sea trout fishery until information from the trap revealed the strength of the annual run and encouraged more anglers to actively pursue sea trout as a target species. This resulted in the declared rod catch increasing from an annual mean of 82 fish between 1976-1990 (range 22-155 fish) to a mean of 270 fish from 1994-2011 (range 177-505 fish). The mean annual rod catch of salmon from 1994-2011 was 621 fish (range 421 - 1,080).

Table 2.1.46 Estimated Monthly Run Strength of Sea Trout in River Dee (1994 – 2011).

Year	Adjusted Number of Sea Trout in Each Month (*0SW + >0SW fish*)												Year Total
	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	
1994	-	-	-	2	13	445	1685	881	58	83	15	1	3,183
1995	-	-	2	2	63	754	1995	364	49	61	61	3	3,354
1996	-	-	2	5	12	587	1116	542	121	60	20	3	2,468
1997	-	-	1	3	180	438	1119	545	59	42	35	5	2,427
1998	-	-	4	1	50	691	2962	269	35	37	3	3	4,055
1999	-	-	1	3	88	549	1365	234	9	22	11	3	2,285
2000	-	-	-	3	103	719	633	114	10	31	-	-	1,613
2001	-	-	6	7	84	667	3528	1017	16	38	8	2	5,373
2002	-	-	1	7	92	682	2390	424	8	31	6	-	3,641
2003	-	-	2	1	85	942	2211	246	4	14	16	-	3,521
2004	-	-	1	2	20	666	2450	110	8	11	1	3	3,272
2005	-	-	-	2	18	764	2602	769	13	22	2	-	4,192
2006	-	-	-	1	10	874	829	755	13	16	5	-	2,503
2007	-	-	-	-	46	587	94	208	14	27	15	-	991
2008	-	1	-	3	10	362	1232	26	7	5	3	-	1,649
2009	-	-	1	1	47	82	439	191	2	-	-	-	763
2010	-	-	1	3	9	834	2423	157	8	11	3	-	3,449
2011	-	-	-	-	191	855	895	133	7	8	8	2	2,099
Mean	-	*	2	2.875	62.3	638.8	1664.9	388.1	24.5	30.5	13.25	2.8	2,824.3

Table 2.1.47 Estimated Monthly Run Strength of Salmon in River Dee (1994 – 2011).

Year	Adusted Number of Salmon in Each Month												Year Total
	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	
1994	0	3	7	16	123	84	235	415	563	234	53	1	1,734
1995	1	2	5	63	81	82	206	125	751	301	185	19	1,821
1996	3	2	16	13	39	63	93	135	537	242	20	10	1,173
1997	2	2	11	26	29	25	211	411	478	139	65	26	1,425
1998	0	4	5	3	45	62	381	397	188	86	8	8	1,187
1999	0	5	6	29	97	70	228	105	175	11	14	3	743
2000	0	2	5	2	26	43	81	271	166	7	2	5	610
2001	1	5	14	1	26	78	190	337	289	17	10	2	970
2002	0	0	4	29	39	30	185	478	286	156	2	3	1,212
2003	0	2	5	22	9	113	135	241	608	182	27	7	1,351
2004	0	3	4	8	78	100	167	298	457	43	24	24	1,206
2005	0	3	14	5	20	132	179	545	841	92	15	13	1,859
2006	0	2	3	8	42	111	84	433	695	63	21	0	1,462
2007	0	1	1	17	27	20	0	387	765	154	92	12	1,476
2008	0	1	1	3	94	60	77	134	198	20	13	5	606
2009	0	0	2	13	50	81	109	148	278	175	4	5	865
2010	0	3	2	6	32	40	89	303	411	106	2	11	1,005
2011	1	0	5	16	26	54	104	263	153	108	55	6	791
Mean	*	**2.2**	**6.1**	**15.6**	**49.1**	**69.3**	**153**	**301.4**	**435.5**	**118.7**	**34**	**8.9**	1,193.8

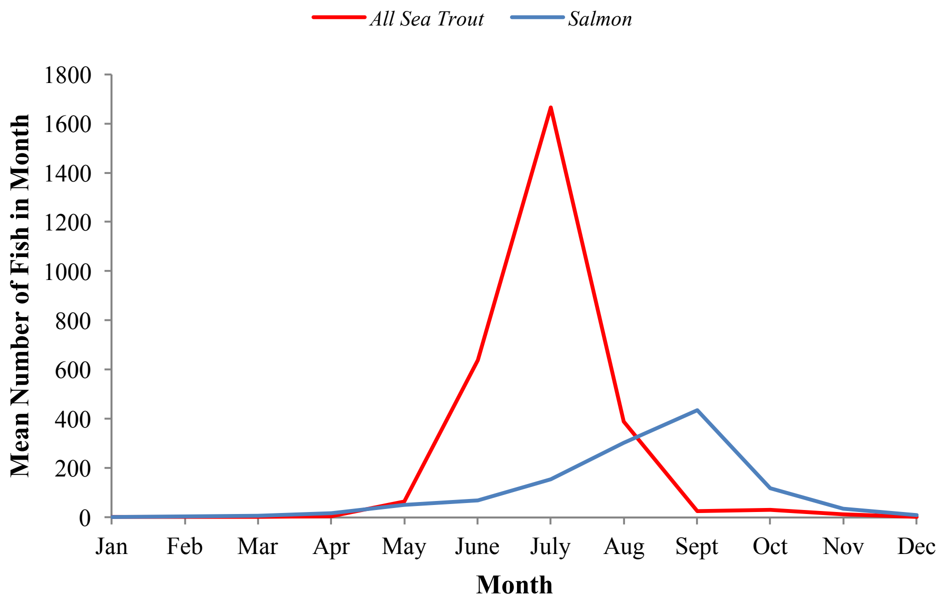


Figure 2.1.38 Estimated Monthly Mean Number of Sea Trout & Salmon Entering River Dee (1994-2011).

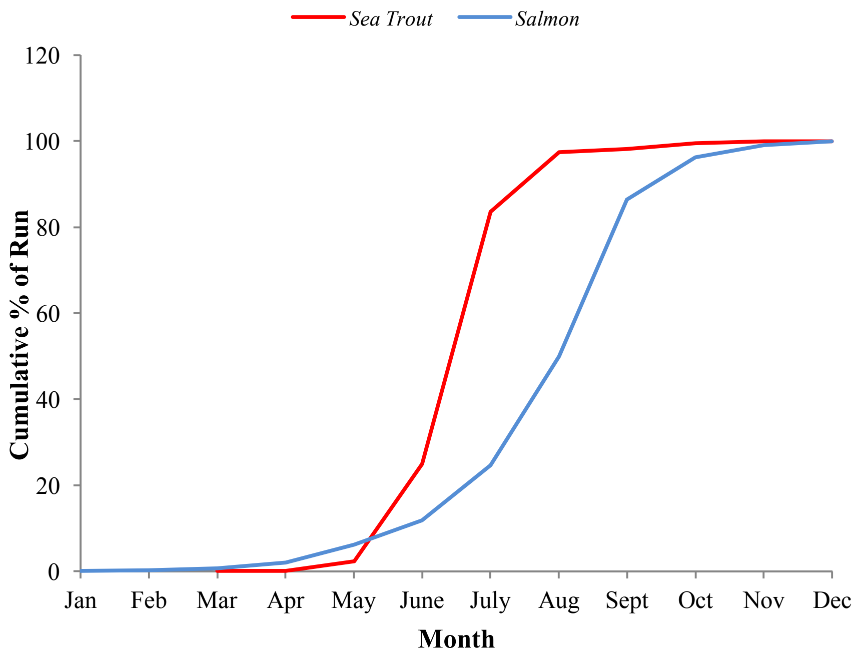


Figure 2.1.39 Cumulative Mean Monthly Proportions of Sea Trout & Salmon Entering River Dee (1994-2011).

Table 2.1.48 Size Distribution of Sea Trout by Weight Class for River Dee Trap (1994-2011).

Year Trapped	Sea Trout Weight Class (kgs) <0.5	>0.5 - <1	>1 - <2	>2 - <3	>3 - <4	>4 - <5	>5 - <6	>6 - <7	>7 +	No. In Sample	Largest Fish
1994	110	119	135	35	10	5	3	2	0	419	*6.23*
1995	93	97	129	40	13	2	3	1	0	378	*6.10*
1996	204	140	128	36	7	5	0	1	0	521	*6.45*
1997	237	184	138	36	19	1	2	1	0	618	*6.15*
1998	149	177	154	57	22	6	5	0	1	571	*7.15*
1999	107	113	133	37	12	8	2	0	0	412	*5.40*
2000	100	99	105	45	35	17	3	0	1	405	*7.35*
2001	165	155	105	57	38	18	5	0	1	544	*8.80*
2002	98	130	147	44	25	13	6	2	0	465	*6.80*
2003	147	116	106	45	22	8	9	2	0	455	*6.95*
2004	188	121	115	52	26	8	2	0	0	512	*5.28*
2005	275	111	137	31	18	15	8	0	0	595	*5.81*
2006	181	102	69	26	11	10	1	0	0	400	*5.60*
2007	108	117	93	21	10	3	5	0	1	358	*7.05*
2008	85	90	87	29	10	3	4	0	1	309	*7.43*
2009	84	48	45	34	20	8	0	1	2	242	*8.25*
2010	143	126	133	36	21	12	1	0	1	473	*8.00*
2011	150	112	160	68	16	9	3	0	0	518	5.20

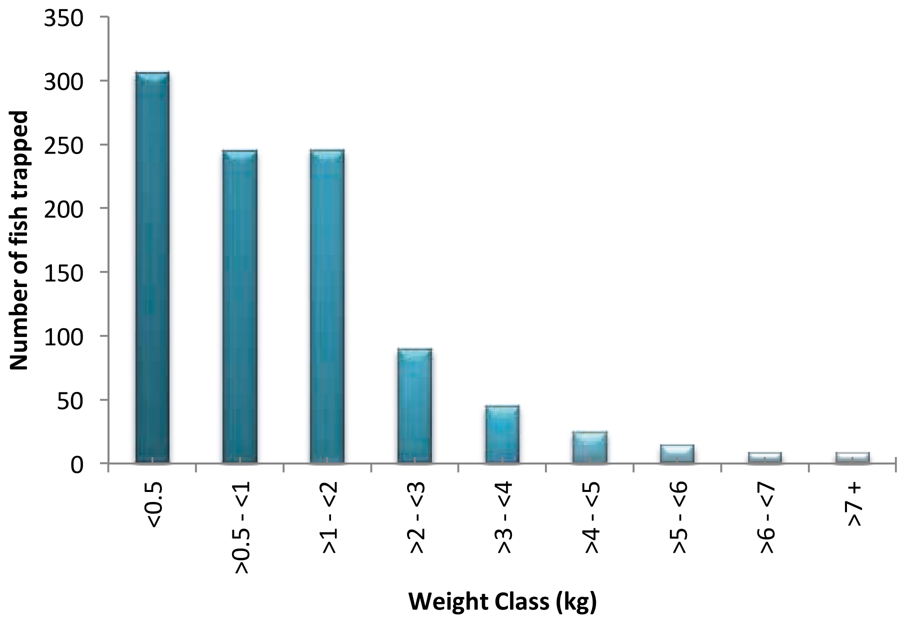


Figure 2.1.40 Mean Proportions of Sea Trout in nine weight classes for River Dee Trap (1994-2011).

2.1.5 Republic of Ireland

2.1.5.1 Introduction

The Republic of Ireland is one of the most significant of the 13 salmon producing nations in the North Atlantic in terms of the reported total weight of salmon and grilse caught by all methods. In 1986, the nominal catch for the Irish Republic of 1,730 tonnes represented 22.5% of the total North Atlantic catch of 7,685 tones and exceeded that of Canada (1,599 tonnes), Norway (1,598 tonnes), Scotland (1,271 tonnes) and all other nations. Although the reported salmon catch throughout the

North Atlantic region has declined steadily over the 17 year period from 1986, the nominal catch for the Irish Republic in 2002 of 673 tonnes represented 25.9% of the total reported catch of 2,607 tonnes for that year and was exceeded only by Norway (1,019 tonnes).

The Celtic Sea Trout Project Area within the Republic of Ireland does not cover the many river systems on the western seaboard from Kerry in the southwest to Donegal in the northwest. It also excludes Northern Ireland. Its geographical coverage is restricted to those fisheries on the east coast adjacent to the Irish Sea that extend from Dundalk on the border with Northern Ireland down to the boundary between the counties of Cork and Kerry in the south (Figure 2.1.41). As noted for Scotland (Section 2.1.2), the rapid expansion in cage rearing of farmed salmon in estuaries and sheltered coastal waters in Ireland from the late 1980s is considered by many to have had a deleterious impact on sea trout stock abundance and fishery performance in many river systems on the west coast. A parallel development occurred on the west coast of Ireland (Gargan et al., 2006) over a similar period. However, these developments have not directly affected sea trout stock abundance for rivers within the Project Area because of the lack of suitable estuaries and sheltered coastal inlets for commercial sea-farm development along the eastern seaboard.

2.1.5.2 Fishery Areas

The government agency responsible for the regulation and management of salmon and sea trout in the Irish Republic is currently Inland Fisheries Ireland. At an administrative level, the country is divided locally into 14 Regional District Boards. These are then further split into a number of smaller area-based operational units within each district for data collection and statistical reporting purposes. These Districts were recently realigned with the statutory River Basin Districts (RBDs) for delivery of the EU Water Framework Directive. The River Basin Districts and sub-districts relevant to the CSTP Project are shown in Figure 2.1.41 as:

- Eastern RBD = the Dundalk, Drogheda and Dublin sub-districts.
- South Eastern RBD = the Wexford and Waterford sub-districts.
- South Western RBD = the Lismore, Cork and Kerry Sub-Districts.

2.1.5.3 General Background

Fishery Features

There is no definitive list of the very many Irish rivers known to contain natural, self-sustaining stocks of sea trout that are subject to a significant level of exploitation by the rod and net fisheries. However, Mc Ginnity et al.. (2003) identified 261 discrete migratory salmonid systems nationally, of which 173 were recorded as being ‘salmon and seatrout’ systems and 88 as being ‘seatrout only’. The report by the Independent Salmon Group (Collins et al., 2006) identified 132 named river systems in the Republic of Ireland of greater or lesser national importance known to contain exploited stocks of salmon. All of these rivers also contained sea trout and 39 were located on the eastern seaboard within the project area. Figure 2.1.42 shows the location of the principal sea trout and salmon fisheries where catch data for the rod fisheries is available or where, in the absence of catch records, the average annual rod catch is likely to have exceeded more than 10 salmon and/or more than 50 sea trout in previous years.

While many rivers in the Republic, such as the Moy, Slaney, Munster Blackwater and Boyne, are well known for their productive salmon fisheries, very few river systems have achieved any general acclaim in the angling literature as significant rod fisheries for sea trout. Nevertheless, in addition to the Slaney and Boyne as productive sea trout rivers, many lake-fed systems in the west, notably

Currane, Ballynahinch, Delphi, Screebe, Fermoyle, Costello, Invermore and Inagh, are recognised as locally significant sea trout fisheries. More recently, a pro-active campaign of promotion of lesser known fisheries by Inland Fisheries Ireland and its predecessor agency (Central Fisheries Board) has identified other worthwhile new venues for sea trout angling, such as the tidal fishing in the Moy, Erne and Gweebarra estuaries and on Carrowmore Lake in Co. Mayo. In very general terms, however, the status and importance of Irish sea trout fisheries remains somewhat overshadowed by the general reputation of the salmon angling on the majority of rivers throughout the region. Indeed, it is only on the many smaller, lake-fed, systems on the West Coast, notably in Connemara, Mayo, Galway and Donegal, that the sea trout fishing has assumed any significant social and economic importance at a district level.

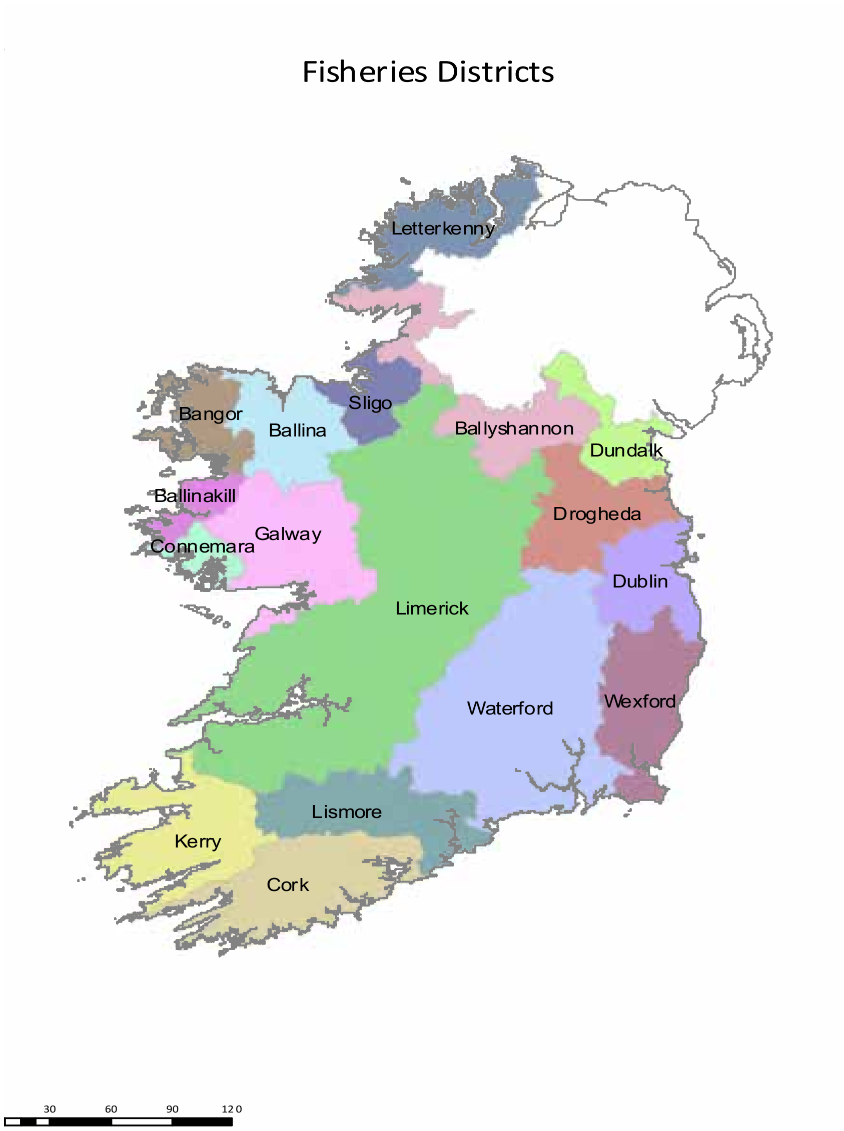


Figure 2.1.41 Fishery Management Districts in the Republic of Ireland

Fishing rights in non-tidal waters are privately owned in the Irish Republic and, as such, public access to the fishing is available in a variety of different ways in common with other regions of the UK and Ireland. Fishing rights on many of the smaller rivers and on sections of the larger, more prestigious, rivers are controlled by local angling clubs. On many of the larger rivers, and on many of the smaller lake-fed sea trout fisheries in the West, access is widely available through larger estates and/or fishing hotels, while other sections of fishing may operate under limited syndication or multiple ownership schemes. A unique feature in the Republic of Ireland is the existence of 'free fisheries' in a few areas (e.g. Lough Currane) where access to the fishing does not require payment to any owner or group of owners. While much of the sea trout fishing in the west of Ireland is linked to a large number of lake-fed systems, fishing around the eastern seaboard is almost entirely on rivers with the notable exception of Lough Currane on the boundary of the CSTP project area.

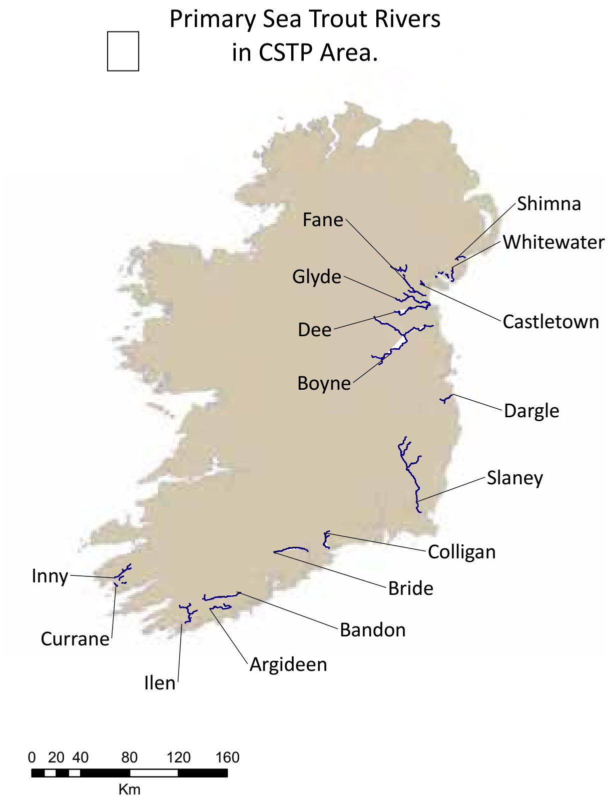


Figure 2.1.42 Principal Sea Trout Rivers on the East Coast of the Republic of Ireland.

Irish sea trout are not noted for attaining any great size. The current record Irish sea trout was caught in the River Shimna in 1983 and weighed 7.43 kg (16.4 lbs), but this was an exceptional fish for the region where the capture of an Irish sea trout in excess of 6 lbs is a rare event. The Irish Specimen Fish Committee has maintained meticulous records of all known sea trout in excess of 6lbs weight caught since 1955. A total of 658 specimen sea trout were recorded up to 2010 of which 532 fish (81%) were from the Lough Currane/Waterville system in Southwest Ireland. The remaining 126 fish reported over the 55-year recording period by the Irish Specimen Fish Committee (www.irish-trophy-fish.com) were from a large number of different fisheries widely spread throughout Ireland. Some of these were in estuarine and coastal waters where it becomes difficult to attribute a fish to any particular river or region of origin.

Only four major scale-reading based investigations to determine the structure and composition of Irish sea trout stocks (Nall, 1931; Went, 1962; Fahy, 1978 and 1985a) have been undertaken in the past. Some of these workers compared aspects of the life histories of several stocks. Focussing on ten west coast systems Nall's (1931a) study was the first substantive review of sea trout in Ireland.

The review by Went (1962) was more extensive and included systems along the west, south and west coasts. His study reviewed the results of a series of ad hoc investigations since 1928 on 17 rivers of which only 4 were in the project area: namely the Mattock (a tributary of the Boyne), Argideen and Currane/Waterville. Unfortunately, only a small number of scales samples were collected from most rivers and the inclusion of fish taken in tidal waters by the commercial net fisheries introduced a non-random, selective, sampling bias for larger and older fish. Fahy (1985a) undertook a series of scale reading investigations on a number of other rivers, notably on the western seaboard. A smaller study by Fahy (1981) described stocks from several fisheries discharging into the Irish Sea and one commercial net fishery off the Irish Sea coast. In general terms, Irish sea trout constitute a type described by Harris (2002) as 'short-lived/slow growing'. They have a relatively short life span with a high proportion returning as 0SW finnock after a short time feeding in the sea and rarely surviving to spawn more than twice. Fahy (1978) suggested that the difference between sea trout from the Irish west and east coasts resulted from better feeding conditions in the shallower, more productive waters of the Irish (and Celtic) sea than the poorer feeding conditions over the narrower continental shelf on the Atlantic west coast.

There was a very significant reduction in the nature and extent of commercial fishing effort in tidal estuaries and coastal waters immediately before and after the introduction of a series of measures to conserve seriously depleted salmon stocks in many parts of the Republic in general and around the east coast in particular from 2001 (see Section 2.2.4.4). Drift netting offshore and around the coastline was prohibited from the start of the 2007 fishing season and any other form of commercial fishing was permitted in only those areas designated as 'open fisheries' (Figure 2.1.43). The only commercial net fishing gear now licensed for use within the project area are draft nets (seines) and, on the Blackwater, Suir and Nore, 'snap' nets (a form of fishing unique to the area).

2.1.5.4 Fishery Regulations

Statutory measures to conserve fish stocks and regulate their levels of exploitation by the rod and net fisheries were relatively simple and straightforward over the earlier years of the study period from 1994-2000. In general terms these defined the dates of the annual fishing season for the rod and net fisheries, the types of commercial fishing gears that could be operated in specified estuaries and marine zones and a 'closed period' when commercial fishing must cease for a period of days in each week. The previously unrestricted number of licences available for commercial net fishing was eventually 'capped' (limited) to fixed number within each district in 1997, when the authorised area of operation of drift nets was reduced from 12 nautical miles to within 6 nautical miles of the coast. In addition, the drift net fishing season was restricted to 2 months between 1st June and 31st July for the drift nets (with a ban on fishing at night) and the draft-netting season was delayed until 12th May.

Under Irish Fisheries legislation, salmon and sea trout (>40 cm length) are defined as the same species and any provisions relating to salmon must apply to sea trout. At that time, there were no statutory bag limits or size limits for either salmon or sea trout and no additional conservation measures relating specifically to sea trout.

This situation changed dramatically from the start of the fishing season in 2001 when the Irish Government drastically overhauled the statutory fishery regulations relating to salmon conservation and introduced series of radical initiatives to protect and conserve future stocks and their associated rod and net fisheries throughout the entire Republic. These initiatives were a structured response to three main drivers:

1) The widespread and growing concern about the clear decline in rod and net catches over the two previous decades

2) Increasing science-based evidence that the escapement of adult salmon into the spawning population on many rivers was insufficient to maintain future stocks at or above their biological ‘safe-limits’ necessary to replace future stocks at the same level of abundance and generate a surplus to sustain the current level of exploitation by the rod and net fisheries.

3) Compliance with its international obligations under the terms of an agreement with NASCO by all salmon producing nations to phase-out all forms of interceptory and mixed stock fisheries in offshore and inshore waters. Also to comply with the legal requirement to maintain sustainable fisheries in accordance with the requirements of both the EU Habitats Directive and the Water Framework Directive.

These pressures resulted in the following time-series of further statutory salmon conservation measures from the start of the fishing season in 2001:

1) A ban on the sale of rod caught salmon and sea trout (2001)

2) The introduction of a minimum size limit of 40 cms (c.16 ins) below which all salmon and sea trout must be returned alive immediately after capture. Only fish >40 cm could be harvested (retained) by their captor (2001).

3) The introduction of a carcass tagging and logbook recording scheme for the rod and net fisheries (2001). The aims of this scheme (officially termed the ‘Wild Salmon and Sea Trout Tagging Scheme’) was to provide a means of collecting accurate nominal catch statistics and estimates of salmon and sea trout stock exploitation (i.e. ‘harvest’) as a basis for determining best management strategies and to ensure that both species are exploited in a manner consistent with their long-term sustainability at a catchment based, regional and national level. It also provided a means to identify illegally caught fish, eliminate sales outlets for the disposal of illegally caught fish and improve traceability through the distribution chain.

4) The introduction of a Total Allowable Catch (TAC) for each Fishery District fixing the maximum number of salmon to be harvested (retained) by the rod and net fisheries (2002). The TAC was reviewed annually, and where necessary adjusted, following a recommendation given to the Minister by the National Salmon Commission based on scientific advice from the Standing Scientific Committee on Salmon on the performance of the rivers within each district in achieving their set District ‘Conservation Limits’. This process was further refined by allocating a TAC to individual river systems instead of Fishery Districts (2007).

5) The introduction in 2001 of a statutory bag limit for all rod fisheries of 1 salmon or sea trout (in excess of 40 cm) per angler per day to 1st June and then 3 fish per day until the end of the season with a maximum bag of 20 fish per angler in any season. This was subsequently amended (2007) to cover only those rivers that remained open to angling with a further restriction of a maximum bag limit of 10 fish a season: with no more than 1 fish per day to 11th May, 3 fish per day until 1st September and then 1 fish per day until the end of the season. After catching a bag limit, anglers could continue to fish these open rivers on a catch-and-release only basis using barbless single hooks and a ban on worm fishing.

The report of the Independent Salmon Group (Anon., 2006) listed the salmon stock status of 132 named rivers in the Republic of Ireland. It reported that a) only 34 rivers had levels of salmon stock abundance that exceeded their set Conservation Limits (CLs), b) that a further 32 rivers were unlikely to achieve their target CLs and c) that the stock status of the remaining 66 rivers could not be assessed because of the lack of scientific evidence and/or very low average salmon catches of <10 fish) a year. This appraisal resulted in the designation of named rivers into one of three categories based on their performance in achieving their fixed CLs, with added restrictions imposed, where necessary, on the permitted levels of harvest. These categories were:

a) Open Rivers: Specified as those rivers that had exceeded their set CLs and where salmon (and sea trout >40cm) could continue to be harvested within existing bag limits.
b) Catch-and Release Only: Specified as those rivers that had exceeded 65% of their set CLs where angling could continue on a catch-and-release basis only (i.e. no salmon or sea trout to be harvested).
c) Closed Rivers: Specified as those rivers that had failed to achieve their set CLs or where insufficient evidence was available to determine their current stock status.

This 3-tiered classification system was adopted in 2007. It resulted in the majority of rivers being closed to angling or otherwise, subject to catch-and release fishing only. Annual reviews of fishery status since 2007 have resulted in several amendments to the original classification, with some rivers moving between higher and lower categories in one or more of the following years. Figure 2.41 shows those river fisheries that were: a) open to angling, b) closed to angling or c) subject to catch-and-release only rod fishing in 2010 within the Republic of Ireland. (It is important to note that anglers could continue to fish for sea trout on rivers closed to salmon angling and on C&R only salmon rivers subject to the statutory minimum size limit of >40 cm for harvested fish).

A total ban on drift net fishing throughout the Republic was introduced in 2007, along with a temporary prohibition on all other forms of commercial fishing near those rivers closed to angling or subject to catch-and-release angling only. In order to compensate those drift net fishermen for permanent loss of income by the ban on drift net fishing, a ‘Fishery Compensation Scheme’ of €30 million was introduced 2007. This made provision to pay compensation to netsmen engaged in other forms of commercial net fishing who were prepared to relinquish their licences and exit the fisheries on a voluntary basis.

2.1.5.5 Historical Catch Records

Any detailed and comprehensive description of the performance of the fisheries in the Irish Republic based on published and unpublished catch statistics is frustrated by the quality and scope of the information available and the many significant gaps in the time series of data within and between districts and regions. The principal difficulties in interpreting the historical record of catches for the Irish Republic in parallel with the approach adopted in this review for the Scottish, English and Welsh Regions are:

1) The different methodologies used for collecting catch data from the rod and net fisheries before and after the introduction of the logbook recording scheme in 2001.

2) Absence of any consistent annual rod catch data from inspectors’ estimates other than for the ‘major’ (salmon) fisheries within each district. There are no catch records for the many ‘minor’ sea trout rivers within the Region.

3) Lack of any information on such key fishery features as a) month of capture, b) weight and size distribution of catch, c) fishing effort and CPUE, d) angling catch-and-release and e) angling method of capture.

4) Lack of data from the logbook scheme on the numbers of sea trout <40 cm caught by anglers and the very small number of rod-caught sea trout of >40 cm recorded in the logbooks for almost all rivers.

5) The closure of many fisheries to all forms of commercial fishing and rod fishing for salmon and the imposition of mandatory catch-and-release angling for salmon on many other fisheries from 2007.

6) A very significant reduction in the number of annual licences issued for commercial net fishing from 2007 and for rod and-line fishing from 2001.

Consequently, any description of the rod and net fisheries based on these historical catch records can only attempt to make the 'best-use' of the limited data available by providing a series of 'snapshots' of the fisheries when and where there is a time-series of comparable data within and between districts.

2.1.5.6 Data Collection Methods

Before the introduction of the logbook recording scheme in 2001, two very different approaches operated in tandem for the collection of catch statistics from the rod and the commercial net fisheries.

Rods

Although a statutory system of licensing anglers has operated throughout the Republic for over 50 years, efforts to obtain a return of catch from individual anglers proved unsuccessful, with less than 10% of licence holders submitting a return of catch in the 1970s. Consequently, the only available time series of historical catch data available over the same study period used to describe the fisheries of the Scottish, English and Welsh regions is the semi-quantitative estimates of catch produced by local fisheries inspectors based on information obtained from local angling clubs, fishery owners and their own personal observations for their respective areas.

Nets

While a mandatory system of licensing has operated for commercial net fishing for many years, catch statistics were not obtained directly from individual netsmen but from the annual returns submitted by licensed salmon dealers authorised to buy and sell fish from the netsmen.

Both approaches are of questionable merit and are not a reliable means of obtaining a robust and reliable measure of actual catches and fishery performance. Nevertheless, they represent the only available information for the earlier part the study period from 1994-2000.

Log-Book Recording Scheme

Increased concern about the declining performance and status of many salmon fisheries and growing evidence of overexploitation by the rod and net fisheries resulted in the introduction of major change in the process of collecting catch data from the start of the fishing season in 2001. This was the introduction of a mandatory 'carcass tagging and logbook recording scheme' to collect reliable catch data directly from each individual licensed angler and netsman in a more comprehensive, complete and standard format.

The logbook recording scheme specifies that all salmon and sea trout in excess of a minimum size of 40 cm that were caught-and retained (harvested) by anglers and netsmen must be tagged and that a logbook entry must then be made giving details of each tagged fish. Tags are issued only to licensed anglers and netsmen and each tag is individually coded so that each fish can be traced back to its lawful captor. Only licensed netsmen can legally sell their catch. Completed logbooks (and any unused tags) had to be returned within a period of 7 days after the end of the relevant fishing season or, in the case of short-term rod licences, the date when the licence expired.

In addition to recording date of capture and the unique tag number attached to each harvested fish, the following additional information is required to complete a logbook entry:

For Netsmen:

- Type of commercial fishing gear
- District
- Vessel
- Fishing Effort – as time each fishing session started and ended
- Number of salmon or sea trout captured.
- Capture location - River/Estuary
- Port or Pier where fish landed
- Date and details of disposal

Note that details of the weight of each individual fish were not requested.

For Anglers:

- Date of fishing trip
- Location – as the Name of River, Fishery Beat and County.
- Number and species of each fish captured
- Weight of each fish
- Method of angling capture – (fly, spinner, worm, prawn or other)
- Whether each fish was harvested or released
- Tag number of each harvested fish
- Total number of days fished (including a ‘nil return’ for days when no fish were caught).

While the logbook recording scheme greatly improved the quality and scope of the catch data required for the sustainable management of salmon fisheries throughout Ireland, this does not apply to sea trout. The failure of the scheme to require a logbook entry giving details of the catch of any sea trout below the minimum size limit for retention of 40cms (16 inches) means that no record exists for the majority of the sea trout caught by anglers on every Irish sea trout fishery.

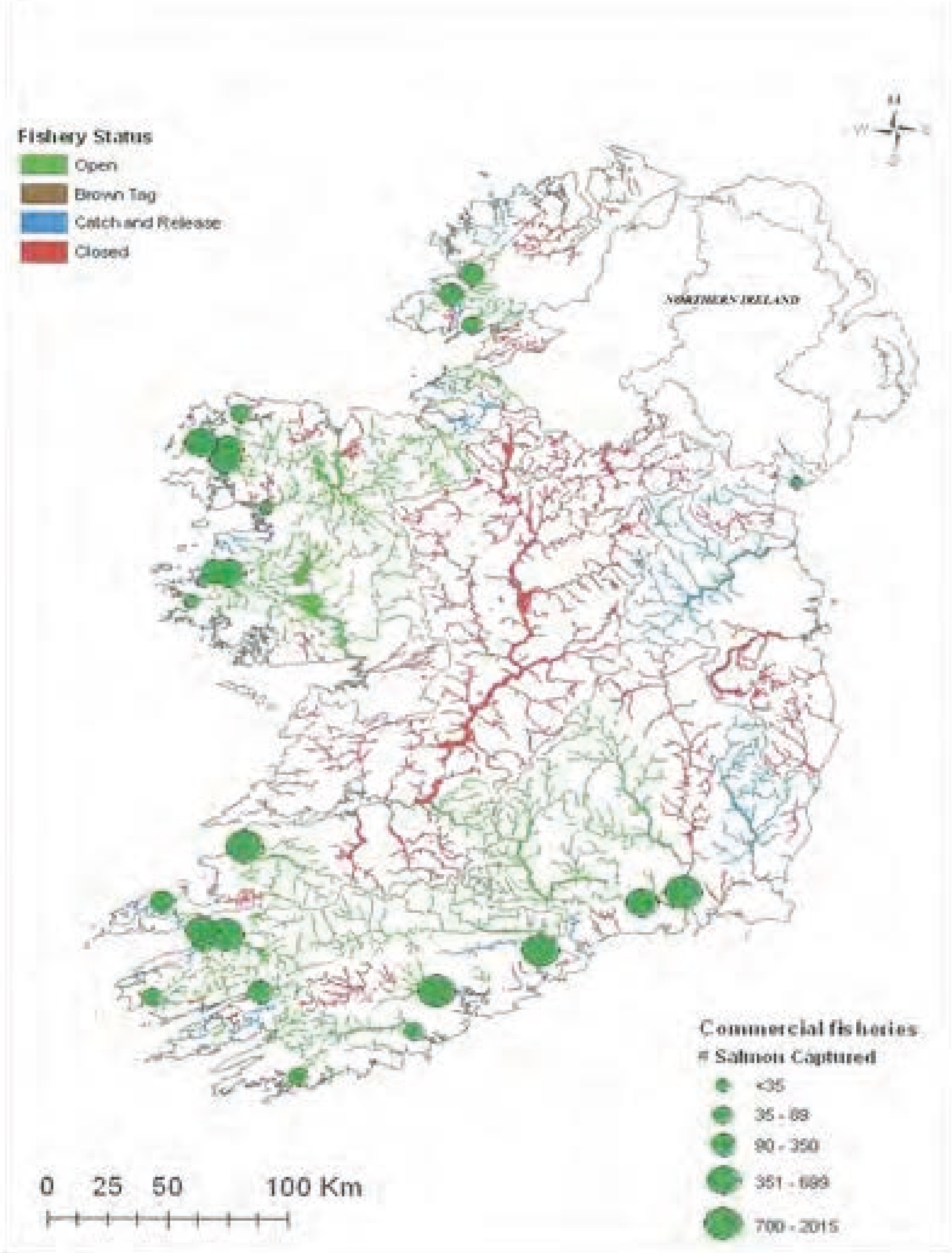


Figure 2.1.43 Irish Rivers Designated for the 2010 Fishing Season as either 'Open or 'Closed' to Salmon Fishing or open for 'Catch-and-Release Only' Angling for Salmon.

Table 2.1.49 Number of Salmon & Sea Trout Rod Licence Issued and Logbooks Returned for the Republic of Ireland (2001 – 2011).

Rod Fishing Season	No. Rod Licences Issued	No. Logbooks Returned	% Logbooks Returned
2001	32,814	14,238	43%
2002	35,024	18,116	52%
2003	31,809	18,088	57%
2004	30,807	17,955	58%
2005	28,738	17,682	62%
2006	27,341	18,554	68%
2007	19,986	12,962	65%
2008	20,061	13,917	69%
2009	18.314	12,890	70%
2010	17,983	12,813	71%

There are no published data on the return rates of completed logbooks for the commercial net fisheries. However, since anglers cannot sell rod caught fish and the carcass-tagging scheme provides an effective means for tracing the sale and disposal of net-caught fish through the market, it is likely that the return rate for net caught fish is greater than the rod fishery.

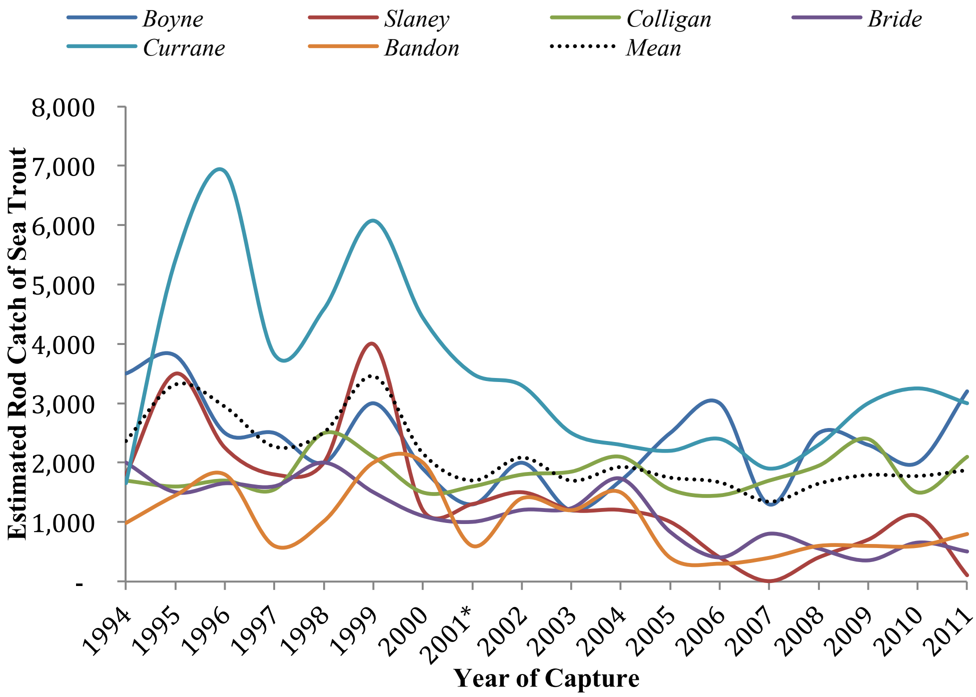
Number of Fish Caught

Rod Fisheries

The only time series of data available to show the pattern of rod catches of sea trout for the 30 or so principal fisheries in the project area is the annual estimate of catch provided by local fisheries inspectors in the three Fishery Board areas. These estimates were restricted to a total of 16 rivers considered important across the three Boards combined where representative catch data was most readily obtainable from local fishery associations and fishery owners within each chosen catchment. They do not cover at least 14 of the 30 or so minor fisheries within the project area where sea trout may be of significant local and collective regional importance. Notwithstanding this limited coverage and the inherent shortcomings of this approach, it is assumed that the inspectors' estimates were produced on a consistent and comparable basis and provides a very basic index of fishery performance over the study period. It is important to note that these estimates of catch include sea trout of all sizes and not just fish larger than the 40 cm minimum size limit introduced in 2001 under the logbook recording scheme.

Table 2.1.50 shows the only 16 rivers in each of the three Fishery Board regions of the Project Area for which sea trout catch estimates are available over the 18-year study period. Only 6 rivers produced annual rod catches in excess 750 fish with any regular consistency: namely Boyne, Slaney, Colligan, Bride, Bandon and Lough Currane. In very general terms, no overall trend of increase or decrease in catch emerges and annual fluctuations in catch between rivers and regions appear to show little relationship. The sustained large increase in catch on the Fane from 2000 – 2011, on the Bandon from 1998 – 2000 and, from one year to the next, on other rivers, such as the Argideen (2002), are remarkable and not readily explained.

Any significant short-term trend in fishery performance is obscured, and difficult to detect, on rivers with small catches of sea trout by changes in local circumstances (such as river flows levels). Figure 2.1.44 shows the pattern of sea trout rod catches for the 6 larger and most productive sea trout rivers listed in Table 2.1.50 that are more likely to show long-term trends within different rivers and different geographical areas.



Note: the Slaney was closed to angling for both salmon and sea trout in 2007.

Figure 2.1.44 Estimated Rod Catch of Sea Trout by Fishery Inspectors for Six Major River Systems on the East Coast of Ireland (1994-2011).

Table 2.1.50 Reported Rod Catch of Sea Trout from Estimates by Fisheries Inspectors Fisheries for Principal Rivers Republic of Ireland (1994-2011).

Year	1994	1995	1996	1997	1998	1999	2000	2001*	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Eastern Region																		
Castletown	400	350	300	400	500	400	500	1,000	200	200	500	2,000	1,500	1,250	1,550	1,600	1,400	1,500
Fane	400	250	350	300	500	500	500	750	200	250	250	100	200	250	200	200	210	200
Boyne	3,500	3,800	2,500	2,500	2,000	3,000	1,900	1,300	2,000	1,200	1,700	2,500	3,000	1,300	2,500	2,300	2,000	3,200
Ballymascanlon	350	200	250	250	150	200	300	400	100	100	150	150	150	175	200	140	100	100
Dargle	258	489	250	150	330	242	180	50	150	150	100	120	80	(Closed)	50	100	100	100
Vartry	200	250	150	125	150	150	80	70	60	70	100	120	60	(Closed)	100	150	130	100
Slaney	1,800	3,500	2,250	1,800	2,000	4,000	1,200	1,300	1,500	1,200	1,200	1,000	400	(Closed)	400	700	1,100	100
Dee	(N/A)	300	400	600	500	3,000	3,000	2,000	300	150	200	180	150	200	220	130	240	200
Total	**6,908**	**9,139**	**6,450**	**6,125**	**6,130**	**11,492**	**7,660**	**6,870**	**4,510**	**3,320**	**4,200**	**6,170**	**5,540**	**3,175**	**5,220**	**5,320**	**5,280**	**5,500**
Southern Region																		
Colligan	1,700	1,600	1,700	1,550	2,500	2,100	1,500	1,600	1,800	1,850	2,100	1,550	1,450	1,700	1,950	2,400	1,500	2,100
Bride	2,000	1,500	1,650	1,600	2,000	1,500	1,100	1,000	1,200	1,230	1,730	830	400	800	550	350	650	500
Total	**3,700**	**3,100**	**3,350**	**3,150**	**4,500**	**3,600**	**2,600**	**2,600**	**3,000**	**3,080**	**3,830**	**2,380**	**1,850**	**2,500**	**2,500**	**2,,750**	**2,150**	**2,600**
South West Region																		
Bandon	986	1,450	1,800	600	1,015	2,000	2,000	600	1,400	1,200	1,500	400	300	400	600	600	600	800
Argideen	530	265	400	150	200	700	700	220	1,200	650	400	250	150	150	350	350	350	400
Ilen	375	388	185	142	215	350	200	85	400	80	100	100	50	30	50	130	50	100
Currane	1,655	5,410	6,899	3,820	4,583	6,073	4,440	3,500	3,300	2,500	2,300	2,200	2,400	1,900	2,300	3,000	3,250	3,000
Inny	(N/A)	N/A	100	20	110	120	125	100	170	400	300	350	300	(N/A)	150	160	170	150
Owenmore	470	250	100	60	200	250	260	150	150	200	200	310	320	432	240	213	147	180
Total	**4,016**	**7,763**	**9,484**	**4,792**	**6,323**	**9,493**	**7,725**	**4,655**	**6,620**	**5,030**	**4,800**	**3,610**	**3,520**	**2,912**	**3,690**	**4,453**	**4,567**	**93,453**

While the pattern of average annual catch for the 6 rivers suggests a general of decline over the 18 year period on all rivers, no clear pattern is apparent until the rivers are separated into their respective geographical areas (Figure 2.1.45 a-c) when notable difference emerge between rivers and regions over the same time frame. Apart from the peak in catches in 1999, the 6 rivers exhibit few other similarities to suggest that the pattern of catches was influenced by any common features other than perhaps in the South Western Region where the Bandon and Lough Currane showed a parallel decline over the period. This general decline is also apparent on the Bride (Southern) and Slaney (Eastern), but not on the Colligan (Southern) and Boyne (Eastern) where the catch trends were relatively stable and showed a slight improvement from 2007. The catch on the Colligan in 2009 of 2,400 is approaching the period peak of 2,500 in 1998.

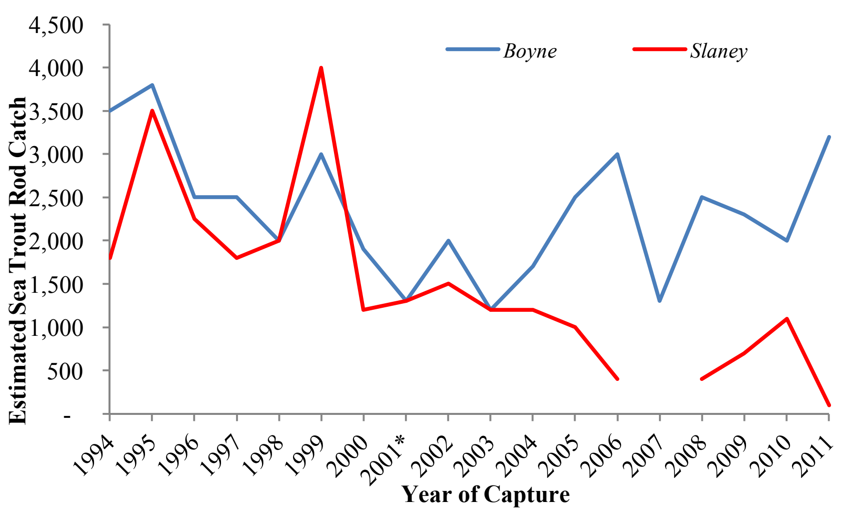
A comparison of catch trends for the Fane (Eastern) and Ilen (South Western), as an example of two widely separated and smaller rivers with low catches (Figure 2.1.46), shows little relationship between the a catch in most years. However, both rivers exhibit a marked decline from 2001 (Fane) and 2002 (Ilen) when catches were at their highest levels and over the period in general.

The logbook recording scheme introduced in 2001, while providing more complete, accurate and robust data on the salmon rod catches than the earlier system of inspectors' estimates, has done little to improve catch data for sea trout because of the exclusion of all fish less than 40 cm in length.

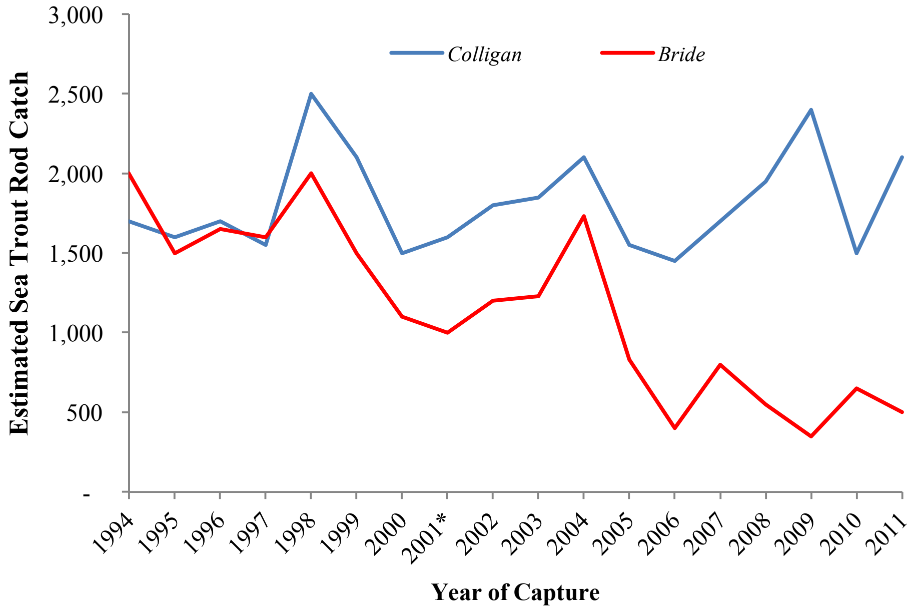
Table 2.1.51 is a comparison of the reported catch by anglers under the logbooks scheme from 2001 with earlier estimates by fishery inspectors of the mean catch for 1994-2000. It relates to only those 8 rivers listed in Table 2.1.50 where logbook rod catch data from 2008 was first included in the Annual Reports.

Even allowing for the inherent unreliability of the catch estimates by fishery inspectors prior to 2000, the logbook scheme grossly undervalues the status and performance of sea trout rod fisheries by the omission of a record of all sea trout of <40 cms caught each season. Thus, for Lough Currane, probably the single most productive and important sea trout fishery in Ireland, the reported rod catch 'apparently' collapsed from an average of 4,679 fish before the introduction of logbook recording scheme to approximately 300 fish in subsequent years. Indeed, for the majority of the many other rivers in Ireland, the recorded sea trout catch from logbooks was less than 10 fish a year and catches for other rivers, including the productive Bride and Colligan, are absent from the published record in all or most subsequent years.

a) Eastern Region



b) Southern Region



c) South West Region

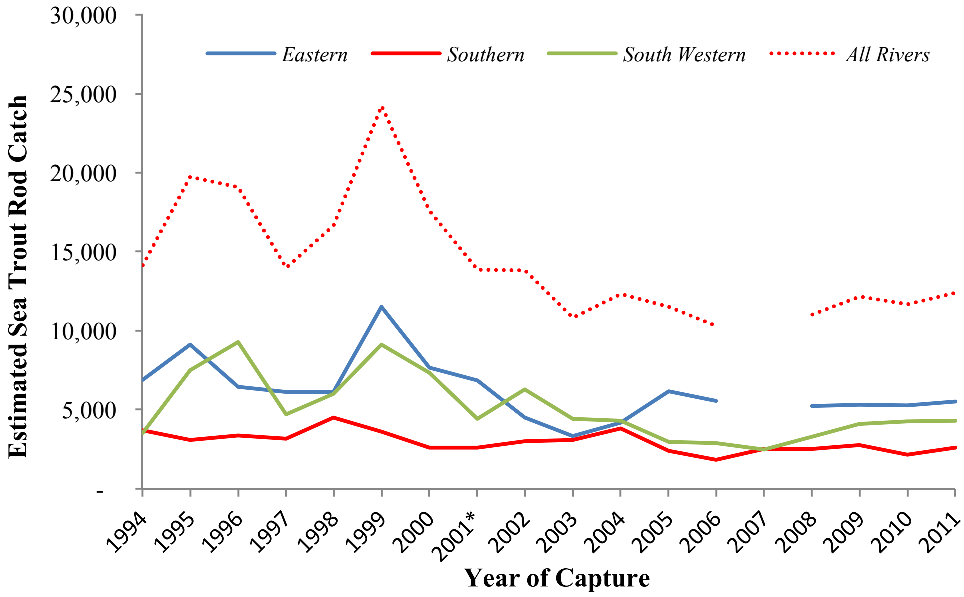
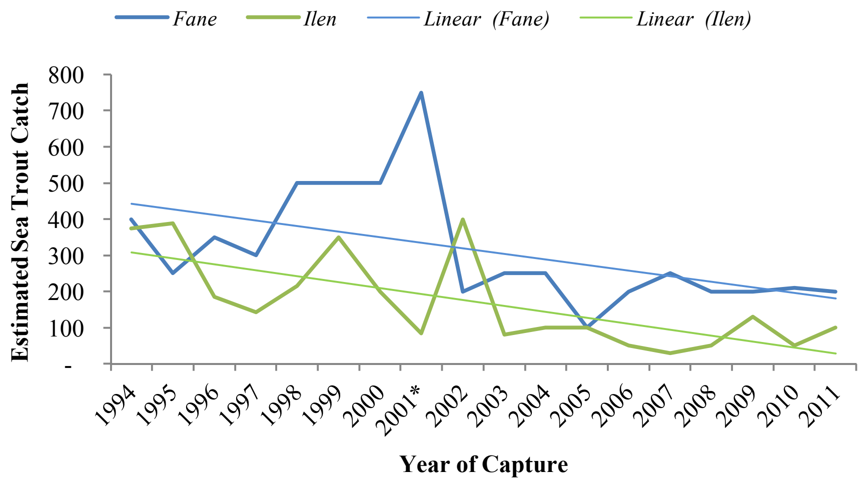


Figure 2.1.45 a-c Estimated Rod Catch of Sea Trout from Major Fisheries in Eastern, Southern & South West Fishery Board Regions (1994-2011).



Note: Both the Ilen and Fane were Open to salmon angling from 2007.

Figure 2.1.46 Estimated Rod Catch of Sea Trout for the Fane (Eastern Region) and Ilen (South Western Region) (1994-2011).

Table 2.1.51 The Mean Rod Catch of Sea Trout from in Inspectors' Estimates (1994-2000) and after the Introduction of the Logbook Recording Scheme in 2001.

Name of River/System	Estimated Mean Catch (1994-2000)	Annual Rod Catch of Sea Trout from Logbooks (only fish > 40 cms length)			
		2008	2009	2010	2011
Castletown	407	232	5	129	9
Fayne	400	130	15	25	9
Boyne	2,743	300	237	120	30
Slaney	2,364	422	441	493	63
Bandon	1,407	24	19	22	27
Argideen	421	28	n/d	52	21
Ilen	265	12	24	4	6
Currane	4,697	332	329	290	331

Commercial Net Fisheries

The nature and extent of the commercial net fisheries for salmon and sea trout in the Republic has undergone extensive contraction since the introduction of stringent measure from 2001 to protect and preserve future stocks from overexploitation by both the rod and nets fisheries. These measures resulted in a significant reduction in the number, location and types of fishing gears licensed to operate throughout the region. This was even more extensive after 2007, when all drift net fisheries around the coast were abolished and when many rivers were closed to all other forms of commercial fishing in estuaries and coastal zones where the adjacent rivers were judged to failing, or at risk of failing, their conservation limits.

Table 2.1.52 shows the total number of salmon harvested (= caught and retained) throughout the Irish Republic by the principal methods of fishing (including rod-and-line fishing) since 2001. The total number of salmon harvested by all commercial methods has declined by 78% over the 11-year period from a total of 259,475 in 2001 to 32,279 in 2011. Much of the decrease after 2006 resulted from the closure of the drift net fishery, but catches by other fishing methods also declined steadily over the same period while rod catches remained relatively stable.

Table 2.1.52 Total number of Salmon Harvested by All Methods in Republic of Ireland (2001-2011).

Fishing Season	Commercial Fishing Gear				Rod-and Line Fishing *1 *2	Total All Methods Catch	Rod Catch as % of Total
	Drift Nets	Draft Nets	Other Gears*1	All Nets Total			
2001	197,172	30,861	5,368	233,401	26,074	259,475	10.0
2002	179,177	23,032	4,690	206,899	29,408	236,301	12.4
2003	141,222	21,100	4,552	166,874	20,888	187,762	11.1
2004	120,303	19,443	3,860	143,606	26,202	169,808	15.4
2005	101,231	16,735	3.214	117,969	22,361	143,541	15.6
2006	70,105	13,398	2,673	86,176	22,485	108,861	20.7
2007	Nil	8,843	n/a	8,843	19,430	28,273	68.7
2008	Nil	8,903	n/a	8,903	22,215	31,118	71.4
2009	Nil	6,178	579	6,757	17,521	24,278	72.2
2010	Nil	12,261	1,898	14,159	22,336	36,495	61.2
2011	Nil	9200	2,773	11,973	20,306	32,279	62.9

Note: *1: Includes Fixed Engines, Loop Nets & Snap Nets. *2 Harvested (retained) fish only. Excludes salmon caught and then released by anglers. *3 Angling harvest raised to adjust for unreported fish (Small, 1991)

Table 2.1.53 summarises the only available catch data for sea trout over the same period. It shows a similar decline in the catch of sea trout larger than 40 cm by rod and nets with an overall reduction in the all-methods catch from 5,291fish in 2001 to 423 fish in 2011. Much of the reduction in the commercial catch resulted from the abolition of the drift net fisheries and the closure of many other forms of net fishing in many districts from 2007. While the rod catch of salmon has remained relatively stable, the sea trout rod catch of harvested fish >40 cm exhibited an obvious decline of 66% over the same period from 1,066 fish in 2001 to 362 fish in 2011.

Table 2.1.53 Total Number of Sea Trout (>40 cm) Harvested by All Commercial Fishing Methods in Republic of Ireland (2001-2011).

Fishing Season	Commercial Fishing Gear				Rod-and-line Fishing *2*3	Total All Methods	Rod Catch as % of Total
	Drift Nets	Draft Nets	Other Gears*1	All Nets Total			
2001	1,787	2,192	246	4,225	1,066	5,291	20.1
2002	874	1,083	126	2,083	1,464	3,547	41.3
2003	712	1,024	203	1,939	997	2,936	34.0
2004	640	929	78	1,647	519	2,166	24.0
2005	279	535	50	864	770	1,634	47.1
2006	116	311	47	474	543	1,017	53.4
2007	Nil	34	N/A	34	331	365	90.7
2008	Nil	59	N/A	59	448	507	88.4
2009	Nil	35	10	45	455	500	91.0
2010	Nil	61	6	67	387	454	85.2
2011	Nil	48	13	61	362	423	85.6

*Note: *1: Includes Fixed Engines, Loop Nets & Snap Nets. *2 Harvested (retained) fish only. Excludes sea trout caught and then released by anglers: *3 Angling harvest raised to adjust for unreported fish (Small, 1991).*

Table 2.1.54 shows the reported commercial catches of sea trout and salmon from 2003-2006 for the Eastern, Southern and Southwest regions of the Project area. This illustrates an extensive range of variability in the number of sea trout caught by different instruments in each district and major differences in the relative importance of the catches of salmon and sea trout by district and instrument. The maximum number of sea trout reported by any instrument in any year was 310 fish by the Wexford draft nets in 2003, with other instruments reporting >100 sea trout in different years.

The regional totals from Table 2.1.54 are summarised in Table 2.1.55.

The highest total catch of sea trout over the 4-year period was 1,821 for the Eastern Region (compared with 9,813 salmon). This was followed by the Southern Region with 1,097 sea trout (compared with 65, 578 salmon) and the lowest catch of sea trout of 662 fish (compared 74,639 salmon) in the South Western Region. It is evident that sea trout represent a minor part of the total catch by all instruments in all regions. The mean catch of sea trout as a proportion of the total catch of salmon and sea trout for all instruments in any year ranged from 1.1% –3.1% and was 2.4% for all instruments in all years.

The only detailed and comparable information on net catches of both sea trout and salmon over long period is for the Eastern District from 1990-2006 (Table 2.1.56). This shows a steady decline in the catch of both species over the 17-year period despite little change in the number of licences issued in each year and that some instruments caught their largest numbers of sea trout over the earlier part of the record. Figure 2.1.47 illustrates the relative number of sea trout and salmon reported for each instrument over the period. The only instrument where the sea trout and salmon catches were similar was the Wexford draft net fishery, where the annual catch of sea trout sea trout catch was greater than the salmon catch in 1993 and 1985 and where both the sea trout catch and salmon catch peaked at about 3,100 fish in 1999.

Table 2.1.54 Reported Logbook Catch of Sea Trout and Salmon for the Principal Commercial Net Fisheries in Each Fishery District of the Eastern, Southern and South Western Regional Boards (2003-2006).

			2003			2004			2005			2006			4-Year Total		
Board Region	**Fishery District**	**Fishing Gear**	**No. Licences**	**Reported Catch**		**No. Licences**	**Reported Catch**		**No. Licences**	**Reported Catch**		**No. Licences**	**Reported Catch**		**No. Licences**	**Reported Catch**	
				Salmon	**Sea Trout**		**Salmon**	**Sea Trout**		**Salmon**	**Sea Trout**		**Salmon**	**Sea Trout**		**Salmon**	**Sea Trout**
Eastern	Dundalk	Draft	42	427	134	34	634	97	42	468	54	42	272	30	160	1,801	315
	Drogheda	Draft	51	1,248	88	42	1,788	62	50	1,361	22	51	799	19	194	5,196	191
	Dublin	*Drift*	*16*	*20*	*40*	*2*	*3*	*103*	*16*	*4*	*41*	*16*	*1*	*23*	50	28	207
		Draft	11	25	173	8	7	209	10	2	56	9	0	17	38	34	455
	Wexford	Draft	75	874	310	64	1,097	252	75	434	79	74	350	12	288	2,755	653
	Regional Total		**195**	**2,594**	**745**	**150**	**3,529**	**723**	**193**	**2,269**	**252**	**192**	**1,422**	**101**	730	9,814	1,821
Southern	Waterford	*Drift*	*172*	*9,758*	*283*	*169*	*8,303*	*111*	*171*	*4,766*	*53*	*171*	*3,307*	*33*	683	26,134	480
		Snap*	*132*	4,269	199	126	3,456	63	133	2,703	39	132	2,303	28	523	12,731	329
	Lismore	*Drift*	*80*	*9,461*	*154*	*80*	*9,173*	*67*	*80*	*4,850*	*57*	*80*	*3,229*	*10*	320	26,713	288
	Regional Total		**384**	**23,488**	**636**	**375**	**20,932**	**241**	**384**	**12,319**	**149**	**383**	**8,839**	**71**	1526	65,578	1,097
South West	Cork	Drift	*105*	*21,644*	*169*	*110*	*19,134*	*214*	*106*	*14,743*	*56*	*106*	*10,746*	*36*	427	66,267	475
		Draft	33	2,995	74	33	2,662	15	33	1,415	62	33	1,030	36	132	8,102	187
	Regional Total		**138**	**24,639**	**243**	**143**	**21,796**	**229**	**139**	**16,158**	**118**	**139**	**11,776**	**72**	559	74,369	662

Table 2.1.55 Aggregated Annual Catch of Sea Trout and Salmon by all Methods and Districts in each Region (2003-2007).

Aggregated Total All Districts	**2003**			**2004**			**2005**			**2006**			**4-Year Total**		
	Licences	**Salmon**	**Sea Trout**	**Licences**	**Salmon**	**Sea Trout**	**Licences**	**Salmon**	**Sea Trout**	**Licences**	**Salmon**	**Sea Trout**	**Licences**	**Salmon**	**Sea Trout**
Eastern	195	2,594	745	150	3,529	723	193	2,269	252	192	1,422	101	730	9,814	1,821
Southern	252	23,488	636	249	20,932	241	251	12,319	149	251	8,839	71	1,526	65,578	1,097
South Western	138	24,639	243	143	21,796	229	139	16,158	118	139	11,776	72	559	74,369	662
Total All Regions	**585**	**50,721**	**1,624**	**542**	**46,257**	**1,193**	**583**	**30,746**	**519**	**582**	**22,037**	**244**	**2,815**	**149,761**	**3,580**
Mean All Regions	***195***	***16,907***	***541***	***181***	***15,419***	***398***	***194***	***10,249***	***173***	***194***	***7,346***	***81***	***938***	***49,920***	***1,193***

Table 2.1.56 Reported Annual Catch of Sea Trout and Salmon for Principal Net Fisheries in Each District of the Eastern Regional Fisheries Board (1990-2006).

District	DUNDALK			DROGHEDA			DUBLIN			WEXFORD		
Gear Type	DRAFT NETS			DRAFT NETS			DRIFT NETS			DRAFT NETS		
Year Caught	Licences Issued	Salmon No.	Sea Trout No.	Licences Issued	Salmon No.	Sea Trout No.	Licences Issued	Salmon No.	Sea Trout No.	Licences Issued	Salmon No.	Sea Trout No.
1990	43	2,888	80	50	3,368	710	16	613	2,605	75	2,872	975
1991	40	2,082	179	50	3,745	254	16	320	1,134	75	1,166	864
1992	40	1,927	142	50	4,071	511	16	372	2,274	75	1,339	1,214
1993	40	2,345	668	50	4,903	1,034	15	102	2,829	74	2,027	2,553
1994	40	3,375	320	50	7,828	1,084	15	220	2,893	74	2,714	1,697
1995	40	1,315	413	50	4,920	1,246	15	149	5,670	75	2,882	2,964
1996	40	913	56	50	6,195	1,068	16	186	4,982	75	2,548	1,533
1997	40	451	281	50	1,758	982	16	224	4,154	75	1,616	1,394
1998	40	1,626	426	50	7,226	2,032	16	131	2,552	75	3,181	1,792
1999	40	760	956	50	4,328	1,646	16	114	2,158	75	3,177	3,090
2000	40	1,401	446	50	2,606	1,025	16	21	1,546	75	962	693
2001	40	1,191	374	50	2,136	180	16	44	121	75	956	574
2002	40	717	280	50	1,254	86	16	42	182	75	805	233
2003	42	427	134	51	1,248	88	16	20	40	75	874	310
2004	34	634	97	42	1,788	62	2	3	103	64	1,097	252
2005	42	468	54	50	1,361	22	16	4	41	75	434	79
2006	42	272	30	51	799	19	16	1	23	74	350	12
Mean	***40.176471***	***1,340.7059***	***290.35294***	**49.647059**	**3,502**	**708.76471**	**15**	**150.94118**	**1,959.2353**	**74.176471**	**1,705.8824**	**1,189.9412**

Catch data obtained from the records of Licensed Salmon Dealers for 1990 – 2000 and from Logbook returns by licensed netsmen from 2001- 2006.

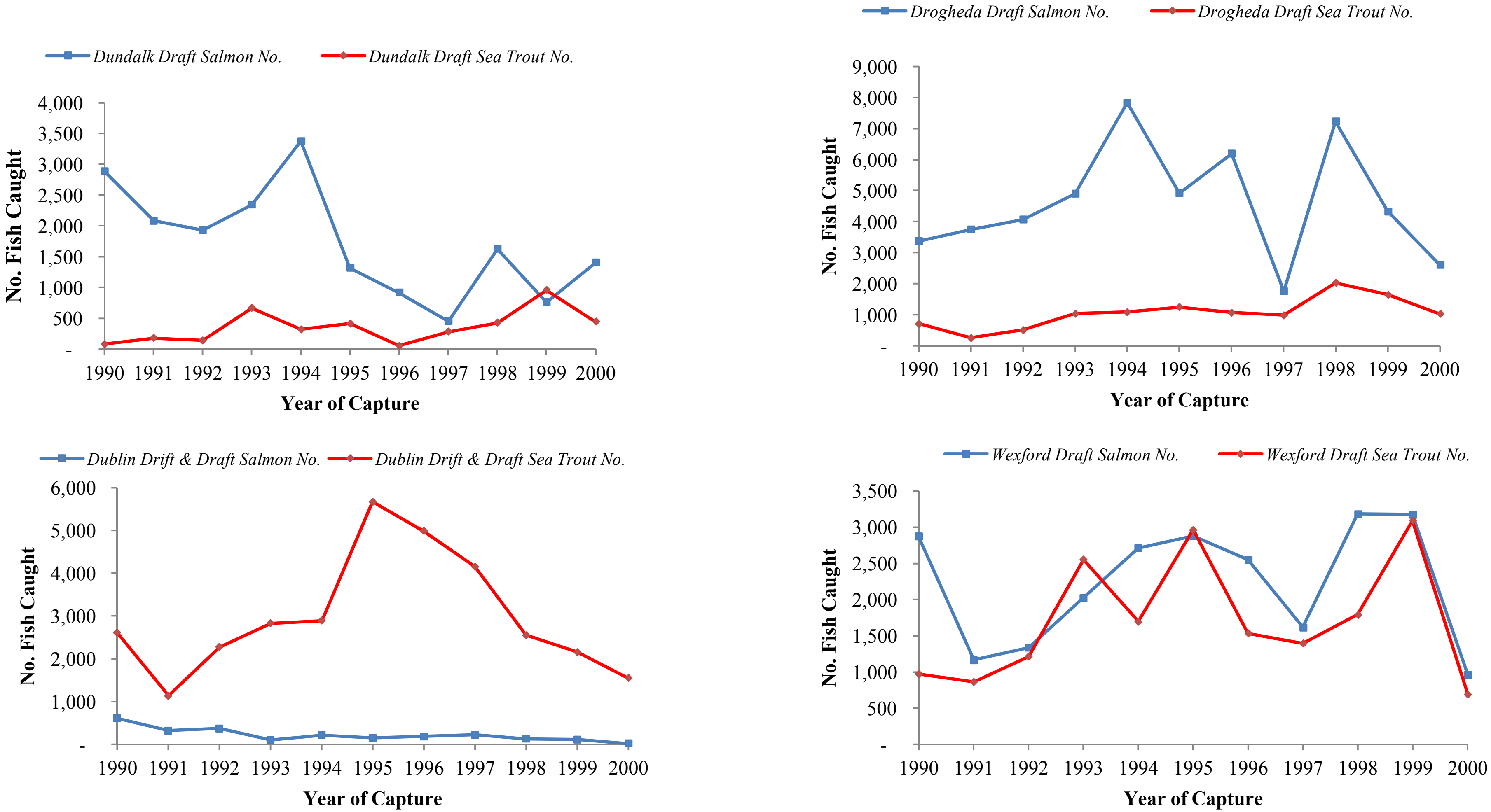


Figure 2.1.47 The Number of Sea Trout & Salmon Caught by the Principal Net Fisheries in the Eastern Region (1990- 2000).

Weight of Fish Caught

Rod Fisheries

There is no information on the total weight, mean weight of individual or size distribution of rod-caught sea trout for any complete river systems in the Republic of Ireland. Information on catch weight is not included in the estimates catches provided by fishery inspectors. Although the logbook scheme required anglers to record the weight of each individual fish caught from 2001, the information abstracted from the logbooks is limited to sea trout in excess of the minimum size limit for retention of >40cm and does not include the very many smaller fish of <40cm caught and released by anglers.

Commercial Net Fisheries

Information on the total weight of the salmon catch by the different types of commercial fishing exists for most years from 1994 for all three of fishery regions, but there is a complete lack of parallel information on the weight of the sea trout catch for the Southern and South Western areas. The only region where the weight of the sea trout catch exists is in the Eastern area, where parallel data for both salmon and sea trout was available over the 11-year period from 1990-2000.

Table 2.1.57 shows the total weight and mean weight of salmon and sea trout recorded by licensed salmon dealers for each of the 4 principal types of netting fishing instrument operation in the Eastern District over the 10 year period 1994 -1999. (Since netsmen sell their catch by weight, these data are likely to be accurate). The mean weight of salmon exhibited little overall annual variation within each district, Although the aggregated (all-years) mean was consistently heavier for the Wexford draft nets at 4.0 kg (range 3.7- 4.2 kg) when compared with the means of 3.1–3.4 kg in the three other districts. The highest aggregated mean weight of sea trout was for the Dundalk draft nets at 1.0 kg (range 0.7-1.2 kg) compared with a means of 0.7-0.9 kg for the other three districts. The lowest annual mean weight reported was 0.5 kg (Wexford draft nets 1993) and the highest was 1.3 kg (Dundalk draft nets 1991 and 1998). The mean weight of sea trout taken by the net fishery was generally less than 33% of the mean weight of salmon: giving each sea trout a lower unit price than salmon when sold.

Angler Catch-and Release

No information is available for sea trout. It is only since the introduction of the logbook scheme in 2001 that any information on the numbers of salmon and sea trout caught-and-harvested or caught-and released by anglers became available but only for sea trout and salmon in excess of the minimum size limit of >40 cm. All fish below this size must be released and their number is not included in the published records. The capture of any salmon smaller than 40 cm is a rare event, but the majority of Irish sea trout caught by the rods are below the minimum size and their capture is not recorded. Consequently, the published information for sea trout will underestimate the actual return rates by a very significant margin and probably exceed 90% on very many rivers.

Table 2.1.57 Total Weight and Mean Weight of Sea Trout and Salmon Recorded from the Principal Net Fisheries in the Eastern Fishery Board Region of Ireland (1990-1999).

Year Caught	Weight of Sea Trout (kg)											
	Dundalk Draft Nets			Drogheda Draft Nets			Dublin Drift & Draft Nets			Wexford Draft Nets		
	No	Total	Mean	No	Total	Mean	No	Total	Mean	No	Total	Mean
1990	80	55	0.69	710	637	0.90	2605	1895	0.73	975	725	0.74
1991	179	227	1.27	254	220	0.87	1134	970	0.86	864	667	0.77
1992	142	158	1.11	511	494	0.97	2274	1675	0.74	1214	801	0.66
1993	668	602	0.90	1034	925	0.89	2829	2242	0.79	2553	1372	0.54
1994	320	323	1.01	1084	919	0.85	2893	2599	0.90	1697	1669	0.98
1995	413	297	0.72	1246	1064	0.85	5670	4507	0.79	2964	2393	0.81
1996	56	67	1.20	1068	865	0.81	4982	4197	0.84	1533	1147	0.75
1997	281	210	0.75	982	740	0.75	4154	3483	0.84	1394	947	0.68
1998	426	542	1.27	2032	1680	0.83	2552	2209	0.87	1792	1445	0.81
1999	956	830	0.87	1646	1548	0.94	2158	1614	0.75	3090	2307	0.75
Mean	**352.1**	**331.1**	**0.98**	**1056.7**	**909.2**	**0.87**	**3125.1**	**2539.1**	**0.81**	**1807.6**	**1347.3**	**0.75**

Year Caught	Weight of Salmon (kg)											
	Dundalk Draft Nets			Drogheda Draft Nets			Dublin Drift & Draft Nets			Wexford Draft Nets		
	No	Total	Mean	No	Total	Mean	No	Total	Mean	No	Total	Mean
1990	2,888	10,683	3.70	3,368	10,449	3.10	613	1,613	2.63	2,872	11,541	4.02
1991	2,082	6,942	3.33	3,745	13,463	3.59	320	972	3.04	1,166	4,368	3.75
1992	1,927	6,459	3.35	4,071	13,055	3.21	372	1,183	3.18	1,339	5,246	3.92
1993	2,345	7,248	3.09	4,903	14,672	2.99	102	313	3.07	2,027	7,842	3.87
1994	3,375	12,462	3.69	7,828	23,617	3.02	220	696	3.16	2,714	11,237	4.14
1995	1,315	4,298	3.27	4,920	15,518	3.15	149	444	2.98	2,882	10,954	3.80
1996	913	2,906	3.18	6,195	19,906	3.21	186	650	3.49	2,548	10,815	4.24
1997	451	1,619	3.59	1,758	6,012	3.42	224	780	3.48	1,616	5,988	3.71
1998	1,626	4,499	2.77	7,226	19,920	2.76	131	315	2.40	3,181	12,720	4.00
Mean	1,768.2	6,001.7	3.38	4,834.2	15,409.7	3.25	243.1	737.7	3.1	2,352.2	9,509.1	4.00

Month of Capture
No records of the month of capture of fish are available for either the rod or the nets prior to the introduction of the logbook recording scheme in 2001. Although the logbook scheme required details of the month of capture, this excluded fish under the minimum size limit of 40 cm and very few (if any) sea trout fish above the this size were recorded to provide any meaningful information. More comprehensive information sea trout by the commercial fishery is available from the logbooks. However, the introduction of statutory measures to reduce commercial exploitation by the nets from 2001 (when the length of the season was curtailed) and the closure of many fisheries in the region to net fishing from 2007 prevents any useful description under this heading for the net fisheries within the project area.

Method of Capture
Information on the method of capture for rod-caught fish was not reported until the introduction of the logbook scheme in 2001 when anglers were required to provide details of all fish caught in excess of the minimum size limit of >40 cm. This excluded the bulk of the sea trout catch on most rivers. The Annual statistical reports from 2005 contain information on the method of capture of salmon for those rivers open to angling, but parallel information on sea trout is not published because too few sea trout in excess of the minimum size were recorded.

Rod Fishing Effort and Catch Success
No information is available for reasons stated above.

Fixed Trapping & Fish Counting Stations

There are no fixed trapping stations within the project area, but electronic fish counters have operated on 5 rivers over the last 11 years to provide actual and raised counts of the number of adult sea trout and salmon passing upstream through the counting site within the CSTP Area. They are:

- **River Dee** (Drogheda District). Vaki counter inserted into fish pass on weir 3 km above tideway. Fish bypass the weir on floods and partial count raised by 100% to provide run estimate. Discrimination between species is by video. Fluvial habitat upstream of counting site = 94% of total catchment fluvial habitat of 119 ha. Site operated from 2002, but no count of sea trout available for 2010/2011.

- **River Boyne** (Drogheda District). Resistivity counter located on existing weir 25km above tideway. Bypassed during floods and partial count raised by 100% to provide run estimate. Video used to discriminate between species. Fluvial habitat upstream of counting site = 84% of total catchment fluvial habitat of 721 ha. Site operated from 2004, but no count of sea trout available for 2010/2011.

- **River Slaney** (Wexford District). Resistivity counter inserted into Denil fish pass some 15 km above tideway. Provides a partial count that is raised by 100% to provide run estimate. Signal strength and video used to discriminate between species. Fluvial habitat upstream of counting site = 66% of total catchment fluvial habitat of 360 ha. Unbroken run of counts over 11 years from 2002 for both species.

- **River Bandon** (Cork District). Vaki counter on existing weir 10 km above tideway. Partial count raised by 100% to provide actual count. Video used discrimination between species. Unbroken run of data from 2002, but sea trout count not considered reliable as many fish ascend over the weir. Fluvial habitat upstream of counter = 79% of total catchment fluvial habitat of 154 ha.

– **Waterville/Currane System** (Kerry District). Resistivity counter situated in old fish trap some 200 m above tideway. Species discrimination is by video and signal strength. Provides a complete count operated from 2002, but the sea trout count from 2009 considered unreliable.

Table 2.1.58 shows the adult run counts for each river. Only two rivers (Slaney and Bandon) provide an unbroken run of data for sea trout and salmon (Figure 2.1.48 & Figure 2.1.49) and gaps in several years for either sea trout and/or salmon prevent any valid comparison of patterns in run strength and the relative importance of sea trout and salmon for the Dee, Boyne and Currane systems. The extensive fluctuations in run count for consecutive years are remarkable. Sea trout numbers on the Slaney alternated from 930, 750, 800, 4172 and 874 over the 5 consecutive years from 2004-2008: with similar consecutive oscillations of 784, 3322, 486, 2836 and 2686 exhibited on the Boyne over the same years.

The Currane system exhibited a dramatic decline in sea trout run strength from 27,793 in 2002 to 12,519 in 2008, with an equally dramatic parallel decline in salmon numbers from 5,581 to 798 over the 11 years from 2002 to 2012. This general decline in sea trout is also evident on the Slaney and to a lesser extent on the Bandon from 2002-2012.

Where comparable year-counts are recorded, sea trout runs exceed salmon runs in the Currane system by a very large margin in all 7 years and were equal to or greater than salmon on the Slaney in 4 of the 11 years and on the Dee in 8 of the 12 years.

Table 2.1.58 Number of Adult Salmon & Sea Trout Running Upstream through Fish Counting Sites on 5 Irish Rivers within Project Area.

Year of Operation	River Boyne		River Slaney		River Dee		River Bandon		River Currane	
	Estimated Run Strength		Estimated Run Strength		Estimated Run Strength		Estimated Run Strength		Estimated Run Strength	
	Salmon	Sea Trout	Salmon	Sea Trout	Salmon	Sea Trout	Salmon	Sea Trout	Salmon	Sea Trout
2002	N/A	N/A	2,916	1,390	146	676	2,896	792	5,581	27,793
2003	N/A	N/A	3,046	1,314	240	786	1,600	636	3,750	29,712
2004	N/A	784	1,888	930	N/A	N/A	2,886	488	5,258	17,943
2005	11,341	3,322	1,536	2,750	322	1,572	2,658	748	3,517	18,062
2006	5,934	468	904	800	422	672	672	404	2,156	10,733
2007	10,490	2,836	2,258	4,172	587	1,722	2,209	368	2,413	12,314
2008	6,640	2,686	594	874	759	942	2,209	442	2,514	12,519
2009	6,112	912	966	606	1,124	1,278	2,524	208	1,118	N/A
2010	5,862	N/A	630	154	720	N/A	2,840	558	1,051	N/A
2011	5,750	N/A	870	524	834	N/A	6,140	162	1,226	N/A
2012	8,839	812	906	954	1,210	1,770	3,428	360	798	N/A

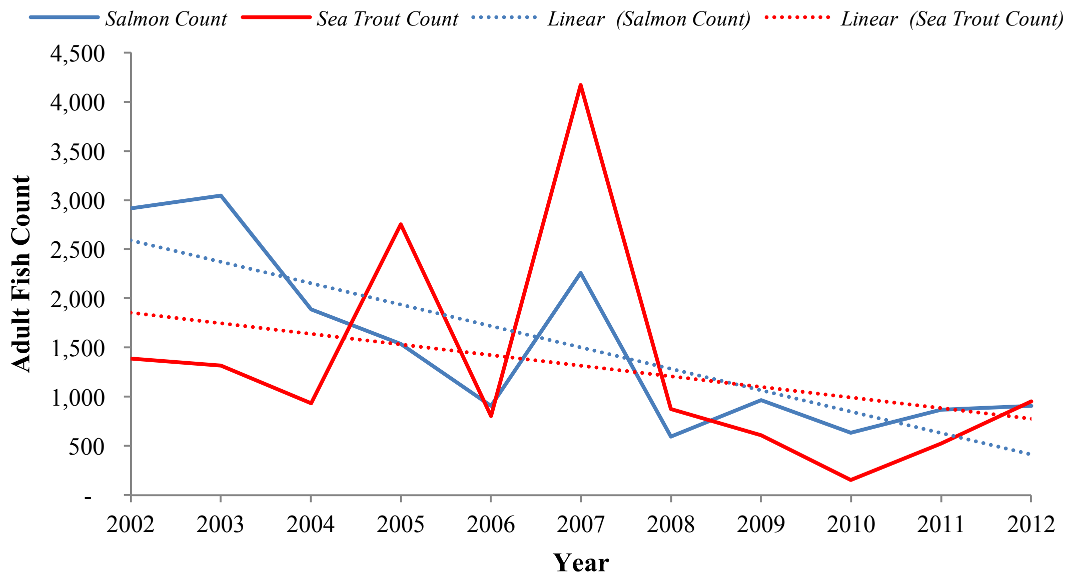


Figure 2.1.48 Adult Run Counts of Salmon & Sea Trout in River Slaney (2002-2012)

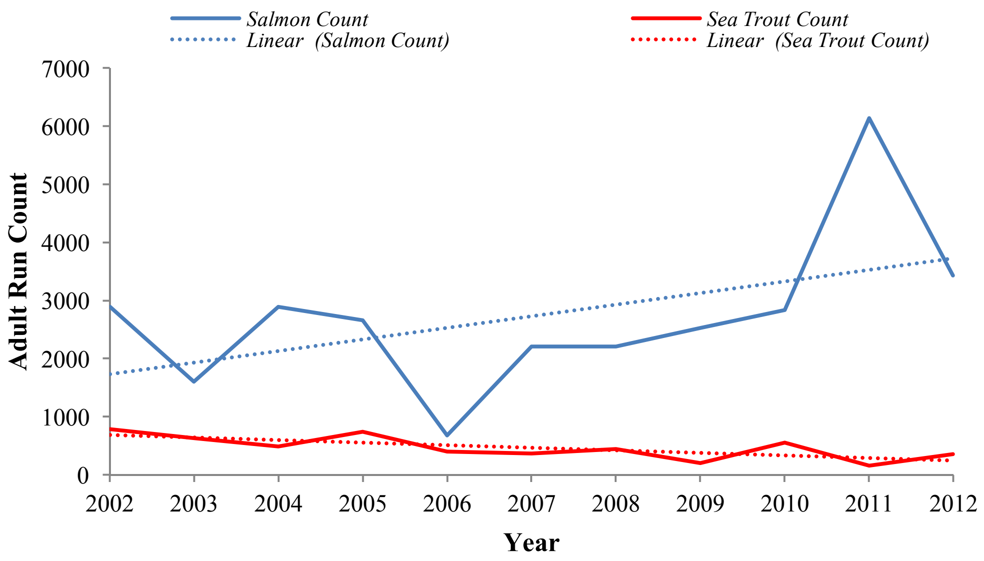


Figure 2.1.49 Adult Run Counts of Salmon & Sea Trout in River Bandon (2002-2012).

2.2 Importance and Value of Sea Trout Fisheries

2.2.1 Introduction

This part reviews the importance and value of the sea trout fisheries in the UK and Ireland in relation to their social and economic benefit to society and their importance in maintaining and sustaining those benefits at a regional and local level. The status of our sea trout fisheries is linked inextricably with the relative importance associated with that of the co-dwelling Atlantic salmon in almost every practical context. Since it is unrealistic to consider the importance and value of sea trout to the fisheries of different rivers and regions in isolation, this review has been expanded to include a comparison of the relative importance of both salmon and sea trout.

This section deals primarily with recreational rod fisheries. The decline in the nature and extent of commercial fishing for sea trout and salmon in all regions of the UK and Ireland over the last 30 years does not allow more than a passing reference to their importance and value.

The use of catch data as the principal basis for comparing the relative importance of sea trout and salmon depends very much on the nature and scope of the information available from the records within each region. The absence of robust, complete and comprehensive catch data on sea trout catches for the Irish Republic and the limited scope of the catch records for Scotland makes it necessary to focus largely on the more detailed catch records available for England and Wales in assessing the relative importance of sea trout and salmon.

Historical Perspective

The long history of fisheries management in the UK and Ireland since the seminal fisheries legislation of the 1880s was, until recently, dominated by the importance and value attached to maintaining, improving and developing Atlantic salmon fisheries. The existence of stocks of co-dwelling sea trout in all the many fisheries containing salmon stocks was largely over-looked and taken for granted in the development of management strategies and the implementation of management programmes for migratory fisheries (Harris & Milner, 2006). Since it was widely held that salmon and sea trout exhibited a very similar life-history embracing both freshwater and marine environments and almost identical habitat requirements while in freshwater, the general assumption was that ‘provided we looked after our salmon, the sea trout would look after themselves’. Harris & Winstone (1990) suggested that the greater importance attached to salmon by Governments and their respective agencies resulted from the overwhelming contribution of catches from a small number of large, highly productive and prestigious salmon rivers in producing the greatest percentage of the National catch. They noted that many more smaller and less well-known rivers attracted only limited management attention and that many of these were potentially important and valuable sea trout fisheries.

The apparent history of general neglect towards sea trout over much of the earlier management history was succinctly encapsulated by Jock Scott (1969) when he wrote “The sea trout is the Cinderella of the of the Game Fish world, authors, government departments, fishing owners and other interested parties pass him by”. He then adds, “This is really not so surprising when one considers that a good sea trout river accommodates salmon also and, naturally, the latter steals all the limelight and money.” He, like other angling authors of the period noted the far greater snobbery and prestige attached to catching salmon than either of its lesser cousins, the sea trout and the brown trout.

Harris & Morgan (1989), in commenting on the greater importance attached to Atlantic salmon, observed that the sea trout had attracted a bad press in the historical salmon angling literature. Various authors described the sea trout in pejorative terms as ‘not worthy of special interest’, ‘a minor quarry’, ‘no more than an interesting diversion’, and more commonly ‘something to fall-back on when the salmon fishing is out of order’. A more radical view, based on the nineteenth century belief that sea trout were serious competitors with the more noble salmon, described them as ‘vermin that should be extirpated from our salmon rivers’.

The period from the mid-1950s to the mid-1960s is often viewed with hindsight as ‘the golden-years’ when salmon stocks reached the all-time peak in living memory. Salmon were then everywhere abundant and rod (and net catches) reached unprecedented levels. Therefore, it is perhaps understandable that few anglers bothered to fish for the smaller and less prestigious sea trout when salmon could be caught in large numbers throughout the season.

However, this situation changed rapidly from the 1970s in response to subsequent developments that combined to raise the profile and status of sea trout to a new level so that it is no longer considered as ‘overlooked’ and ‘taken-for-granted’. These developments, as listed by Harris & Milner (2006), are updated and summarised as follows:

Decline in Salmon Stocks
The outbreak of the pandemic disease ‘Ulcerative Dermal Necrosis’ (UDN) throughout the UK and Ireland from the late 1960s to the mid-1970s devastated adult salmon and sea trout stocks in general until the mid-1970s. However, whereas sea trout stocks recovered steadily to achieve something like their original levels of abundance by the mid-1980s, salmon stocks continued a seemingly ineluctable decline over the next 40 years to a point where they are considered either ‘at-risk’, ‘threatened’ or ‘endangered’ in relation to their depleted spawning stocks on many once prolific salmon rivers.

Problems associated with the quantitative reduction in the total numbers of fish returning to almost all salmon fisheries from the 1970s were further exacerbated on many major fisheries from the 1990s by the introduction of powerful measures to protect the depleted runs of the early-running MSW ‘spring’ component of salmon stocks. In Wales, the parlous state of salmon stocks on the Wye, once famed for its prodigious runs of very large MSW salmon fishing from January to June, combined with depleted runs of salmon throughout the remainder of the year, led to the introduction of compulsory catch and release of all salmon throughout the entire year from 2012.

Government acknowledgement of the parlous state of salmon stocks throughout the much of the Irish Republic triggered the introduction of a series of stringent regulatory measures to reduce levels of exploitation by the rod and net fisheries on all but a few salmon rivers from 2003. From 2007, those rivers where salmon stocks were judged to be endangered were ‘closed’ to all rod and net fishing and other rivers where stocks were deemed to be at risk remained open to ‘catch-and-release-only’ rod fishing: with closure of the commercial net fisheries. Subject to certain byelaw restrictions requiring the release of all sea trout >40 cm in length, rod fishing for sea trout was allowed to continue on all Irish rivers with only a very few exceptions. This fact may have helped to offset the otherwise negative impact of the salmon conservation measures on the social and economic benefits that otherwise would have been lost to many communities throughout the region.

Angler Awareness
While few books on the attractions or appeal of sea trout angling were published over the last 200 years compared with the extensive library of salmon angling literature, sea trout angling has increased in popularity and demand for it has increased significantly over the last 40 years. This was partly due to the decline in salmon stocks and many salmon anglers adopting sea trout as an alternative to salmon on many rivers for all or much of the season. However, much of the new demand was the result of increased recognition within the angling community that sea trout angling was much more than merely a scaled-down form of salmon fishing or a scaled-up version of brown trout fishing, but a separate branch of angling with its own very special challenges and attractions.

While Falkus (1962) and a few subsequent angling authors did much to change the traditional attitude to sea trout fishing that subsequently attracted a growing number of anglers into the sport, much of the increased demand for sea trout fishing resulted from a parallel development in England

and Wales from the 1970s. This was the new duty imposed on the Water Authorities to promote increased public access to water supply reservoirs for the purpose of recreation. It encouraged a massive increase in demand for stillwater trout fishing on the many high quality, low-priced and heavily stocked 'put-and-take' reservoir fisheries that rapidly became available near large centres of population and introduced many new participants into the sport. Over the years, many of these anglers, perhaps weary of the 'sameness' of this form of fishing, eventually graduated to fishing for sea trout on rivers and lakes in the wilder and more remote scenic locations of the UK and Ireland.

Salmon Farming Development

The negative impact on stocks of wild sea trout in many sea trout fisheries resulting from the massive growth of the commercial fish farming sector by rearing salmon in cages moored in estuaries and sheltered coastal inlets from the late 1970s on the west of Scotland and Ireland was a major development in raising the profile of sea trout. The collapse and near extinction of many small but once productive sea trout fisheries was attributed to the effect of acute infestations with the sea lice (*Lepeophtheirus salmonis*) on the subsequent survival and return of outgoing sea trout smolts during their migration into the sea and early feeding as post-smolts in coastal water adjacent to salmon farms (Gargan, 2000; Butler & Walker, 2006: Hatton-Ellis et al., 2006; Poole et al., 2006). In the early years of this collapse, which had severe social and economic consequences for many afflicted fisheries and their local communities, the cause was little understood at the time. Growing concern that a similar collapse might occur in England and in Wales, where salmon fisheries were already depressed, led to a crash-programme of research to fill the many gaps in our knowledge about the status and wellbeing of the sea trout fisheries and how best to manage them should a similar collapse occur. This did not materialise but it served to establish the importance of sea trout as the mainstay of many fisheries where they had previously been taken-for-granted.

Management Benefits

Increased understanding of the complex life history, ecology and migrations of sea trout over the years has established certain key features that provide practical management advantages not exhibited by salmon. Harris & Milner (2006) listed these benefits as:

- **Robust Life History -** Sea trout have a more robust life-history in that the pattern of divided smolt migration to sea and adult return to freshwater as maiden fish is spread across up to 7 year classes of fish and a proportion of the returning adults can survive as kelts to make multiple return visits to the river to spawn in subsequent years. Consequently, they can spread the risks to survival in both the freshwater and marine environments across several more year classes and cohorts of fish than salmon and are better able to withstand and recover from short-term factors and events affecting their survival.

- **Catchment Utilisation -** Sea trout return to freshwater over a greater range of sizes than salmon and are better able to utilise a wider range of spawning and nursery habitats within a catchment to maximise their potential yield of smolts and returning adults. They can utilise the smaller streams and spawning gravels unsuitable for salmon and also spawn in the larger gravels that cannot be used by resident brown trout.

- **Lifetime Egg Yield -** Adult sea trout are generally much smaller 'on average' than adult salmon. However, their innate potential to live longer and survive to spawn on several occasions means that their total cumulative contribution to egg deposition and spawning success over their lifetime may be several times greater than each salmon.

- **Marine Movements -** Adult sea trout do not make extensive long-distance migrations in the sea and their marine feeding habit is generally confined to inshore coastal waters than salmon. They are therefore less vulnerable to exploitation by high-seas interceptory fisheries while feeding at sea and on returning to freshwater and they are less likely to be influenced by those oceanic factors thought to be affecting the marine survival of salmon.

- **Return to the River -** Sea trout are much less dependent than salmon on the occurrence and timing of natural floods to trigger migration from the sea, through estuaries into freshwater and then their upstream distribution throughout the catchment. Sea trout, unlike salmon, will also enter rivers and penetrate upstream under extreme drought conditions to become available to anglers when fresh salmon are absent. This behaviour reduces their exposure to problems associated with illegal fishing and poor water quality that can adversely affect accumulating salmon stocks in tidal waters until the next flood triggers migration into freshwater.

2.2.2 Social and Economic Values

The results of an increasing number of investigations into the economic value of fisheries have been published in various formats over the last 30 years. Most of the more comprehensive and authoritative studies were commissioned by Government Departments and their respective Agencies to assess if the return on the investment of public funds to support the management and development of different fishery sectors represented 'value-for-money' in relation to the return of benefits accruing to society as a whole. Although information on economic values is clearly of importance in itself, it is now widely recognised that the social benefits of angling, while difficult to quantify in economic terms as yet, are of equal if not more important than economic values in many contexts.

2.2.2.1 Economic Benefits

Many of the earlier economic studies compared the relative values of the recreational and commercial fisheries for salmon and sea trout. Later studies were then broadened in scope to cover, variously, game fish (salmon, trout and sea trout), freshwater fish (covering salmon, sea trout, brown trout and coarse fish) while others added angling for sea fish to the mix. Few of these studies are comparable because of differences in the sampling methodologies, the inclusion or exclusion of different elements of expenditure (e.g. travel costs) and different approaches in the application of economic theory to the interpretations and/or presentation of the results. Two other issues arise in relating these investigations to this Section of Task 2. The first is that the presentation of economic values for the different parts of the UK and Ireland does not correspond with the main geographical regions within the Project Area. The second, and most problematic, is that none of the studies provides a separate value for sea trout. Any values that were attributable to sea trout were subsumed and combined within the values derived for salmon.

A key point that is stressed in recent studies was that only the imported expenditure by non-resident (visiting) anglers was of any great significance in a national context: although the imported expenditure by resident anglers who fished in different parts of the UK and Ireland may be important at a regional and local community level: particularly in remote rural areas.

The two most recent and authoritative studies providing any information relevant to the CSTP area are concerned with recreational angling. They cover England and Wales and Ireland. The relevant headline values summarised below. There is no information for the Scottish Solway Region within the Project Area.

England & Wales

The report on an "Economic Evaluation of Inland Fisheries" (Mawle & Peirson, 2009; Radford et al., 2009) provides the most up to date information. This survey (commissioned by the Environment Agency) covered recreational angling across all regions of England & Wales. It was based on telephone and on-line questionnaire surveys of 7,000 anglers who had purchased a rod fishing licence to fish for migratory salmonids, non-migratory trout or coarse fish during the annual fishing season in 2005/6. The main findings on angling expenditure and impacts on regional economies are summarised in Table 2.2.1 for all regions in England & Wales and the English Northwest and Welsh Regions.

- **All Regions -** The one million anglers who obtained rod licences in 2005 made some 30 million fishing trips and spent £1.2 billion in pursuit of their sport. This generated £980 million in household income and supported 37,000 full-time jobs. Anglers fishing specifically for salmon and sea trout in England & Wales made 429,000 fishing trips. While this represented only 1.4% of all fishing trips made over the season compared with 11.3% (3.4 million trips) by trout anglers and 87% (28.3 million trips) by coarse anglers, it was not distributed evenly throughout the 10 regions. The total number of angling trips (and economic activity) is heavily biased towards those regions with the greatest population density and the greatest number of anglers. These regions are generally those where there are relatively few, if any, migratory fish rivers but a preponderance of coarse fisheries. Only four of the 10 regions contain any significant migratory fish rivers.

- **Northwest England -** Anglers made 4 million fishing trips and spent £141 million. This generated £79 million in household income and supported 3,247 jobs. Those anglers fishing for salmon and sea trout made 108,000 fishing trips (2.6% of the all-regions total). Their expenditure of £7.7 million supported £4.2 million in household income and 180 jobs in the Welsh Region. All anglers made 1.7 million fishing trips. Their expenditure of £74 million generated £32 million in household income and supported 1,454 jobs. Salmon and sea trout anglers made 171,000 fishing trips (10% of regional total). Their expenditure of £11.6 million generated £5.3 million in household expenditure and supported 263 jobs.

- **Combined Wales & Northwest England -** These two regions of the Project Area bordering the Irish Sea supported 283,000 fishing trips for salmon and sea trout generating £44 million in angler expenditure and supporting £9.5 million in household incomes and 443 jobs. The combined totals for these two regions represented: a) 66% of all fishing effort, b) 52% of gross angler expenditure, c) 33% of supported household income, and d) 37% of supported jobs associated with salmon and sea trout angling in all Regions of England & Wales.

Ireland

The most recent investigation, a 'Socio-economic Study of Angling in Ireland' (Tourism Development International, 2013), was commissioned by Inland Fisheries Ireland and covered all forms of angling in freshwater and the sea in the Irish Republic. It reported that the 406,000 anglers who fished in 2012 for game, coarse and sea fish generated a total direct expenditure of €555 million of which visiting anglers contributed €121 million. After considering indirect and induced impacts, the overall economic impact was €755 million of which €280 million (48%) related to angling tourism. The estimated number of jobs (FTEs) supported by tourist angling was 10,080. [€1 = £0.82.] These headline values are not broken down by geographical area or into different species groups of fish and so no separate estimate are available for the economic value of sea trout and salmon angling within the project area on the east coast of the Republic. However, it has provided a useful breakdown of the proportion of all fishing trips associated with different groups and species of fish under the seven category headings shown in Table 2.2.2

The total number of targeted fishing trips made by all Irish anglers in 2012 was 477, 000. The number of trips targeted specifically at sea trout-only was 32,000 (6.7% of total) while an additional 91,000 trips (19.1% of total) were targeted at both salmon and sea trout. The combined number of trips where anglers fished for either or both sea trout and salmon was 123,000 and represented 25.6% of all anglers fishing trips in Ireland. This compared with 28.7% (137,000 anglers) fishing for all sea fish (including bass) and 28.5% (136,000 anglers) fishing for all coarse fish (including pike).

Table 2.2.1 Summary of Economic Activity for Northwest England, Wales and All Regions in England & Wales (for 2005 Fishing Season).

Entry Heading	Species & Angling Sector	Northwest England Region	Welsh Region	All Regions England & Wales
Number of Days Fished ('000s)	Coarse Fish	3,474	847	26,387
	Trout	431	692	3,434
	Salmon & Sea Trout	*108*	*175*	*429*
	All Sectors	4,013	1,714	30,250
Gross Angler Expenditure (£'000's)	Coarse Fish	£117,128	£24,731	£971,228
	Trout	£16,336	£37,666	£172,707
	Salmon & Sea Trout	*£7,655*	*£11,607*	*£36,958*
	All Sectors	£141,119	£74.004	£1,180,893
Income: (GVA) Supported (£000's)	Coarse Fish	£67,042	£11.204	£804,203
	Trout	£7,985	£15.,307	£147,603
	Salmon & Sea Trout	*£4,216*	*£5,294*	*£28,612*
	All Sectors	£79.24	£31,805	£980,418
Supported Employment (FTEs)	Coarse Fish	2,736	501	30,580
	Trout	331	680	5,628
	Salmon & Sea Trout	*180*	*263*	*1,179*
	All Sectors	3,247	1,454	37,386

Note: Because of different multiplier effects. estimates of GVA (Gross Value Added) and FTE (Full Time Equivalents) are not summations of individual regions. Only Angler Days and Gross Expenditure can be summed across regions and species.

Table 2.2.2 Target Species Preferences for Anglers in Ireland (2012)

Category by Species/Group	Anglers on Day Fishing Trips	Anglers on Overnight Fishing Trips	All Fishing Trips by Anglers
Salmon & Sea Trout	69,000	22,000	91,000
Sea Trout-Only	22,000	10,000	32,000
Brown Trout	67,000	14,000	81,000
Pike	62,000	15,000	77,000
Coarse Fish (excl. pike)	42,000	17,000	59,000
Bass	33,000	11,000	44,000
Sea Fish (excl. Bass)	71,000	22,000	93,000
Total All Categories	**366,000**	**111,000**	**477,000**

2.2.2.2 Social Benefits

An enhanced understanding and appreciation of the social benefits of angling has emerged gradually over the years from a wide range of separate, and largely opportunistic, local studies undertaken by various organisations, agencies and government department. The report on ‘Angling in Britain 1980’ (Travis, 1980) assembled much of the information then available on the social, economic, therapeutic, environmental and ethical benefits of angling. The most recent report, ‘Fishing for Answers’ (Substance, 2013), provides a comprehensive review of some 200 publications evidencing the social and community benefits of angling in the United Kingdom. These complex and inter-linked benefits societal benefits were listed as:

1) **Sports Participation**
   Angling encourages very large numbers of people to participate in a healthy outdoor sport that encompasses a breadth of physical activity for people of all ages and abilities. It provides a national infrastructure of clubs and governing bodies and is a gateway for a wide range of positive social and environmental activity and behaviour.

2) **Health & Wellbeing**
   Angling plays a positive role in improving public health and wellbeing. It offers specific benefits as an informal recreational activity that can build resilience against ill health by providing opportunities for relaxation, relief from stress, improved physical activity and access to the natural environment and as part of targeted intervention programmes to assist in recovery from physical and mental ill health. It provides opportunities for 'active ageing' and helps young people build confidence and relationships.

3) **The Natural Environment**
   Angling delivers benefits for the environment and for people by delivering environmental benefits through angler engagement in conservation, ecosystem monitoring and raising environmental awareness. It also acts as a gateway for people to access green spaces and create connections with nature that improves the well-being of people and their communities.

4) **Community Development**
   Angling and anglers can play a positive role in local communities by empowering people to be active citizens by the development of water-based community assets and creating opportunities from greater cohesion and integration within communities.

5) **Rural Communities & Angling Tourism**
   Angling can make a valuable impact in rural and remote communities in terms of economic impact by extending the tourist season and contributing to sustainable community development through portfolio employment and sustaining cultural heritage.

6) **Young People**
   Angling has a positive role in the education, personal development and social inclusion of young people. It provides a distinctive contribution in providing opportunities for personal and social development, raising attainment in education and employment, diverting young people from crime and antisocial behaviour and in helping those with additional behavioural or learning needs – especially Attention Deficit Hyperactivity Disorder (ADHD).

The contribution of sea trout and salmon fisheries in providing these benefits is unknown. It will depend largely on the nature and extent of angling activity within the catchment areas of different communities and the range of different species present within any given area providing alternative angling opportunities. However, in those many geographically remote parts of the UK and Ireland where sea trout are more common and abundant than any other freshwater fish species, their contribution may be of significant importance and value.

2.2.3 Relative Importance

Virtually all rivers in most regions of the UK and Ireland now contain co-dwelling, sympatric stocks of both salmon and sea trout, albeit at different levels of relative abundance. Many of these rivers support recreational rod fisheries, which, in the absence of worthwhile brown trout fisheries or fisheries for other species of freshwater fish, are wholly dependent on sea trout and salmon. Their individual contribution to the social and economic benefits to local communities within their catchments depends, among other things, on the availability of attractive and worthwhile fishing that is perceived by anglers as 'value-for-money by local and visiting anglers. This in turn depends on the characteristics of each fishery, which can vary widely in terms of the relative abundance of each species and their relative availability over the fishing season.

Investigations into the social and economic value of migratory fisheries have focussed on the term 'salmon' and have combined sea trout with salmon under this composite generic heading for practical and pragmatic reasons because both species may be caught while fishing for either species in many situations. It is therefore impossible to derive a separate value for each species and so obtain an estimate of the value for sea trout. However, some measure of the relative importance of sea trout and salmon is available from the catch records for each species under five key feature headings.

1) The total number of each species caught each year.
2) The pattern of catches in each month of the season.
3) The fishing effort required to catch each species (CPUE).
4) The fishing effort directly targeted at each species.
5) The importance of sea trout and salmon in minor rivers.

2.2.3.1 Number of Fish Caught

The total number of sea trout and salmon caught each year provides a basic measure of their relative importance in each river and, when catches for a number of different rivers are aggregated, for an area or region.

Scotland

The aggregated mean annual catches of sea trout and salmon from the rod and net fisheries for all 14 Fishery Regions in Scotland and for the Solway Region over the 18-year period 1994-2011 are summarised in Table 2.2.3. The annual mean rod catch of sea trout for the entire Scottish region of 32,599 fish was 42% of the rod catch of 77,208 salmon and 30% of the combined catch of both species. The ratio of fish caught by the rods was 1 sea trout to 2.4 salmon. This relationship changed slightly in favour of salmon for the commercial net fishery, where the mean net catch of 11,569 sea trout was 32% of the Scottish net catch of 36,348 salmon and 24% of the combined catch of 47,917 fish. The ratio of fish caught by the nets was 1 sea trout to 3.1 salmon.

Table 2.2.3 Summary of the Mean Annual Catches of Sea Trout & Salmon for All Scottish Regions and the Solway Region. (1994-2011).

Region & District	Rods			Nets		
	Sea Trout	Salmon	Combined	Sea Trout	Salmon	Combined
All Scottish Regions	32,599	77,208	109,807	11,569	36,348	47,917
Solway Region	3,131	3,995	7,126	1,816	3,176	4,992

Figure 2.2.1 shows the annual pattern of catches for the Scottish Rod and net fisheries over the 18-year study period. The rod catch of salmon exceeded the sea trout catch by a large margin in all years for both the rods and nets: with the ratio of sea trout to salmon caught ranging widely from 1:1.6 to 1: 3.7 for the rods and from 1.4:1 to 4.4:1 for the nets.

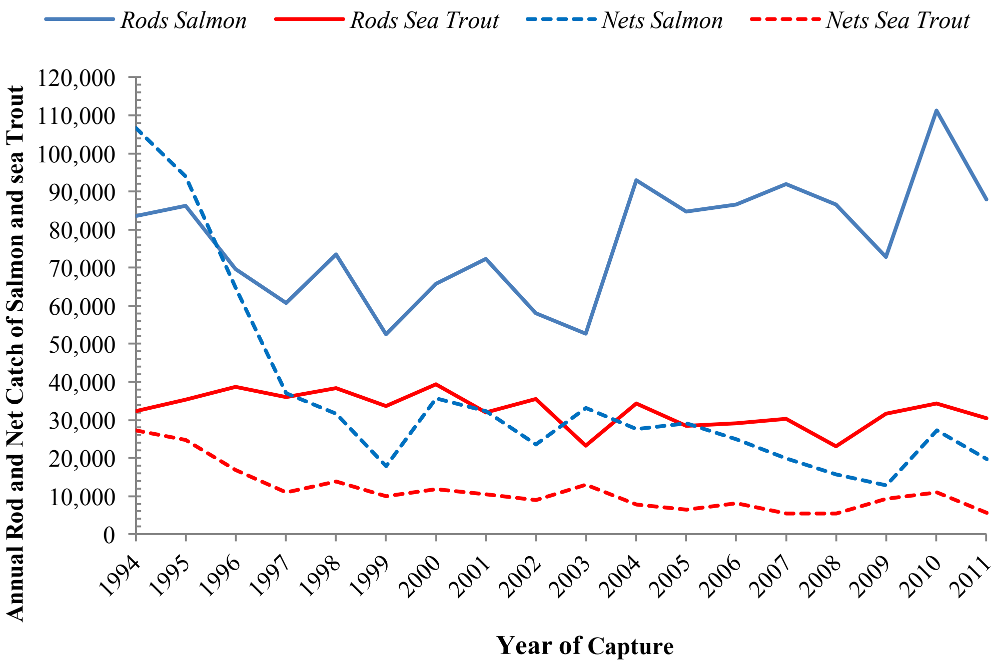


Figure 2.2.1 Aggregated Mean Annual Rod and Nets Catches of Sea Trout and Salmon for All Scottish Fishery Districts (1994-2011).

Solway District

The mean annual rod and net catches of sea trout and salmon for all Solway rivers are summarised in Table 2.2.4. The rod catch of 3,131 sea trout was 44% of the catch of 3,995 salmon and 43% of the combined catch of both species of 7,126 fish. The ratio of fish caught by the rods was 1 sea trout to 1.3 salmon. The mean annual net catch of 1,816 sea trout represented 57% of the catch of 3,176 salmon and 36% of the combined catch: a ratio of 1 sea trout to 1.75 salmon.

Table 2.2.4 Mean Annual Rod Catches of Sea Trout & Salmon for Individual Solway Rivers (1994-2011).

Fishery District	Salmon		Sea Trout		Combined Catch	% Sea Trout	Catch Ratio
	Mean	*Range (Min - Max)*	Mean	*Range (Min - Max)*			
Annan	**860**	*203 - 1,723*	**987**	*208 - 2,734*	1,847	53.4	1.1:1
Nith	**2,143**	*983 - 3,345*	**1,557**	*489 - 3,384*	3,700	42.1	0.7:1
Urr	**197**	*23 - 419*	**62**	*12 - 204*	259	23.9	0.3:1
Dee	**65**	*20 - 106*	**35**	*0 - 218*	100	35.0	0.5:1
Cree	**409**	*209 - 608*	**261**	*65 - 615*	670	39	0.6:1
Fleet	**6**	*0-27*	**30**	*0 - 90*	36	83.3	5.0:1
Bladnoch	**166**	*83 - 331*	**3**	*0 - 16*	169	1.7	.02:1
Luce	**142**	*57 - 264*	**129**	*53 - 274*	271	47.6	0.9:1

The mean rod catch of 3,131 sea trout from the 8 rivers within the Solway District represented 9.6% of the entire rod catch of 32,599 sea trout for Scotland while the rod catch of Solway salmon of 3,995 fish was lower at 5.2% of the Scottish National catch. The Annan and Nith collectively produce the greater part of all rod caught sea trout and salmon caught in the Solway Region. Their combined annual rod catch of 2,554 sea trout and 3,003 salmon was 83% of the total of 3,064 sea trout and 75% of the 3,998 salmon caught in the District. These two rivers produced 7.8% of all sea trout caught in Scotland.

England & Wales
Significant rod and net fisheries for salmon and sea trout are located in only 4 of the 8 regions of England & Wales: namely the Welsh Region and the Northwest, Southwest and Northeast Regions in England. The other English regions (Southern, Thames and Anglia) have few rivers supporting small or marginal stocks of sea trout with little or no rod fishing effort, while the River Severn in the Midland Region yields a catch of 330 salmon (but almost no sea trout) to the rods and 1,040 salmon to the nets on the River Severn. Although there are no significant stocks of migratory fish in the Anglian region, the commercial net fishery produces a mean annual catch of 1,348 sea trout but only 15 salmon.

Table 2.2.5 summarises the mean total catch of salmon and sea trout by the rod and net fisheries in England and Wales over the 18-year period 1994-2011 for the four principal fishery regions and for aggregated rod and net catches for the 4 other regions under the composite heading 'Other Regions'.

Table 2.2.5 Aggregated Mean Annual Rod & Net Catches of Sea Trout & Salmon for Different Regions of England & Wales (1994-2011).

EA Region	Rods		Nets	
	Sea Trout	**Salmon**	**Sea Trout**	**Salmon**
Northwest	6,416	6,465	1,283	2,861
Wales	18,054	4,418	1,624	1,269
Southwest	7,319	2,338	1,480	1,484
Northeast	4,300	4,403	29,835	20,289
Other Regions	862	561	1,350	1,056
All Regions	**36,951**	**18,185**	**35,576**	**26,959**

The mean total rod catch of 36,576 sea trout and 18,185 salmon for the 8 Regions of England & Wales was larger than the Scottish rod catch of 32,599 sea trout but very much smaller than the Scottish rod catch of 77,208 salmon. The commercial net catch in England & Wales of 35,576 sea trout and 26,959 salmon was much greater than the Scottish net catch of 11,569 sea trout but smaller than and the commercial salmon catch of 36,348 salmon. [It is notable that the highly productive commercial net fishery in Northeast England of 29,835 sea trout and 20,289 salmon represents 84% and 73.4% respectively of the total commercial catch of the two species in England & Wales.]

Northwest and Welsh Regions
Within the Project Area, the combined rod catches from the Northwest and Welsh Regions of 24,470 sea trout and 10,883 salmon was 66.2% and 40.4% respectively of the total catch of fish from all Regions of England & Wales. Within these two regions, Wales produced 48.9% of all sea trout and 24.3% of all salmon caught by the rods in England & Wales, while the Northwest Region produced 17.4% of the sea trout rod catch and 35.6% of the salmon rod catch.

The annual mean catches for the rod fisheries given in Table 2.2.5 are the aggregated means over an 18-year period for some 30 rivers in the Welsh Region and 15 rivers in the Northwest of England. The temporal variability in the mean annual catches of salmon and sea trout for each year are given in Figure 2.2.2 for Wales (1976-2011) and Figure 2.2.3 for Northwest England (1974-2011).

Table 2.2.6 shows the mean annual rod catch of sea trout and salmon caught and their catch ratio for the 14 principal fisheries in the Northwest Region over the recent 5-year period 2006-2011. The aggregated mean annual catch gave a ratio of 1.31 salmon for each sea trout caught for all rivers. However, the salmon catch exceeded the sea trout catch on 9 rivers by margins ranging from 1.03 (Kent) to 5.00 salmon (Eden) while the ratio favoured sea trout on 5 rivers by margins of between

1.44 (Irt) and 3.13 ((Ellen) to each salmon caught. The three rivers with high catches of sea trout (Border Esk, Ribble and Lune) also had the highest catch of sea trout and exhibited catch ratios that were very similar at 1.09:1(Ribble and Border Esk) and 1: 1.04 (Lune).

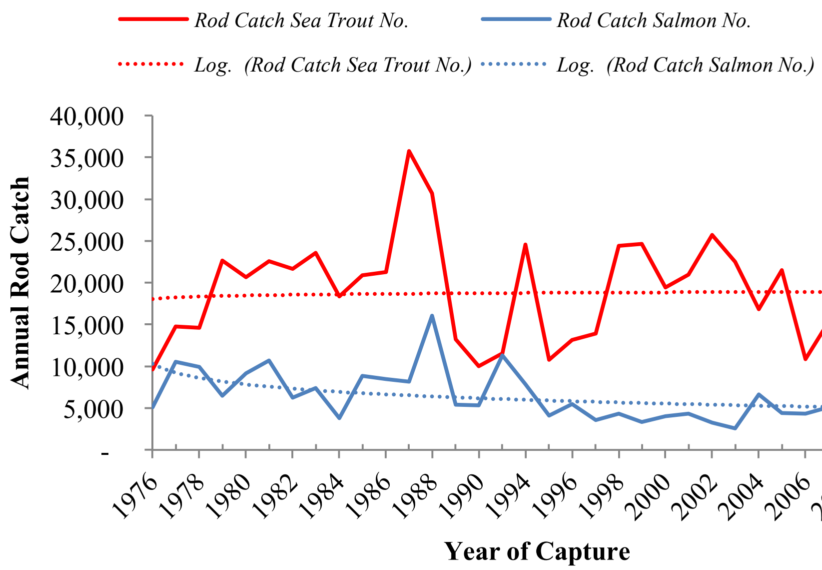


Figure 2.2.2 Annual Rod Catch of Sea Trout & Salmon in Welsh Region (1976-2011)

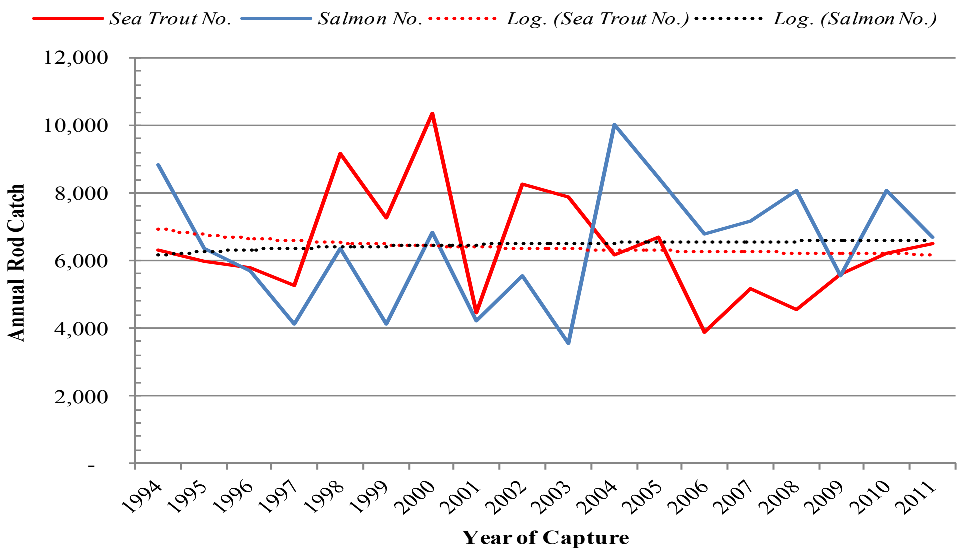


Figure 2.2.3 Annual Rod Catch of Sea Trout & Salmon in Northwest Region (1994-2011).

Table 2.2.6 Mean Annual Rod Catches and Catch Ratios for Sea Trout & Salmon for Principal Rivers in Northwest England (2006-2011).

River	5-Year Mean Annual Catch		Catch Ratio
	Sea Trout	Salmon	Sea Trout : Salmon
Calder	12	46	1 : 3.85
Derwent	236	1,156	1 : 4.90
Duddon	172	79	2.17 : 1
Eden	275	1,376	1 : 5.00
Ehen	353	383	1 : 1.08
Ellen	75	24	3.13 : 1
Border Esk	1,068	980	1.09 : 1
Cumbrian Esk	144	86	1.67 : 1
Irt	144	110	1.44 : 1
Kent	470	483	1 : 1.03
Leven	60	66	1 : 1.10
Lune	1,071	1,112	1 : 1.04
Ribble	1,250	1,149	1.09 : 1
Wyre	35	14	2.50 : 1

Welsh Region
Table 2.2.7 compares the rod catches of salmon and sea trout caught by anglers on the 30 principal river fisheries in Wales over the recent 6-year period 2006 – 2011.The aggregated mean catch ratio of sea trout to salmon was 3.1:1 for all 30 rivers. There were only 3 rivers where the ratio of sea trout caught exceeded salmon (Dee, Usk and Wye). The catch ratio for these rivers ranged from 1: 2.2 (Dee) to 1: 13.4 on the Wye. (The sea trout rod catch on the Dee has increased steadily over the last 20 years whereas the rod catch of salmon on the Wye has decreased dramatically).

On the remaining 27 Welsh rivers, the sea trout catch exceeded the salmon by a wide margin ranging from 1.8:1 (Ogwen) to a remarkable 132.0:1 (Dysynni). Within this group, the ratio of sea trout to salmon caught was: a) >1 to <5 on 8 rivers, b) >5 to <10 on 7 rivers, c) >10 to <25 on 6 rivers, d) >25 to <50 on 3 rivers and e) >50 on 3 rivers. The 4 rivers with the greatest catches of sea trout (>1,000) and salmon (>150) were the Clwyd, Dyfi, Teifi and Tywi. Their sea trout to salmon catch ratios ranged from 4.1 :1 to 11.1:1 (Dyfi). Their combined rod catches of 7,739 Sea Trout and 1,579 salmon represented 51.4% and 32.5% respectively of the total mean catch of 15,041 sea trout and 4,854 salmon for the 3 rivers. Subtraction of these catches from the total catch for the Region adjusts the ratio of sea trout to salmon caught from the remaining 26 rivers to 2.23:1.

2.2.3.2 Month of Capture
Any comparison of the relative importance of the sea trout based solely on the total number of fish caught by the end of the fishing season inevitably masks any differences in the expression of that relationship over the fishing season. These may result from differences in the pattern of timing and relative abundance of the annual runs of fish and in the river levels over the course of the year. These inter-annual differences determine the relative availability of fish to the anglers and their likelihood of capture at any time during the season. This may be particularly important on those rivers that still sustain reasonable numbers of early MSW spring salmon that run upstream from February to June (Dee, Usk & Wye) and/or a later running MSW 'autumn'.

Table 2.2.8 and Figure 2.2.4 compare the mean numbers and proportions of sea trout and salmon caught in each month of the annual rod-fishing season for the Solway, Northwest of England and

Welsh on the east coast of the Irish Sea. [Parallel data are not available for the Irish Republic.] It is relevant to note that the starting and finishing dates for the annual fishing season varied within and between regions over the period. Those rivers with important runs of spring salmon (e.g. Wye and Eden) usually started earlier than the other rivers in a region, while those with significant salmon runs in the autumn (e.g. Annan and Nith) finished later than other Solway rivers and other regions. For most rivers in England and Wales, the starting and finishing dates for salmon and sea trout fishing are identical on most rivers.

Table 2.2.7 Mean Annual Rod Catches and Catch Ratios for Sea Trout & Salmon in Principal Welsh Rivers (2006-2011).

River Name	5-Year Mean Catch		Catch Ratio
	Sea Trout	Salmon	Sea Trout : Salmon
Aeron	165	2	82.5 : 1
Afan	139	11	12.6 : 1
Cleddau	557	75	7.4 : 1
Clwyd	1,005	154	6.5 : 1
Conwy	484	205	2.3 : 1
Dee	330	732	1 : 2.2
Dwyfach	82	3	27.3 : 1
Dwyfawr	328	15	21.8 : 1
Dwyryd	47	10	4.7 : 1
Dyfi	1,768	159	11.1 : 1
Dysynni	396	3	132.0 : 1
Glaslyn	648	29	22.3 : 1
Gwendraeth	56	1	56. 0 : 1
Llyfni	154	3	51.3 : 1
Loughor	258	44	5.8 : 1
Mawddach	578	105	5.5 : 1
Neath	447	73	6.1 : 1
Nevern	566	33	17.5 : 1
Ogmore	418	67	6.2 : 1
Ogwen	185	98	1.8 : 1
Rheidol	321	32	10.0 : 1
Seiont	62	28	2.2 : 1
Taf	346	109	3.1 : 1
Taff	89	42	2.1 : 1
Tawe	250	166	1.5 : 1
Teifi	2,153	583	3.6 : 1
Tywi	2,813	683	4.1 : 1
Usk	130	819	1 : 6.3
Wye	42	566	1 : 13.4
Ystwyth	224	8	28.0 : 1
Mean	501.4	161.9	3.1 : 1

Table 2.2.8 Monthly Mean Numbers and Proportions of Sea Trout & Salmon Caught by Anglers for the Solway, Northwest England and Welsh Regions (1994-2011).

Species	Catch No / %	Month of Fishing Season									
		Feb	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**
SOLWAY REGION: Mean Rod Catch = 2,901 Sea Trout & 3,750 Salmon											
Sea Trout	No.	1	10	40	209	759	936	457	271	142	75
	% No	0.0	0.3	1.4	7.2	26.2	32.3	15.7	9.3	4.9	2.6
	Cum. %	0.0	0.3	1.7	8.9	35.1	67.4	83.1	92.4	97.3	100.0
Salmon	No.	7	17	29	47	85	219	485	934	1,235	691
	% No	0.2	0..5	0.8	1.3	2.3	5.8	12.9	24.9	32.9	18.4
	Cum. %	0.2	0.7	1.5	2.8	5.1	10.9	23.7	48.6	81.7	100.0
NORTHWEST ENGLAND: Mean Rod Catch = 6,289 Salmon & 6,358 Salmon											
Sea Trout	No.	Closed Season	13	37	201	834	1,591	1,493	1,285	834	Closed Season
	% No		0.2	0.6	3.2	13.3	25.3	23.7	20.4	13.3	
	Cum. %		0.2	0.8	4.0	17.3	42.6	66.3	86.8	100.0	
Salmon	No.		39	52	100	288	544	915	1,936	2,484	
	% No		0.6	0.8	1.6	4,5	8.6	14.4	30.5	39.0	
	Cum. %		0.6	1.4	3.0	7.5	16.1	30.5	60.9	100.0	
WELSH REGION: Mean Rod Catch = 17,319 Sea Trout & 4,294 Salmon											
Sea Trout	No.	Closed Season	41	297	760	2,699	4,871	4,373	3,141	1,138	Closed Season
	% No		0.2	1.7	4.4	15.6	28.1	25.2	18.1	6.6	
	Cum. %		0.2	1.9	6.3	21.9	50.0	75.2	93.3	100.0	
Salmon	No.		36	86	241	568	656	708	1,131	869	
	% No		0.8	2.0	5.6	13.2	15.3	16.5	26.3	20.2	
	Cum. %		0.8	2.8	8.4	21.6	36.9	53.4	79.7	100.0	

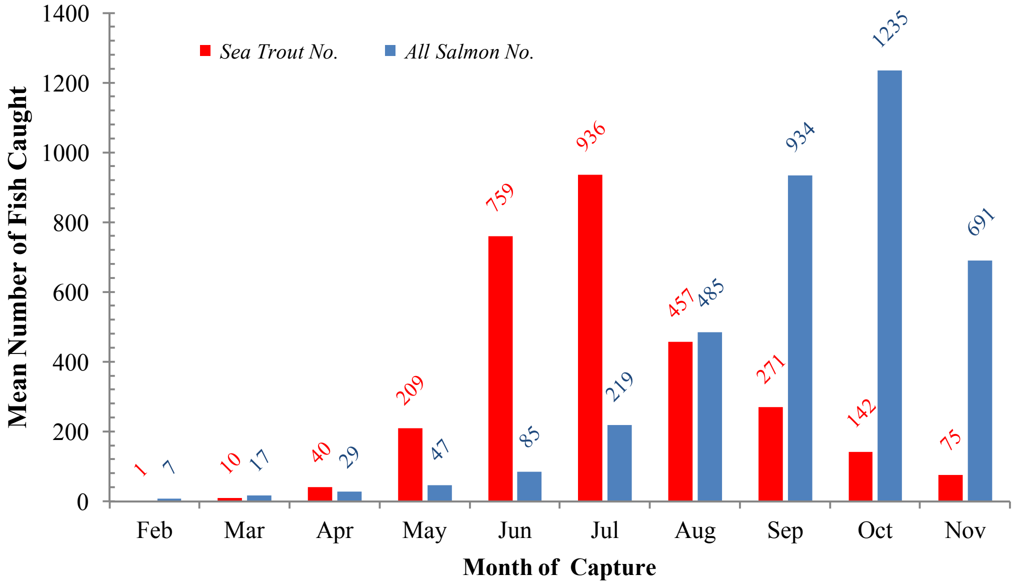
The general pattern of monthly rod catches of sea trout and salmon catches is broadly similar across the three regions, but there are notable differences in the relative proportions of fish caught in each month. In general, few salmon or sea trout are caught at the start of the season. Sea trout catches increase rapidly from late spring to reach a peak in the mid summer months and then decrease steadily to the end of the season. Salmon catches increase less rapidly from early spring to reach a peak in the late summer and autumn months. This late-season peak is most evident in the Solway Region where there is a strong run of 'autumn' salmon in October and November.

- **Solway Region** (Figure 2.2.4A). With aggregated mean annual catches for the eight rivers of 2,901 sea trout and 3,750 salmon, the sea trout catch exceeded the salmon catch from May to June and was roughly equal in August. However, the salmon catch exceeded the sea trout catch by a wide margin from September through to the end of the season in November. The relative proportion of the annual catch for the 7 months to August was 83.1% (2,412 fish) for sea trout compared with 23.7%.(882 fish) for salmon. The proportion of fish caught in the last three months of the season from September was 76% (2,860 fish) for salmon compared with only 16.6% (488 fish) for sea trout.

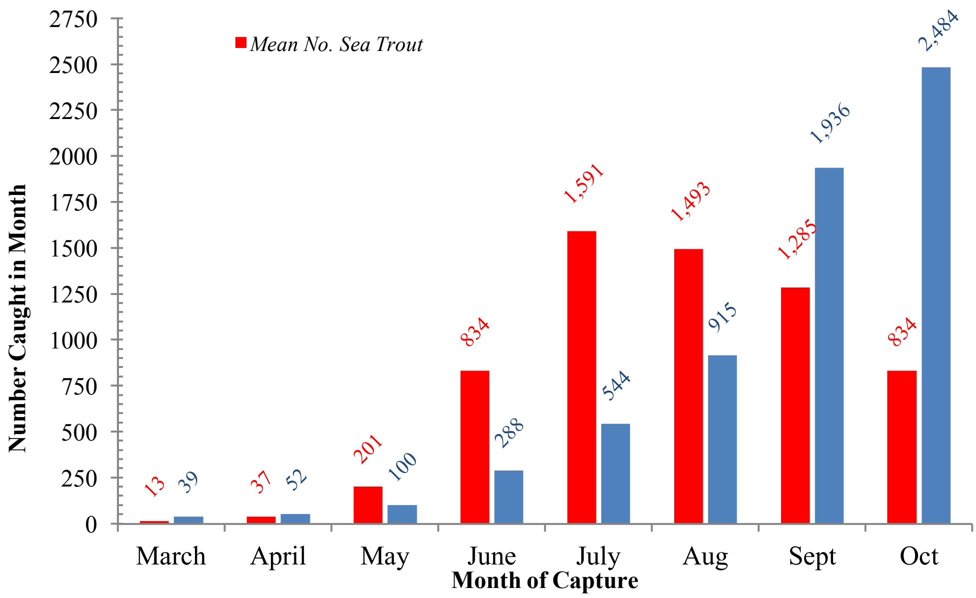
- **Northwest England** (Figure 2.2.4B). With similar annual mean rod catches 6,289 of sea and 6,358 salmon for the 15 rivers, the sea trout catch exceeded the salmon catch in the 5 months from May to August while the salmon catch was greater in September and October. The rod catch of salmon exceeded the sea trout catch in the last two months of the season from September to October.The relative proportion of the annual catch of sea trout for the 6 months to August was 66.3% (4,169 fish) compared with 30.5% (1,938 fish) for salmon. About 70% of the annual catch of salmon (4,402 fish) was caught in the last two months of the season compared with 34% for sea trout (2,119 fish).

- **Wales** (Figure 2.2.4C). The mean annual catches were 17,310 sea trout and 4,294 salmon for the 30 rivers. The sea trout catch was greater than the salmon catch in all 8 months of the season, often by the very large margins (>2,000 fish in June and September and >3000 fish in July and August). The proportion of the sea trout catch caught in the first 6 months of the season to August was 75% (13,041 fish) compared with 53% (2,658 fish) for salmon. The proportion of sea trout caught in the last two months of the season was 25% (4,479 fish) compared with 47% (2,000 fish) for salmon.

A. Solway



B. Northwest England.



C. Wales.

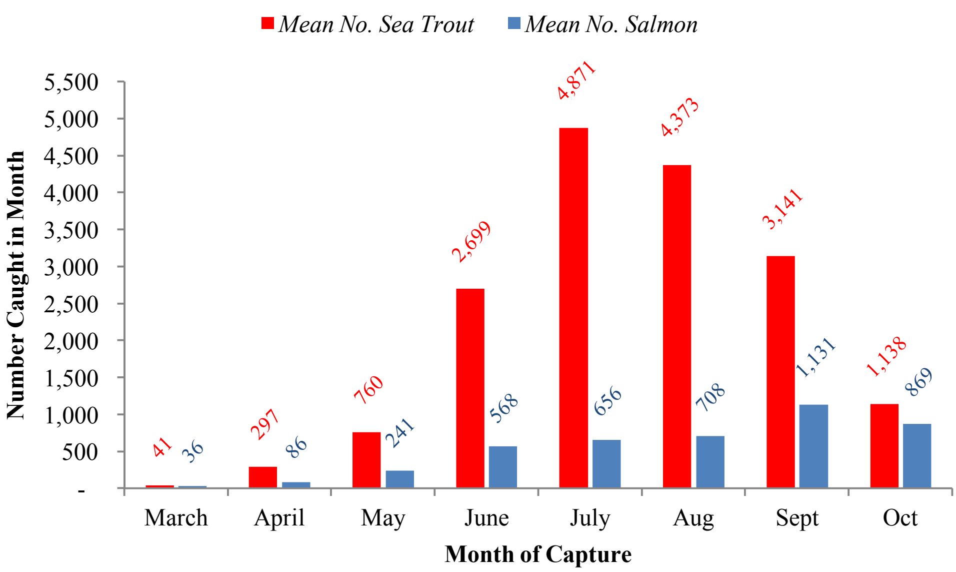


Figure 2.2.4 A-C Monthly Mean Rod Catch of Sea Trout & Salmon for the Solway, Northwest England & Welsh Regions (1994-2013).

2.2.3.3 Targeted Angling Effort

A clearer indication of the importance attached to sea trout by the angling community in England and Wales is available from an unpublished survey undertaken by the Environment Agency based on a questionnaire survey of anglers who purchased a rod licence to fish for salmon and sea trout during the 2006/2007 fishing season (Rob Evans – personal communication). The mandatory catch return completed by each angler at the end of the year provides information on fishing effort (days or part-days) and the number of sea trout and salmon caught over the season but it does not allow effort to be apportioned between the two species. The purpose of the study was to isolate that proportion of the fishing effort targeted solely at salmon in order to better calculate the exploitation rates used in setting Conservation Limits for salmon fisheries. Nevertheless, it also provides a unique insight into the relative importance of both salmon and sea trout in sustaining the recreational fisheries and, as such, provides an indirect measure of their separate contribution to the socio-economic value of the fisheries.

Separate questionnaire forms were distributed in November 2006 to some 22,000 anglers who obtained a rod fishing licence (all categories) for the 2006 fishing season. This asked each angler to cross-reference the details on catch and effort previously entered on their mandatory return and then complete the questionnaire by giving a further breakdown of their targeted fishing effort (on no more than the three rivers) that they had fished most frequently that year. This subsequently provided details of all fishing sessions during the day and at night and the a further breakdown of the daytime fishing effort targeted at: a) salmon-only, b) sea trout-only and c) both species combined on the same trip (Environment Agency, 2007).

Night fishing during the hours of darkness (dusk to dawn) entails fly-fishing during periods of low river levels. It can be highly productive at certain times of the year - especially during the peak months of the sea trout run from late spring to early autumn. In practice, night fishing is unproductive and unsafe when river flows are above 'normal summer level' for practical and safety reasons. Because it is very rare for anglers to catch a salmon during the hours of darkness, it safe to assume that all night fishing is targeted specifically at sea trout-only.The 'adjusted' return rate for the 8,537 questionnaires completed by anglers was 50-60%. Targeted effort data was obtained from 65 named rivers in all regions of England & Wales - including 15 in Northwest England and 23 in Wales. Table 2.63 summarises details of targeted fishing effort for Northwest England and for the other English Regions falling outside the Project Area.

Table 2.2.9 Summary of Targeted Rod-Fishing Effort for Sea Trout & Salmon in England & Wales (2006).

Targeted Angling Effort by Species and Time	Northwest England		Welsh Region		All EA Regions*	
	No. Trips	% Trips	No. Trips	% Trips	No. Trips	% Trips
Night Fishing - *Sea trout only*	4,007	19.8	11,881	36.6	22,042	27.6
Day Time - *Sea Trout only*	949	4.7	2,293	7.1	4,662	5.8
Daytime - *Salmon only*	11,288	55.7	9,144	28.1	30,679	38.4
Day time - *Both species*	4,018	19.8	9,167	28.2	22,584	28.2
Total Effort - Day + Night	**20,262**	**100**	**32,485**	**100.0**	**79,967**	100.0

**Includes a further 27 rivers in the Southwest, Southern, Northeast and Midland Regions of England 0utside the Project Area.*

The total number and proportion of all fishing trips in England & Wales targeted directly at sea trout-only was 22,042 at night (27.6 %) and 4,662 by day (5,8%). The combined day and night fishing effort targeted at sea trout-only was therefore 26,704 (33.4%) of all fishing trips in England & Wales. By contrast, fishing for salmon-only attracted 30,679 of all trips (38.4%), while day fishing for both species on the same occasion attracted 22,584 (28.2%) of all trips.

Within the Project Area, there were notable differences in the targeted fishing effort of anglers in the Northwest England and in the Welsh Regions. A greater proportion of the total effort in Wales was targeted at night fishing for sea trout (36.6%) compared with 19.8% in Northwest England. Welsh anglers also devoted more effort to sea trout fishing in daylight (7.1%) than in the Northwest (4.7%). The higher profile and popularity of sea trout fishing in Wales is also apparent from the level of effort targeted at daylight fishing for both sea trout and salmon on the same visit; with 28.2% of

Welsh anglers fishing for both species compared with 19.8% in Northwest England. By contrast, 55.7 % of anglers in the Northwest fished by day for salmon-only compared with 28.1% in Wales. After excluding the daytime fishing effort targeted at both species, anglers in Wales fished exclusively for sea trout on 14,174 trips compared with 9,144 trips targeted at salmon only while anglers in the Northwest fished exclusively for sea trout on just 4,956 trips compared with 11,288 trips targeted at salmon-only. Consequently, 69.1% of all fishing trips for either salmon-only or sea trout-only in Wales were targeted at sea trout-only compared with 31% in Northwest England.

The information in Table 2.2.9 represents the aggregated mean values for 38 separate rivers within the Project Area. As such, it incorporates a wide range of temporal and spatial variability in the importance of sea trout and salmon between different rivers. It is impracticable here to describe the broad nature and extent of this variability other than in very general terms based on the following arbitrary grouping of rivers into 5 general categories with a named river as an example of each Group. Table 2.2.10 provides a breakdown of effort for the named rivers listed in each group. [It is inevitable that there is a major degree of overlap between the rivers in each arbitrary grouping.]

- **Group 1.** Rivers with good salmon stocks but very few sea trout. Virtually all fishing occurs in daylight and is targeted at salmon only: with very little fishing for sea trout by day or night unless combined with salmon during the day (e.g. Wye).

- **Group 2.** Rivers with good salmon stocks and only moderate runs of sea trout. There is a modest increase in fishing for sea trout at night and by day but main effort is targeted at salmon (e.g. Eden).

- **Group 3.** Rivers with good stocks of both sea trout and salmon. They show increased fishing for sea trout at night and in daylight. Similar effort targeted at salmon-only and sea trout-only and in fishing for both species in daylight at the same time (e.g. Border Esk).

- **Group 4.** Rivers with moderate runs of salmon and good runs of sea trout. They show a high level of night fishing effort and greater proportion of day effort targeted at sea trout-only and a much reduced effort targeted at salmon-only (e.g. Dyfi).

- **Group 5.** Generally, the shorter rivers with moderate runs of sea trout but only a small run of salmon appearing in the autumn. They have a high night fishing effort for sea trout with only marginal daytime effort targeted principally at sea trout. There is little direct fishing for salmon-only (e.g. Rheidol).

Table 2.2.10 Summary of Targeted Fishing Effort for Sea Trout and Salmon in Example Rivers.

Example	Total No Trips in Season	Sea Trout - Only				Salmon - Only		Combined Species	
		Night		Day		Day		Day	
		Trips	%	Trips	%	Trips	%	No	%
Group 1. (Wye)	2,672	114	4.3	24	0.9	2,097	78.5	437	16.4
Group 2. (Eden)	4,201	520	12.4	167	4.0	2,953	70.3	561	13.4
Group 3. (B. Esk)	2,517	625	24.8	210	8.3	897	35.6	785	31.2
Group 4. (Dyfi)	502	387	77.1	48	9.6	45	9.0	22	4.4
Group 5. (Rheidol)	1,220	1,006	82.5	15	1.2	4	0.3	195	16.0

The assumption that the daytime fishing effort targeted at both species can be split equally (i.e. 50:50) between salmon and sea trout may or may not be valid for all rivers at all times over the fishing season. On those rivers not noted for their salmon stocks, it is probable that a high proportion of the anglers who reported fishing for both species at the same time were in fact fishing for sea trout in the 'hope' of catching the larger and more prestigious salmon (but not expecting to do so) throughout much of the season. On such occasions, any salmon caught would represent a lucky by-catch and 'bonus' while fishing for sea trout as the principal attraction and main target species. However, if it can be assumed that the reported daytime fishing effort targeted at both species can be divided equally between sea trout and salmon over season, the allocation of all effort targeted at sea trout-only can be recalculated as 34.4% for all rivers in the Northwest Region and 57.8% for all rivers in the Welsh Region.

2.2.3.4 Importance of Minor Rivers

The relative importance of sea trout far exceeds that of salmon in 'minor rivers' than is apparent from the aggregated catches for a given area or region. These minor rivers are essentially the shorter rivers with small catchment areas and small runs of fish as a consequence of their size. They have runs composed predominantly of sea trout and only very small numbers of salmon, almost exclusively the smaller 1SW grilse stock component entering the river in the last few weeks of the normal fishing season.

Total Catch

The importance of sea trout in sustaining the recreational fisheries on minor rivers is illustrated by a comparison of the reported monthly rod catch of sea trout and salmon for four small rivers entering Cardigan Bay in West Wales. Their main river lengths are <40 km and much of the available fishing is controlled by local angling clubs. Table 2.2.11 shows the mean monthly rod catch of sea trout and salmon reported for each river over the 12-year period 2001 – 2012.

The maximum and minimum mean annual catch of sea trout ranged from 275 (Aeron) to 662 (Nevern) and compared with a far lower salmon catch of 4 (Aeron) to 37 (Nevern). The aggregated mean annual catch for the 4 rivers was 456 sea trout and 18 salmon. All four rivers exhibited a similar monthly pattern of catches, with numbers increasing steadily from April and peaking in July and August before declining to the end of the season (17th October). Although an occasional salmon was recorded for the each month on the Dysynni, few fish were recorded in most months of the year from all 4 rivers. No salmon were caught in the Aeron until August and the Dysynni produced only a single salmon in 3 of the 7 months of the season. A rod catch of >10 salmon in any month was only achieved on the Rheidol (October)) and Nevern (September/October).

Table 2.2.11 Monthly Mean Rod Catch of Sea Trout and Salmon from Minor Rivers in West Wales (2001-2012).

Species	River	Month Caught							Total Catch
		April	May	June	July	August	Sept	Oct	
Sea Trout	Aeron	3	11	50	103	69	30	10	275
	Dysynni	18	30	48	94	94	73	14	371
	Rheidol	3	7	67	144	165	96	34	515
	Nevern	1	23	137	218	171	87	24	662
	Mean	**6**	**18**	**75**	**140**	**125**	**72**	**20**	456
Salmon	Aeron	0	0	0	0	1	1	2	4
	Dysynni	0	0	1	1	0	0	1	3
	Rheidol	1	1	2	3	3	7	11	29
	Nevern	0	0	2	5	13	11	7	37
	Mean	**0.2**	**0.4**	**1.1**	**2.2**	**4.2**	**5.0**	**5.1**	18.2

Pattern of Catches

Figure 2.2.5 gives the combined mean monthly pattern of rod catches for these four rivers. It is evident that the rod fishery on these rivers is almost entirely, if not wholly, dependent on the availability of sea trout in every month of the fishing season and that, in the absence of sea trout, the recreational fishery would cease to exist on these rivers.

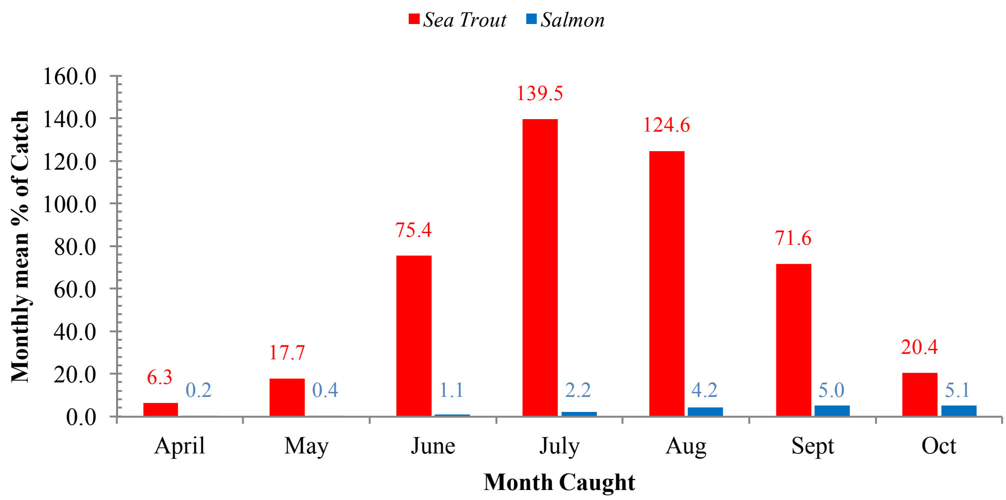


Figure 2.2.5 Aggregated Monthly % Mean Rod Catch of Sea Trout and Salmon from 4 Minor Rivers in West Wales (2001-2012).

Fishing Effort

Table 2.2.12 gives a summary of the mean total fishing effort (day or part day trips), reported annual catch of sea trout and salmon and relative performance expressed as the number of fishing trips required to catch one salmon or sea trout on each of 10 'minor' rivers in the Welsh Region. The rivers extend around the Welsh coastline from the Afan in South Wales to the Lyfni in Northwest Wales. Mean values are averages for the 5-year period 2007-2011.

Table 2.2.12 Mean Fishing Effort, Rod Catch and Angler Success from 10 'Minor Rivers' in Wales (2007-2011).

Welsh River	Total No. Trips in Season	Mean No. Trips per Return	Mean No. Fish Recorded in Season			Mean No. Days fishing Required to catch one fish		
			Sea Trout	Salmon	Combined*	Combined	Sea Trout	Salmon
Afan	482	13.0	127	9	136	3.5	3.8	54.8
Gwendraeth	193	19.8	23	1	24	8.0	8.4	160.7
Nevern	981	11.2	466	23	489	2.0	2.1	43.4
Aeron	448	14.6	157	2	158	2.8	2.9	280.3
Ystwyth	338	11.3	212	8	219	1.5	1.6	43.4
Rheidol	972	14.3	278	29	306	3.2	3.5	34.0
Dysynni	671	9.5	322	3	325	2.1	2.1	239.6
Glaslyn	782	12.3	547	26	574	1.4	1.4	29.6
Dwyfor	622	13.0	251	12	263	2.4	2.5	51.8
Llyfni	263	10.7	103	2	105	2.5	2.6	109.8
Mean	**575**	**13.0**	**249**	**11**	**260**	**2.9**	**2.3**	**50.4**

* *'Combined' = any salmonid of either species.*

The mean number of annual fishing trips made for all rivers was 579 for a catch of 249 sea trout and 11 salmon and the mean number of days required to catch any one salmonid (either a sea trout or a salmon) was 2.9, and favoured sea trout on all rivers. However, there was an major disparity in the average level of angling success between the two species. The mean number of days required to catch one sea trout was 2.3 compared with 50.4 days to catch one salmon. Since the average number of fishing trips made over one season by each angler was 13, it would require four fishing trips to catch one sea trout each year compared with at least four full seasons of fishing at the same frequency before catching a single salmon!

The aggregated total number of fishing trips made each year on these 'minor rivers' represented 8.5% of the annual total of 68,000 trips made each year on all Welsh rivers over the same period. The aggregated total of 2,490 sea trout and 110 salmon caught each year represented 3.3% of the mean total of 75,674 sea trout and 2.2% of the total of 4,872 salmon caught over the same 5-year period for the entire Welsh Region.

The importance of these minor rivers to the Welsh Region is not judged by their contribution to the total catch of fish within the region, but by their collective contribution to the social and economic benefits of the region in general and to the many small, often remote, rural communities within their separate catchments. In this respect, it is relevant to note that the total annual fishing effort on these 10 rivers of 5,750 trips was greater than on each of the 15 larger, better known and more prestigious, major rivers, including the Dyfi, Mawddach, Conwy and Clwyd, and was only exceeded on the Usk, Wye, Dee, Teifi and Tywi. It is also relevant to note that it is the sea trout and not the salmon that sustains and maintains that collective fishing effort throughout the entire season for all ten minor rivers and that it is this that is of paramount importance in providing social and economic benefits derived by many communities throughout Wales.

2.3 Review of Past Stocking Programmes with Sea Trout & Brown Trout

2.3.1 Introduction

This section provides background information on the nature and extent of stocking with juvenile and adult stages of the migratory and non-migratory forms of *Salmo trutta* L. that were artificially reared in hatcheries and culture units to various stages of development prior to their introduction into rivers and lakes within the project area. It supports the genetics and stock discrimination studies in Tasks 4 and 5 of the Celtic Sea Trout Project. It also provides a starting point to investigate any anomalies and inconsistencies that may arise in attributing individual adult sea trout to a particular region or river system when comparing their DNA profiles with the baseline genetic profiles for the different populations of juvenile sea trout and brown from rivers bordering the Irish Sea.

The inclusion of non-migratory brown trout in this review recognises the central fact that sea trout and brown trout are expressions of two different forms of the same single species complex *Salmo trutta* L. Both forms can freely interbreed and their offspring may produce either migratory sea trout or non-migratory brown trout depending on the prevailing environmental conditions they experience in freshwater as juveniles.

2.3.2 Genetic Concerns

A better understanding of evolutionary theory in relation to the sea trout/brown trout species complex (Thorpe, 1990), combined with the rapid advances in genetic technology and its increased application as a fisheries management tool over the last 40 years, have confirmed the existences of different stocks of sea trout and brown trout as postulated by Day (1887), Regan (1911), Nall (1930) on the basis of differences in their morphology, anatomy and behaviour.

Ferguson (2006) provided a seminal review of the genetics of sea trout with particular reference to Britain and Ireland and presented the now powerful evidence for the existence of genetically distinct and separate stocks and sub-stocks of migratory and non-migratory trout in an ever-increasing number of rivers and lakes throughout the UK and Ireland. These differences, variously expressed as differences between adult stocks in their longevity, life-history, run-timing, growth rate and marine migrations, had evolved in response to different environmental selection pressures following their post-glacial colonisation from the sea so that they were genetically adapted to survive and thrive in their local environments. He highlighted the fundamental importance of preserving the genetic integrity and diversity of local stocks by avoiding any form of stocking that entailed the introduction of non-compatible 'alien genes' from other rivers and regions with different genetic characteristics that may interbreed with native stocks and so dilute their subsequent fitness and ability to survive and thrive in their original environment

2.3.3 Stocking Records

All proposed stocking with salmon, sea trout and brown trout requires formal consent from the relevant regulatory agencies in Scotland, England, Wales and the Irish Republic. This statutory requirement has existed in various forms for several decades in most regions for salmon and sea trout, but it is only in recent years that it has effectively included brown trout (see Section 2.4.5).

Relevant background information on past stocking programmes in individual catchments is sparse for much of the historical record. It was only from 1998 for England & Wales and from 2008 for Scotland that details on the nature, extent and location of stocking programmes became retrievable from a central database. In Ireland, records exist of all stocking with salmonids from state culture units for several decades, but Marine Science Scotland has no central records of any stocking with sea trout and salmon previously approved by the Salmon Fishery District Boards and no records of brown trout stocking prior to 2008. Although details of earlier site-specific stocking programmes may have been retained in separate databases in some regional offices for some of the preceding years, any earlier paper records before the 1980s are unlikely to have archived and were probably destroyed. Consequently, almost much the information summarised here was provided by local management sources within the CSTP area and much of it is anecdotal for the earlier years.

2.3.4 Background

General Perspective

The persuasive views of influential authors in the later part of the last century (Ashworth & Ashworth, 1853; Francis,1865; Buckland, 1867, Day, 1867 and Armistead, 1895) established a popular view that artificial propagation was 'panacea to cure all ills affecting our salmon stocks'. Consequently, the long history of stocking in the UK and Ireland became driven almost entirely by the traditional priority given to protecting, maintaining and improving wild salmon stocks. Until the about the late 1960s, this was almost exclusively to produce more fish for anglers to catch, but was later expanded to include other purposes under the broad headings of 'restoration', 'mitigation' and 'rehabilitation'.

Harris (1978) reviewed the long history of artificial propagation of salmon in the UK and Ireland in response to widespread concern by fishery management agencies that the traditional and costly practice of artificially rearing fish to various stages of juvenile development for release into the wild over the last century had not been shown to produce any tangible benefit. This included a summary of the results of a questionnaire circulated in 1970 to all significant organisations operating salmon hatcheries in the UK and Ireland over the preceding 5-year period (1965-1969).

At that time, some 40 organisations operated one or more hatcheries and/or culture units rearing fish for subsequent release as eyed eggs, unfed fry, early feeding fry, parr or smolts from approximately 15 million eggs incubated in hatcheries each year. More than 20 organisations rearing fish obtained their eggs to support rearing programmes from rivers other than those where the progeny were to be released and the translocation of eggs from one region to another was commonplace. Some Scottish District Fishery Boards generated a substantial income from the sale of eggs to other areas in England and Wales. Eggs were also imported into the UK and Ireland from Greenland, Iceland, Sweden and Canada to support local stocking programmes and improve the 'vigour' of native stocks, both in general and to improve the more important and valuable early runs MSW 'spring' salmon in particular (e.g. the Wye and Conwy).

A summary of the annual salmon stocking programmes for England & Wales over the 5-year period from 1965-1969 is given in Table 2.3.1 to illustrate the overall commitment to artificial propagation and river restocking at that time.

Table 2.3.1 Numbers of Juvenile Salmon Reared for Stocking into Rivers in Scotland England, Wales & Ireland (1965 - 1969). From Harris (1978).

Stocking Stage	5-year mean	Range (min – max)
Ova (eyed)	3,774, 000	2,843,000 - 4,959,000
Unfed fry	5,526,000	4,500,000 - 6,071,000
Fed fry	1,803,000	1,597,000 - 1,930,000
Parr (0+ & 1+)	62,586	45,134 - 71,493
Smolts (1+ & 2+)	235,512	216,979 - 246,071

Unfortunately, in the present context, this early review did not include any information on the nature and extent of any stocking with sea trout in the UK and Ireland. Nevertheless, although the rearing of sea trout was not undertaken to the same extent as salmon, it is known to have occurred in some parts of Wales and Northwest England during the 1960s and early 1970s (see Section 2.4.6). The review also noted the emerging scientific evidence from early pioneer studies regarding the existence of genetic differences between salmon stocks within and between regions. Whilst alluding to the potential importance of maintaining the genetic integrity and genetic diversity of individual stocks as a general principle in future stocking programmes, this subject area rapidly became a major consideration by the regulatory agencies (see Section 2.4.5).

Sea Trout Stocking

Despite the perceived benefits of salmon stocking in improving salmon fisheries, stocking with sea trout never became a standard management practice at any time over the period of the record. Four possible reasons may explain this apparent contradiction:

1) The substantially greater importance and value attached to improving salmon fisheries and the historical influence of owners and tenants on the larger and more valuable salmon fisheries within a region that gave little or no priority in allocating hatchery space to the less prestigious sea trout.

2) The common perception that any stocking with sea trout was a waste of time and effort was based on two general assumptions expressed by angling authors that:

   a) sea trout, unlike salmon, did not migrate for any great distance in the sea but were “a child of the tides” (Stuart, 1917) that only fed in the estuaries and near-coastal waters in the vicinity of their parent rivers where they were more vulnerable to marine predators and illegal fishing.
   b) on returning from the sea, a large proportion of sea trout strayed into different rivers to spawn other than their natal river of origin. Consequently, the intended benefits of stocking were lost to other rivers in an area making the practice less worthwhile.

3) Difficulties in rearing sea trout reported by stocking agencies throughout Europe (Mills, 1983) that were caused by disease, mortality in broodstock retained for egg stripping, low fertilisation efficiency of eggs and poor survival to later stages of development.

4) Evidence from experimental feeding studies suggesting that artificial rearing to the later stages of juvenile development was likely to produce brown trout instead of sea trout. Jonsson (1982) found that offspring of the same pair of trout became resident or migratory according to the amount of food available. Later work by Morgan & Paveley (1993), based on rearing eggs from sea trout of known migratory habit under different feeding regimes of “normal rations” and “short rations,” showed that the smolt transformation and ability of two-year old fish to survive in sea water was suppressed under the normal feeding regimes used for rearing juvenile salmon in culture units. Both studies indicated that conventional artificial propagation (at least to the smolt stage) reinforced the non-migratory brown trout habit and the view that sea trout stocking was a waste of time, effort and resources.

Brown Trout Stocking

Any stocking with brown trout until the mid-1960s appears to have been local and restricted to the release of small numbers of fish of takeable (or near takeable) size into small lakes and ponds by private owners to improve the quality of the fishing. Many of these waters were isolated from streams within a catchment and the released fish were almost certainly obtained from private fish farms in the commercial sector. There were also a small number of reservoirs where stocking occurred on a regular basis, notably those controlled by private water companies or linked to electricity generating schemes. These were stocked on a regular basis with fish reared in their own on-site culture units using eggs obtained from commercial fish farms or with various sizes of trout purchased directly from such farms. River stocking with brown trout was infrequent.

The most significant change in the nature and extent of brown trout stocking is apparent from the late 1960s when several of the large water supply reservoir constructed around that period were developed as recreational trout fisheries for public use. These were heavily stocked on a regular basis over the season with takeable (or near-takeable) brown trout (and rainbow trout) of c.25 cm in length or larger. These fish were supplied from commercial fish farms and either stocked directly into the reservoirs or reared-on to the required release size in separate culture units attached to each reservoir, with subsequent annual stocking using fish produced from retained broodstock.

The demand for stillwater trout fishing increased dramatically during 1970s when a statutory duty to develop ‘water based recreation’ (including angling) was imposed on the 10 Water Authorities established in 1974 that assumed responsibility for the many water supply reservoirs previously controlled by various water boards and other undertakings. Many reservoirs were subsequently developed as high-quality ‘put-and-take’ trout fisheries and the demand from private sector fish farms for takeable fish increased dramatically. Some of the water authorities who inherited salmon culture units adapted their rearing programmes to produce brown trout and established their own broodstock with eggs supplied initially from private fish farms. Some of the commercial units that had been rearing trout for the table-market for almost 100 years then increased their output to meet the demand for trout for stocking recreational fisheries from line-bred broodstock that had been domesticated for up to 30 generations.

These developments in England & Wales were not paralleled in Scotland or Ireland to the same extent – primarily because of the widespread availability of better quality wild brown trout fishing in rivers and lakes. Nevertheless, a growing number of intensively stocked put-and-take trout fisheries gradually appeared during the 1970s and 1980s at strategic locations (usually near high-density centres of population or tourist destinations).

Strategic Reviews

Periodic reviews of stocking strategies, policies and programmes have been undertaken by state agencies at various times over the years in response to the ever present concerns regarding: a) the high cost of maintaining fish culture units and routine programmes of stocking, b) the lack of any evidence of tangible benefit in increasing wild stocks, and c) the increasing pressure on limited budgets to support their other fishery management activities as fisheries expenditure came under increasing scrutiny in terms of delivering value-for-money.

Cragg-Hine (1993) reported that the annual cost of rearing some 3-4 million juvenile stages of salmon and sea trout for stocking in England & Wales was approximately £732,000 in 1991. This was equivalent to 10% of all expenditure available for the management of migratory fisheries. Milner (1993), using extrapolated survival rates and estimated production costs for different life stages of salmon, calculated that the costs of stocking to yield one returning adult were £186 from fry stocking, £167 from 0+ parr and £86 from 1+ smolts. These amounts increased by a factor of x10 for the cost of each extra fish caught by anglers.

In order to reduce costs most agencies adopted a general presumption against on any form of improvement or supplementary stocking where the purpose was to maintain and improve the number of fish caught (and killed) by anglers from the early 1990s. In England & Wales, this led to the prioritisation of future culture operations under three general-purpose headings as:

1) **Mitigation**: Stocking to replace the losses in natural production because of an activity or development, usually for the wider benefit of society, which cannot be prevented. This is usually linked to a legal or statutory obligation to operate fishery protection schemes to replace a loss of smolt production associated with the construction of reservoir impoundment and tidal barrages affecting natural recruitment.

2) **Restoration**: Stocking undertaken where a factor limiting the recovery of improvement of stocks has been removed or reduced. It includes the rehabilitation of migratory fish stocks following water quality improvement, habitat improvement or fish pass construction and is typically part of a wider fishery improvement programme. It also includes replacement of fish following pollution related fish kill incidents, land drainage operations and other developments and is usually funded by the developer.

3) **Enhancement**: Stocking under taken to supplement existing stocks where natural production is less than the water body could potentially sustain. It includes stocking above

natural barriers. Its purpose is to maintain and improve existing stocks and it is essentially of short duration.

Subsequent reviews of the ineffectiveness and high cost of salmon stocking programmes (e.g. Harris 1994) then triggered the progressive closure or 'moth-balling' by state agencies of many of the culture units inherited from their predecessor organisations as routine improvement stocking went out of fashion. Their role in maintaining, improving and developing fisheries was steadily replaced by an extensive commitment to structured programmes of 'habitat improvement' for addressing the negative impact of environmental factors affecting the survival, production and yield in the freshwater environment. This was seen as a better, effective and more enduring alternative to artificial propagation This cost-effective and 'holistic' approach was particularly attractive to state-funded agencies as it also helped their respective governments to achieve greater compliance with their legal obligations under the EU Water Framework Directive for restoring natural watercourses to 'good ecological status' by 2027. There was also a greater commitment to the promotion of catch and-release as an effective means of increasing spawning success by reducing the numbers of fish 'harvested' (= killed) by anglers and to the buy-out and closure of commercial net fisheries in some areas as a simple and direct means of increasing the abundance of adult salmonids entering rivers.

2.3.5 Regulatory Controls

General

All stocking with salmonid species in the UK and Ireland has been subject to some form of statutory control by the relevant management agencies under the provisions of secondary legislation for at least 60 years in all regions. However, while the statutory regulations and subjugate policies relating to their implementation have differed widely within and between different jurisdictions over the years they have become increasingly robust by the inclusion of measures to conserve the genetic integrity and genetic diversity of wild populations and to prevent the introduction of fish diseases and parasites between regions.

While the importance of maintaining genetic integrity was broadly acknowledged from the 1970s and a 'precautionary approach' generally adopted for regulating stocking to exclude fish of non-local origin, it has now become central to the requirements to be fulfilled before a formal stocking consent will be granted. This stems in large part from the United Nations 'Earth Summit' in Rio de Janeiro in 2001 and the subsequent 'Convention on Biological Diversity' which required home governments to take active steps to halt biodiversity loss. This was defined as the loss of species, ecosystem and genetic diversity of our natural flora and fauna. Its subsequent implementation required a closer working relationship with those other government agencies responsible for wildlife conservation within the regions. This then led to robust measures to protect genetic biodiversity as an over-arching imperative in the issue of a stocking consent at sites designated as 'Special Areas of Conservation' (SAC sites) and 'Sites of Special Scientific Interest' (SSSIs) under the provisions of the EU Habitats Directive. It also became a more general principal applied to stocking in other non-designated natural waters.

Consequently, most agencies soon made it a mandatory requirement to use only local eggs from the same river where stocking was intended or, if unavailable, from the nearest available local source. Controls were also introduced that stipulated the number of male and female fish to be used when fertilising eggs from broodstock retained to support future culture operations on order to prevent the negative consequences of 'genetic drift', inbreeding' and 'sibling mating' during subsequent spawning in the wild. The local regulations relating to the issue of formal stocking consent for salmonid fish are outlined below for each region.

Scotland (Solway District)

Any proposed stocking with salmon or sea trout has required the formal consent from the local District Salmon Fishery Board and will stipulate the use of eggs from native broodstock obtained from the river to be stocked. The remit of the District Boards to regulate the release of reared fish salmon and sea trout into the wild operated over several decades but this power did not include control over stocking with brown trout. This was amended in 2008 and any proposal to introduce brown trout now requires the consent of Marine Science Scotland after consultation with the local District Board. Formal approval from Scottish Natural Heritage is also required for any stocking in a designated conservation site.

From 2013, applicants for a stocking consent must now provide details on: a) the origin of the fish from which the stock will be taken; b) the stocking location and life-stage of the released fish; c) evidence of the need for stocking, showing that the carrying capacity of the receiving water is sub-optimal and an evaluation of any potential negative impacts on wild fish populations in the receiving waters; d) an evidence-based assessment of the anticipated outcome of the stocking programme; e) a statement of how the benefits of the stocking will be monitored; f) evidence that the removal of broodstock from the wild will not be detrimental to the donor stock and g) a subsequent report on the outcome of the stocking programme.

There is now a general presumption against a) stocking with sea trout and salmon where the aim is to supplement existing stocks in situations where natural spawning and regeneration is believed to be below the natural optimum for reasons that are unknown and b) where there is an intention to increase stocks above the existing natural level.

England & Wales

Under S30 of the Salmon & Freshwater Fisheries Act 1975, any proposed stocking with migratory and non-migratory salmonids into inland waters in England & Wales must be subject to a formal consent issued by the statutory fishery agency. From 1976, the basic information required in support of every application included: a) the species to be stocked, b) the proposed stocking date (s), c) the proposed stocking location, d) the number of each life-stage to be stocked and e) the source of supply and origin of the fish. However, this basic requirement has since been strengthened over the intervening years and applicants for stocking consent must now state whether the stocking site is within a designated conservation area (SSSI/SAC) and (from 2009) if the supply source was registered with Cefas under the animal health regulations.

Applications for stocking with brown trout must now state whether the fish are either diploid or triploid and (for salmonids) whether the supply source had been subject to a health check in the preceding 12 months. An applicant for stocking in a designated conservation site will also require a formal assent from the statutory conservation Agencies (now Natural England or Natural Resources Wales). From 2011, applications for stocking to maintain or increase catches should be supported by a Salmonid Stocking Plan stating the overall objectives of the stocking. In 2009, the Environment Agency stated its intention to prohibit the release of any domesticated farm-strain fertile brown trout into all rivers from 2015. Any subsequent stocking into non-enclosed waters with brown trout after that date must be with sterile triploid fish. The Agency's criteria for regulating stocking programmes to safeguard future genetic integrity and diversity were updated by the Environment agency in 2011 to incorporate best practise (Environment Agency, 2013).

Republic of Ireland

All movements of salmonids in the Republic have been closely regulated since 1959 and formal consent is required from Inland Fisheries Ireland (IFI) to introduce fish into inland waters within its remit. An application to stock brown trout is considered in relation to the status of the proposed stocking location and any previous stocking history. There is a requirement for fish health clearance prior to stocking of any fish. An application to stock with salmon would be made under the same arrangement.

IFI policy is that stocking of hatchery reared fish is regarded as the exception and restoring or optimising habitat is the preferred management policy approach.

2.3.6 Regional Summaries

Scottish Solway District

There is no extensive history of hatchery operations on the Cree, Fleet, Luce and Urr. A salmon hatchery operated by an angling club on the Dee ceased production in the early 1990s. Since then, several small rearing units have since been established on the Cree (2011), Luce (early 2000s) Dee (2006) Urr (2008) and Bladnoch. These units are managed by local angling clubs and/or the local District Salmon Fishery Boards under the technical supervision of the Galloway Fisheries Trust. The main reason for restocking in the earlier years on the Luce, Bladnoch, Cree and Fleet was to repair damage to the fisheries following severe acidification caused by forestry. In the last three catchments, salmonid stocks had declined dramatically in the headwater tributaries, with some becoming fishless. All units produced salmon with the exception of the Bladnoch unit that also produced sea trout for stocking into the Fleet. This unit has also produced sea trout for release into the Piltanton Burn in the Luce catchment to compensate for pollution damage. Eggs used in these hatchery programmes were sourced from local broodstock: although it is reported that some 16,000 sea trout eggs were imported from Sweden during the 1980s for stocking into the main stem of the Fleet.

The only rivers with any programme of regular sea trout stocking over any significant length of time in the Solway District are the Fleet and Nith. From 1993-2009 annual released of 3,000-39,000 early feeding fry were stocked into the Fleet in 11 of the 17 years to mitigate the negative impact of acidification caused by extensive forestry planting within the catchment. These fish were reared in the Bladnoch using eggs from wild Fleet broodstock.

There has been a history of hatchery propagation within the Nith catchment for many years, when early attempts to increase stocks were focused on salmon by angling associations. In the early 1990s, the Nith District Salmon Fishery Board assumed control of the hatchery and reared both salmon and sea trout. It produced 300,000 fry of which 50,000 were sea trout in the early 1990s; with production peaking at 1,200,000 salmon fry and 300,000 sea trout fry in 2010. This culture unit now rears some 140,000 fry for mitigation purposes only.

The Annan District Fishery Board operated a salmon hatchery capable of incubation of some 250,000 eggs a year between 2006 and 20011 until its closure in 2012. Small numbers of sea trout parr were produced from 1994-97 by a local training College from native broodstock. Between 2006 and 2011 the Annan Board operated a salmon hatchery unit incubating some 250,000 eyed ova a year. This ceased in 2012. An attempt was made to rear sea trout in 2008, when 50,000 fry were produced, but unacceptably high mortality among retained native broodstock prevented its continuation.

Some river stocking with brown trout has occurred on the Annan in the past. The Annandale Angling Association stocked regularly with brown trout (presumably obtained from a commercial source) at various locations and sizes over a long period from the 1950s until 1995. The Royal Four Towns water was stocked with 1,000 'takeable' brown trout (>20cm/8in) a year from 1952 until the Annan Fishery Board expressed concern on environmental and ecological grounds. This ceased in 2004 for cost-benefit reasons.

Stocking with brown trout into private lakes within the Solway District is known to have occurred at various times in the past but there is no record of the nature and extent of such stockings. These fish were almost certainly purchased from commercial trout farms and produced from domesticated broodstock. However, it is likely that most of the stocked lakes were 'off-stream' and unconnected to the rivers in a catchment area. Consequently, downstream escapement into the river catchments was unlikely and that the rate of exploitation by anglers was probably high with few fish surviving to spawn with local brown trout stocks in the year of introduction.

England & Wales

Anecdotal evidence from the historical angling literature refers to the transportation of wild brown trout within and between local catchments in Wales by anglers at various times during the 19th and 20th centuries. Cliffe (1860) records the removal of brown trout from Llyn Bugeilyn (Dyfi catchment) and their transport by pony over the mountain for release into the then fishless River Rheidol. Similarly, brown trout from Llyn Tal-y -Llyn (Dysynni catchment) were carried up to Lyn Cader near the top of Cader Idris in the 18th century: and Llyn Tal-y-Llyn on the headwaters of the main river was also stocked intermittently by the Ty'n-y-Cornel hotel with 'several hundred' takeable (20+ cm) brown trout from a commercial fish farm in Southwest England in the 1950s and 1960s.

Other anecdotal sources refer to the importation of salmon eggs from Scotland and Germany (Rhine) to stock the Conway and Wye to improve the early runs of spring salmon. It would appear that there was no known stocking with sea trout into any rivers until about the 1960s when small numbers of sea trout were reared for experimental purposes in North Wales. It is believed that many of the small mountain lakes in Snowdonia in the vicinity of several slate quarries were stocked in the 18th and 19th centuries with wild brown trout taken from local rivers to provide food for the workers who lived in 'barracks' on the mountainside during the week.

Until the formation of the River Boards in 1948, small salmon hatchery units producing unfed fry operated on several major rivers during the early part of the 20th century. These became defunct in the early 1960s when the River Authorities developed their own facilities and adopted artificial propagation as a standard management tool. The River Authorities in the Welsh region operated six rearing units producing unfed fry, fed fry, and parr, with two unit rearing to the smolts stage. The only units rearing sea trout until the late 1960s were all in Gwynedd area. They produced unfed fry, fed fry and parr for release into local rivers with the occasional shipment of unfed fry to South Wales. The development of the Dolbantau salmon rearing unit in Southwest Wales (Teifi catchment) from the late 1960s allowed a small number of sea trout to be reared when space was available. A few water supply undertakings stocked their local reservoirs with brown trout (and rainbow trout) purchased from commercial fish farms located in England.

In 1974, Welsh Water Authority inherited seven salmon rearing units from its predecessor river authorities. These units all reared unfed and fed fry, but only the Dolbantau unit (Teifi catchment) the Maerdy Unit (Dee catchment) reared to the more advances stages. These produced salmon parr and smolts in connection with three statutory fishery protection schemes associated with large reservoir impoundments on the Dee (Llyn Celyn), Eastern Cleddau (Llysyfran Reservoir) and Tywi (Llyn Brianne). Sea trout were also reared to the unfed and fed fry stages and the larger units were also adapted to produce brown trout to takeable size for the Authority's extensive stocking requirement for its own reservoir fisheries. The eggs required for the sea trout rearing programme were all obtained by electro-fishing and trapping in local streams and no eggs were imported from outside the area. Some of the brown trout reared were sourced from local reservoirs and streams but most of the larger fish were purchased from commercial fish farms in England.

Although details of salmon stockings were given in the Annual Statistical Reports for England & Wales from the early 1980s, it is only since 2009 that this had included reference to sea trout. Consequently, Harris (1994) provides the only earlier information of the sea trout stocking requirement for the two regions for any earlier years (Table 2.3.2). Virtually all sea trout required for stocking in 1993 were in the Northwest and Welsh Regions and linked to river restoration schemes, statutory fishery protection schemes and stock enhancement. Annex 1.

Table 2.3.2 Number of Different Life-Stages of Sea Trout Required for Stocking in England & Wales by Regions of the NRA (1993).

EA Region	Eggs*[1]	Fry*[2]	0+ Parr	1+ Parr	1+ Smolts	2+ Smolts
Northumbria/Yorkshire	20,000					
Southern		8,000				
South West			82,000			
Wales		280,000	30,000	45,000	22,000	
Northwest		180,000		33,000	65,000	15,000
E & W Total	**20,000**	**468,000**	**112,000**	**78,000**	**87,000**	**15,000**

The only data for subsequent years is from the Annual Reports for 2009 and 2010 (Table 2.3.3). It is evident that the general reduction in the Environment Agency's overall commitment to stocking in general and to improvement stocking in particular has continued over the following period with only the Welsh Region maintaining any commitment to sea trout stocking: and then predominantly with unfed and fed fry and much reduced numbers of later stocking stages of one-year parr and smolts. The only rivers then stocked were the recovering river Ebbw in South Wales, the Taff and Tywi (fishery protection schemes) the Mawddach in mid-Wales (fish-kill damage compensation) and the Lune and Ribble in Northwest England. By 2011, the Annual Report shows that sea trout stocking had virtually ceased altogether, with only 3,000 0+ parr released in the Lune.

Details on brown trout stocking were never included in the Annual Fisheries Reports for England & Wales. However, Gray & Mee (2002) provide a general 'snapshot' of the nature and extent of all consented stocking proposals into rivers and stillwaters for the 8 regions of England & Wales in 2000 (Table 2.3.4). Almost all of the 62,000 larger (>10cm) trout stocked in the Welsh and Northwest regions would have been of takeable size (>25+ cm) to support put-and-take reservoir fisheries. The number of trout of <10cms required for stocking rivers in Wales (62,000) appears high, but this included a significant short-term commitment to brown trout rehabilitation on the upper Teifi following a major pollution incident using eggs derived from local wild broodstock.

The risk of genetic damage by the release into the wild of stocked fish of non-native parentage was probably greatest during the 1960s and 1970s. This was when the demand for stocking with sea trout and brown trout was reaching a peak but before the effective conservation of genetic integrity and diversity became effectively incorporated into the statutory consenting process as a central concept.

Table 2.3.3 Number of different Life-Stages of Sea Trout Stocked by Regions in England & Wales (2009 – 2010).

Region	Year	Eggs	Fry	0+ parr	1+ parr	1+/2+ smolts
Wales	2009		103,600	16,900	13,056	
	2010		6,000	20,000	19,000	
Northwest	2009			4,500		
	2010			3,000		
Other Regions	209		7,000	10,000	7,000	
	2010					
All E & W	**Total**		**116,000**	**47,400**	**39,056**	

Table 2.3.4 Summary of Brown Trout Stocking in Rivers and Stillwaters in England & Wales (2000 season only).

Regions	No. S.30 Consents Issued	No. & Size Group of Brown Trout Stocked					
		Rivers			Stillwater		
		>10cm	<10cm	All Sizes	>10cm	<10cm	All Sizes
Wales	136	67,074	62,200	129.274	41,644	3,000	44,644
Northwest	64	22,786	3,000	23,086	20,987	-	20,987
All E & W	804	296,098	130,850	426,948	130,685	3,000	133,685

The dearth of any comprehensive details on the nature and extent of stocking during this early period in the UK and Ireland is partly rectified by the availability of unpublished annual reports by the former Welsh Water Authority for the period 1974-1982. These contain comprehensive and detailed information details of all stocking with salmon, sea trout and brown trout from the Authority's own culture units and the consented stocking by private individuals. This includes the source of the fish released on each occasion. It is impossible to summarise this mass of information here in any simple form because the reporting format was not consistent over the period, the fish released into various tributaries were not always attributable to a known river catchment and transfers between commercial fish farms in Wales and England were not always identifiable. Nevertheless, the following key-point summary for 1997 provides a broad perspective of the nature and extent of fish culture operations and stocking for the Welsh region during that early period. [Appendix 2.3 provides more detailed and site-specific information on all private stocking with brown trout and all stocking undertaken by the former Authority for each of its 6 administrative districts in Wales.]

The summary data are:

1) *Total number of sea trout released as unfed and fed fry = 457,000*

2) *Total number of brown trout stocked by private individuals = 81,250 - of which 54,500 were stocked into rivers and 26,750 were stocked into small lakes and ponds.*

3) *Total number of brown trout stocked by Water Authority = 101,220 - of which 26,770 were stocked into rivers and 74,450 were stocked into its own reservoir fisheries.*

4) *Number of eggs incubated at Authority culture units to support future stocking programmes = 424,000 sea trout and 224,000 brown trout.*

5) *Number of private fish farms supplying non-native brown trout for stocking in Wales = 20.*

Republic of Ireland

Inland Fisheries Ireland, a semi-State agency, has operated two separate culture units for brown trout since the mid-1950s at Roscrea and Mullingar to support general stocking programmes in rivers and lakes throughout the Republic. Some smaller private aquaculture units also operate. The Electricity Supply Board rears salmon to late juvenile stagesfor restocking to mitigate against losses arising from hydro-electric power generation schemes on the Shannon, Erne, Lee, Liffey and Clady. The Marine Institute also produce juvenile salmon at its facility in Mayo. Eggs obtained for the salmon rearing programmes are from locally sourced broodstock, but brown trout reared in the state units are from line-bred broodstock originally developed at each of the two culture units.

The Irish sea trout broodstock programme was initiated following the collapse of sea trout stocks in fisheries on the west coast of Ireland in 1989 and 1990 (Poole et al. 2002). Wild sea trout kelts and post-smolts were successfully reconditioned and used as broodstock to produce eyed ova for distribution to affected fisheries. From 1991 to 1999, a total of 8.2 million green ova from four separate stocks were produced and eyed ova were subsequently distributed to 23 affected fisheries along the west coast. Apart from this joint MI/IFI programme no sea trout have been produced by ESB or any other State body. Fahy (1985) records that although very little attention has been given to sea trout stocking, they have been reared for as long, if not so abundantly, as salmon for more than a century. The earliest reference is a report in 1898 of sea trout stocking from the Costello hatchery in Connemara. No further detail is provided, but it is reasonable to assume that any such stockings entailed only limited numbers of unfed or early feeding fry in the smaller river systems on the west coast where sea trout are locally important in sustaining the rod fisheries. It is also likely that eggs to support these stocking programmes were from native sea trout within the receiving catchments.

In recent years, some sea trout fry were reared for small-scale local stocking programmes from independent culture units maintained by local fishery interests within the CSTP area on the Fane and the Currane system but these operations have ceased . No culture units rearing sea trout are currently operating in the CSTP area.

Brown trout stocking into rivers and lakes has occurred in several catchments to support recreational rod fishing, but to a far lesser extent than in England and Wales. Table 2.3.5 provides a breakdown of all brown trout stocking into 18 rivers within the CSTP area over the 8-year period 2004-2011. All fish were reared in the state fish farms at Roscrea and Mullingar using a line-bred hatchery strain. The number of fish stocked each year is given as either a) <1 year old for fry and O+ ‘summerlings’ or as b) larger fish of 1+ and 2+ years of age. Not all rivers were stocked every year; some rivers (Slaney and Coomhola) were stocked only once while others (Delvin and Barrow) were stocked in every year. The total number of fish released each year has also varied widely over the period: from 4,450 – 15,150 for older 1+/2+ parr and from 0 – 30,000 fry and summerlings. The three most heavily and regularly stocked rivers were the Liffey, Nanny and Barrow. All these released fish were from line-bred, domesticated, stock produced at state rearing units.

2.3.7 Stocking Synthesis

It is apparent that the artificial propagation of sea trout for stocking into rivers and streams has never been a widespread or routine management practice in the UK and Ireland other than in Wales from the 1960s to 1990s, and an intensive programme on the west coast of Ireland following the sea trout stock collapse. Apart from some very local stocking of older parr and smolts in connection with a fishery protection schemes on a few rivers, almost all other sea trout releases have entailed the stocking with less than 50,000 unfed fry and/or early feeding fry within a few weeks after hatching. While this may appear a significant number, their impact on the genetic integrity of local stocks is likely of little or no consequence for 3 reasons:

1) Notional survival rates to the 2 and 3 year-old smolt stage typical of most sea trout stocks (@ 0.5%) and then their subsequent rate of return to the river as 0+ and 1+ maiden fish (@ 10%) would yield roughly 25 adults.

2) No stocking stages were from a domesticated line-bred stock and no eggs were imported from other regions. In almost every situation, the eggs used in stocking programmes were obtained by trapping or electro-fishing in the streams to be stocked, for some restoration stocking in the recovering industrial rivers in South Wales, from other local rivers.

3) Many of the streams stocked already contained well established natural spawning populations of wild sea trout.

The risk posed by past stocking to the genetic integrity and diversity of brown trout is less certain than for sea trout. The very large numbers of brown trout of takeable (or near takeable) size released on a regular annual basis to support recreational fisheries in a number of the large, heavily stocked reservoir trout fisheries developed from 1970s to date (mainly in England and Wales) would seem to represent a more significant concern if large numbers of fish escaped downstream into sections of river frequented by populations of wild sea trout and brown trout. Virtually all of these fish were purchased from commercial trout farms at diverse locations outside the immediate area using domesticated line-bred broodstock, either for stocking directly into the wild or for developing separate lines of broodstock at local culture units.

However, since such losses would affect the economic performance of the stocked fishery, screens are normally inserted at the spillway outlet to minimise losses when the reservoir is at top water level and this level normally falls below the spillway as the demand for the supply of potable water increases during the spring and summer months. This, combined with the very high rate of angler exploitation in such fisheries, might be expected to minimise any subsequent negative impact from the downstream escapement fish on natural spawning populations of brown trout.

Ferguson (2007) investigated the genetic impacts of stocking on indigenous brown trout populations. From a comprehensive review of some 336 scientific and management papers from Britain, Europe and North America on the genetic impact and management implications of stocking with juvenile and adult trout, he concluded "There is no evidence of reduced genetic diversity within England and Wales compared with other areas in Scotland, Ireland and Northwest Europe where little if any supplemental restocking has taken place. There is therefore no evidence that previous supplemental stocking with farm-reared brown trout has resulted in a widespread decline in natural genetic diversity". However, he cautions that, although past stocking had little or no impact in either increasing fish numbers or in producing genetic changes, this does not mean that stocking can continue with impunity. He recommends that all supplemental stocking with fertile farm-reared and non-native brown trout is prohibited and that the only forms of stocking permitted should be from supportive breeding or stocking with sterile triploid fish.

It is evident that all statutory agencies in the UK and Ireland have now adopted policies and criteria to regulate the release of reared salmonid fish into the natural environment that provide stringent controls to prohibit all forms of stocking into rivers and non-enclosed waters with fertile fish that were not derived from local wild stocks. Consequently, any problems that may have arisen in the past should no longer occur in the future.

Table 2.3.5 Number and Age Group of Brown Trout Stocked into Eastern Irish Rivers within the Project Area (2004 -2011)

River	Year of Stocking with fish of < 1 year and 1+/ 2+ years of age															
	2004		2005		2006		2007		2008		2009		2010		2011	
	< 1	1+/2+	< 1	1+/2+	< 1	1+/2+	< 1	1+/2+	< 1	1+/2+	< 1	1+/2+	< 1	1+/2+	< 1	1+/2+
Onavarragh	5,000	500	20,000													
Fane		3,200		850		725		725		500						
Liffey	2,000	3,700		1200		700	5,000	3,250			300	1,200		1,800		
Tolka		1,800		3,000		2,600		2,500	2,000	2,500		2,300				2,300
Broadmeadow				3,000												
Delvin				500												150
Nanny		500		500		500	7,000	1,500	7,000	500	4,000	500	500	500	3,000	300
Dodder		800		1,000		1,000		800		1,600		750		750		700
Boyne						2,500	5,000	800			10,000	1,300				
Blackwater			10,000	2,000												
Suir		500						300								
Barrow	11,500	1,400		1,750		250	4,000	1,800		1,000	5,000	7,800		4,000	3,000	1,000
Nore		2,000		1,100		1,300		1,100		1,070		1,100				
Camac							4,000				3,000					
Coomhola							5,000									
Slaney												200				
Total	**18,500**	**14,400**	**30,000**	**14,900**	**Nil**	**9,575**	**30,000**	**12,755**	**9,000**	**7,170**	**22,300**	**15,150**	**500**	**7,050**	**6,000**	**4,450**

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3 Sampling

3.1 Introduction & Background

Sampling of freshwater and marine sea trout populations was fundamental to the project to provide samples for several of the work packages. River- specific sampling of sea trout populations by anglers (e.g. Harris, 2002; O'Farrell & Whelan, 1989), trapping (Davidson et al., 2006; Poole et al., 2006), electrofishing (Bohlin, 1977; Elliot, 1995; Fahy et al., 1984; Walker, 2006; Byrne, 1998) is well documented due to the numbers of sea trout systems or populations that have been investigated throughout the UK and, to a lesser extent, in Ireland. Sampling, or co-ordination of sampling of sea trout populations in freshwater at various life stages, using some or all of these methods, was a core element of this task in which many of the CSTP team had considerable experience.

Gaps in knowledge about the ecology of sea trout at sea, identified by Milner et al, 2006 at the 1st International Sea Trout Symposium in 2004, were a major driver for the overall CSTP. Collection of samples at sea was a primary focus of the sampling programme to support workpackages addressing distribution, movement and general marine ecology of sea trout in the Irish Sea.

Marine sampling for CSTP posed a significant challenge given the extent of the combined coastline and the absence of consolidated data about the distribution of sea trout in the Irish Sea. Previous studies of the marine phase of the sea trout throughout its distribution have tended to focus generally on sampling discrete inshore coastal areas (e.g. Knuttsen et al., 2001; Fahy 1981 and 1985, Rikardsen et al, 2006) and these studies provided useful insight into identifying potential sampling habitats in inshore areas for CSTP. In offshore coastal waters in the North Atlantic (SALSEA, 2011) and off the North American coast (Sheehan et al, 2011) surface trawling for salmon smolts has proven to be a highly successful sampling approach. Some guidance was available from sea trout by-catch which was recorded in 2001 off the west coast of Ireland during a surface trawling survey for salmon smolts (Gargan, pers. comm), and this approach was identified as the preferred method for the CSTP sampling programme in offshore coastal waters, although it was understood that the trawling would be largely experimental.

Another important consideration was the co-operative nature of the sampling programme, both in freshwater and the marine environment, with regionally based team of professional fisheries staff from various agencies and trusts undertaking sampling within their region, without any cost to CSTP. This project depended on this level of co-operation and input from the staff involved. CSTP project officers supported this task directly by undertaking sampling and managing sample collection from the various sampling teams and commercial sources.

This chapter reports sampling strategies, methods used and the numbers of samples recorded. Summary results are presented and sampling protocols, sample processing protocols and a description of the CSTP database are contained in Appendices 3.1 to 3.19. Detailed task-specific sample processing and methods (i.e. relating to genetics, microchemistry, scale reading etc.) are reported in the relevant task report chapter.

3.2 Sampling Programme Aims and Objectives

The overall aim of Task 3 was to sample various juvenile trout and adult migratory trout life stages in the freshwater and marine environments within the Irish Sea ecosystem to provide various samples for individual workpackages within the Celtic Sea Trout Project specifically for Tasks 4 (genetic stock identification), 5 (microchemistry: stock identification and movement patterns) & 7 (marine ecology and life history variation).

Three discrete activities were identified as sampling objectives. These were sampling in freshwater, sampling in the marine environment and sample processing.

The specific sampling objectives in freshwater were to:

1) Sample juvenile trout (0+ and ≥1+ age classes), in spawning and nursery areas, in selected rivers discharging into the Irish Sea, to provide samples for genetic and microchemistry baselines, and for juvenile trout growth studies.
2) Collect scales from rod-caught or trap caught adult sea trout (upstream migrants) in productive sea trout rivers within a wide geographical area for description and analysis of sea trout life history variation and growth.
3) Sample downstream migrating juvenile sea trout (smolts) from some systems to test the assumption that sea trout and non-migratory brown trout are interbreeding populations.

In the marine environment the sampling objective was to:

1) Sample offshore, inshore coastal waters and estuaries, for post-smolt and adult sea trout using various survey and/or existing commercial methods, and in commercial fisheries, to provide a range of samples to support the study of stock structuring, marine ecology, feeding, growth & life history variation of sea trout around the Irish Sea

Sample processing objectives were to:

1) Process all samples, extract and distribute relevant tissue samples for different tasks.
2) Develop and populate a comprehensive sampling database which would capture all of the sampling data including survey and sampling events, individual fish data, and sample tracking details.

3.3 Study Area

Figure 3.4.1 shows the study area which includes marine habitat, mainly the Irish Sea and two coastal extensions. The study area extended in two directions - one off the south coast of Ireland extending westwards to Co. Kerry and the other to the south Pembrokeshire and Carmarthenshire coast in Wales. The Irish Sea study area is effectively ICES Division VIIa and the extended sampling areas were included as several major sea trout fisheries discharge into both.

The Irish Sea, where the marine sampling effort was mainly focussed, is defined as the area between 51.0 – 55.6 degrees North and 2.0 - 6.5 degrees West. Connected at its northerly and southerly limits to the Atlantic Ocean it is a north-south orientated channel which is approximately 300km in length. With a surface area of 47,000 km^2, (Howarth, 2007) it is largely shallow, apart from the North Channel (off the Northern Ireland/Scotland coast). In general, depths range from 20-100m over the greater extent of the basin but a deeper channel, exceeding 100m, extends north-south in the central part of the Irish Sea and reaches a maximum depth of 315m in Beaufort's Dyke (off the Scottish coast) (Figure 3.3.1). This deeper channel connects with the Malin Shelf through the North Channel and in the south to the Celtic Sea via St George's Channel. The project area coastline exceeds 6,500 km in length (Table 3.3.1).

The Irish Sea biotope is described in Section 7.8.3 in the context of sea trout feeding.

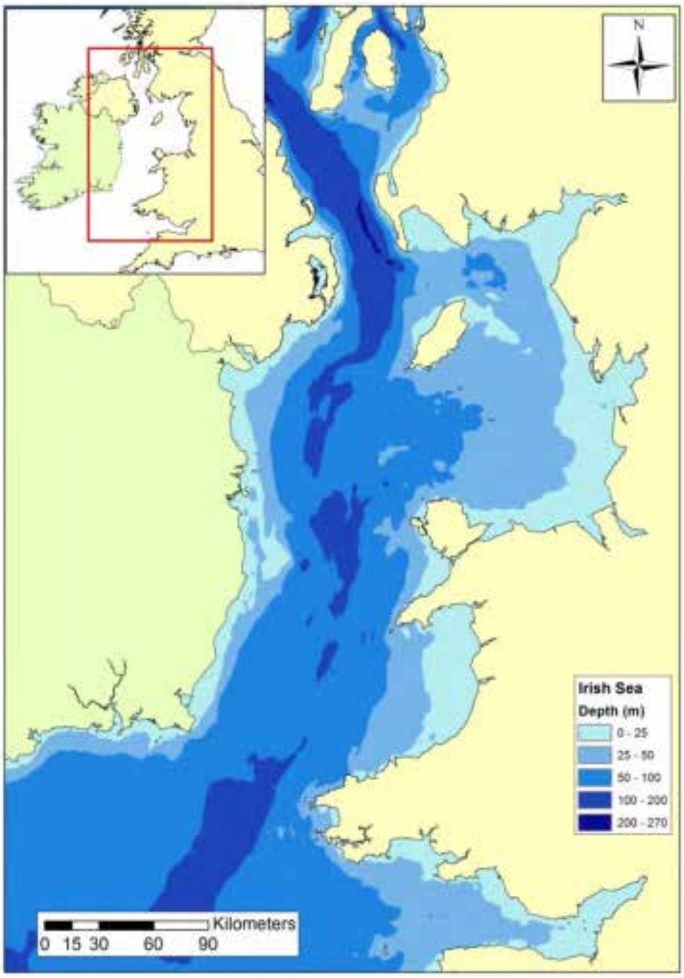

Figure 3.3.1 Bathymetry of the Irish Sea

Table 3.3.1 Length (km) of coastline by region within CSTP project area

Coastline within CSTP project area	CSTP zones	Linear length (km)	% of total project area coastline
Ireland	MZ01 to MZ08	3,432	52.3%
Scotland	MZ09 to England Border	469	7.2%
Northwest England waters (England)	England border to Wales border)	775	11.8%
Wales	Wales border to MZ18	1,685	25.7%
Isle of Man	MZ23	197	3.0%
TOTAL		**6,558**	**100%**

The marine sampling area was divided into discrete marine sampling zones for management of sample planning and reporting. Thirty individual zones (MZ01-MZ30), which spanned the full extent of the extended project area, were identified (Figure 3.4.1). Zonation was based on a two stage process. Delineation of potential inshore sampling zones was carried out by selecting sections of coastline of approximately equal length, within each jurisdiction. Identifiable limits such as prominent headlands or bays were extended seawards for 10km and conjoined to form each zone. These limits were extended into offshore waters (i.e. >10km from base) and joined to generate the full complement of marine sampling zones.

All freshwater systems discharging into the defined CSTP marine sampling zones were included as potential sampling sites. Strategic decisions based on system size, likely contribution to sea trout production in the Irish Sea and geographical location determined if sampling was conducted. The sampling rationale applied to the freshwater and marine resource is outlined below.

3.4 Juvenile Freshwater Sampling

3.4.1 Sampling Rationale

For Task 4 (genetics) a baseline of juvenile trout from all (or the majority) of potentially contributing populations of migratory trout in the Irish Sea ecosystem was required in order to provide a comprehensive study of the sea trout resource. As has been demonstrated for salmon (Ensing et al., 2013) it was hypothesised that each system would have one or more genetically discrete trout populations which would, most likely, be defined by the distribution and quality of spawning habitat within each catchment. Spawning areas for salmonids are not distributed evenly throughout a river system but occur in identifiable spawning areas or zones. The distribution of these areas is usually related to river gradient and availability of suitable gravels.

A strategic sampling plan was devised which identified and prioritized productive sea trout systems within the wider project area based primarily on rod catch. Recorded or estimated rod catch was used as an indicator of abundance to prioritise sampling efforts and maximise benefits from the available sampling and analytical resource. Wetted area (or catchment size) and the geographical distribution of systems also drove the process. Geographical distribution was considered important for potential determination of a regional signal. Where resources permitted biodiversity considerations also applied as the lowest priority driver where smaller populations of potentially interesting sea trout populations may have occurred. A total of 100 systems were identified for sampling, with high sampling density in Ireland and Wales, to provide samples for the genetic and microchemistry baselines. This total included important sea trout systems in England, Scotland, Northern Ireland and the Isle of Man which discharge into the Irish Sea (and the northern part of the Celtic Sea).

Identification of the principal sea trout spawning area(s) in each system and sampling juvenile populations in these habitats was of overriding importance. Where known, sea trout spawning areas were targeted, but 'most likely' areas (i.e. where high 0+ trout fry densities had been recorded previously or where suitable trout spawning habitat occurred) were sampled if specific spawning areas were unknown. At least one spawning site per river system was sampled in CSTP Priority Rivers (See Section 3.5.1) and in large complex systems additional sampling was undertaken. Where multiple spawning areas were known in a system the most significant area was prioritised and lesser sites were included in order of likely contribution. 0+ and 1+ trout parr were the sample targets for the genetics workpackage and both age groups were sampled to facilitate investigation of temporal variation.

A parallel but related task applying the potential of otolith microchemistry to discriminate region or possibly river of origin, and movement patterns of adult sea trout at sea was the sampling driver from Task 5. Samples of trout parr (1+ fish) from a subsample of rivers draining different geologies within the project area were the target life stage in order to develop the juvenile microchemistry baseline to test various hypotheses, and for investigation of juvenile trout growth. Sampling was conducted concomitantly with the genetic sampling programme. The sampling window was June to end September. Commencing sampling in June meant that juvenile trout (0+) could be easily distinguished from juvenile salmon of the same general size.

A detailed description of the sampling rationale and sampling protocol is provided in Appendix 3.1.

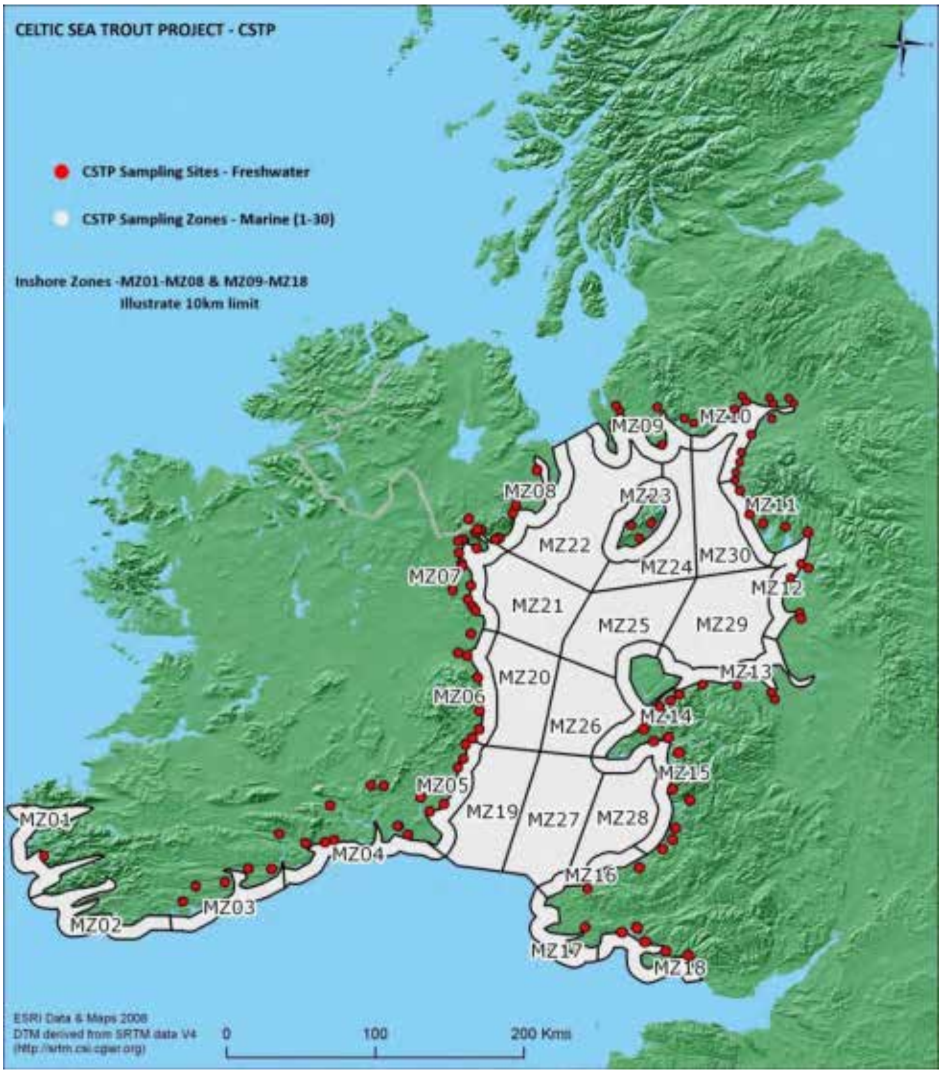

Figure 3.4.1 Celtic Sea Trout Project area with Marine Zones and freshwater sampling sites

3.4.2 Sampling Protocol

Fish Sample Collection

Sampling was carried out using standard electrofishing backpack sampling equipment. Sampling was conducted within a given spawning zone over a continuous distance > 500 m length, or within a number of non-contiguous river segments to ensure that multiple families were sampled. Target sample size was 50 x 0+ and 50 x 1+ trout per site. A standard survey sheet was completed for each site sampled (See Appendix 3.2).

3.5 Adult Freshwater Sampling

3.5.1 Sampling Rationale

From the outset of the project it was understood that sampling of rivers for adult sea trout to provide scales and other relevant information would be mainly be undertaken by anglers using rod-and-line. Public participation was an essential component of the broader project brief from INTERREG IV and sampling by anglers fulfilled both the sampling and participation requirements. Adopting a standard sampling method like angling allowed for between river data comparisons, and delivery of a low cost and relatively efficient adult sampling programme.

25 of the 100 rivers which had been selected for juvenile sampling were prioritised for detailed investigations of sea trout life history (Table 3.5.1 and Figure 3.5.1). The selection criteria for these rivers/systems, termed 'priority rivers' for the CSTP, was as follows:

- Sea trout rivers deemed 'important' within the confines of the Irish Sea and respective geographical/regional areas (Ireland East, Ireland South, South Scotland, England, Wales and the Isle of Man)
- Rivers with sea trout populations likely to represent stock characteristics for the area or region
- Rivers with a sufficiently large rod catch where adequate samples could potentially be collected by anglers
- Rivers where anglers and clubs would engage with the project and the sampling programme

Applying these criteria the CSTP team selected the priority rivers which are listed in Table 3.5.1.

Table 3.5.1 Priority CSTP Rivers

Region	Rivers
Ireland East Coast	Shimna
	Castletown
	Dee
	Boyne
	Dargle
	Slaney
Ireland South Coast	Colligan
	Bandon
	Argideen
	Currane
Scotland	Luce
	Fleet
	Nith
	Border Esk
England	Ehen
	Lune
	Ribble
Wales	Dee
	Conwy
	Clwyd
	Dwyfor
	Dyfi
	Teifi
	Tywi
	Tawe

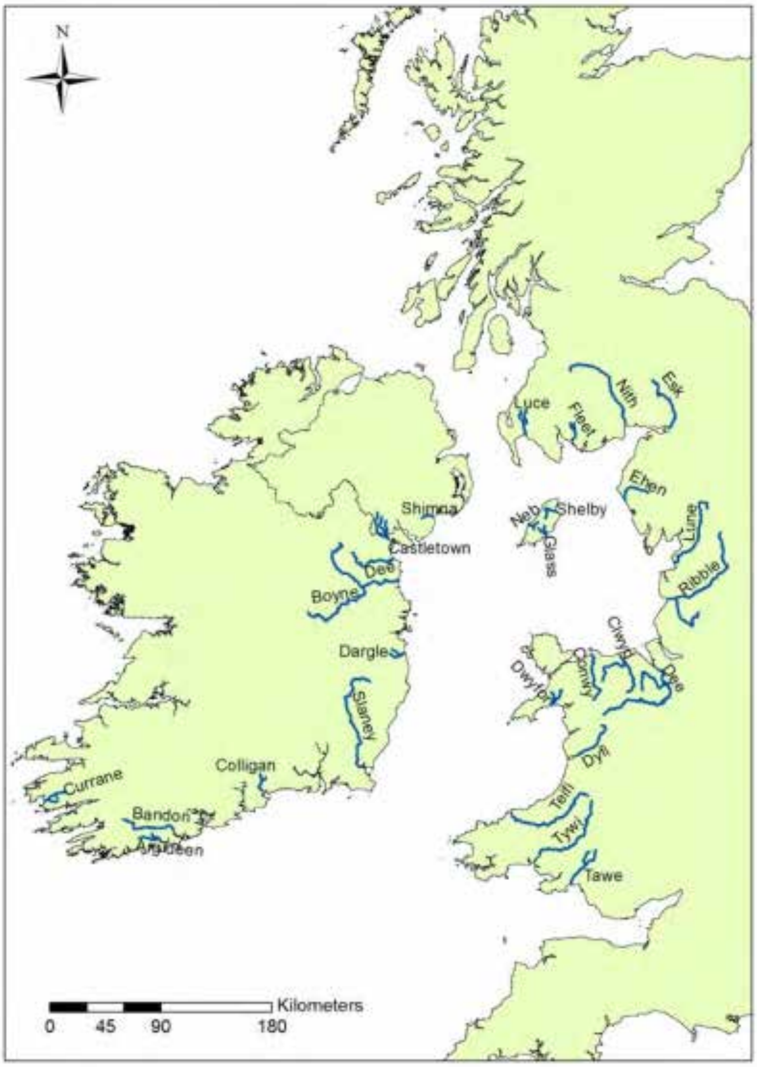

Figure 3.5.1 CSTP Priority Rivers for collection of adult sea trout samples

3.5.2 Sampling Methods

Anglers were issued with scale sampling kits and detailed instructions (See Appendix 3.3). A target of 300 fish, to be collected over the 2010-2012 period, was set for each priority river. It was emphasised that samples should be collected in a scientifically unbiased way to ensure that the sample was representative of the stock and collected throughout the angling season. The sampling kit, sealed in a Ziploc bag, included a plastic tape measure, a plastic knife to ensure no metal contamination of scales from metal sampling knives, a pencil and 10 specially designed project scale envelopes. Anglers were requested to collect a scale sample and record forklength measurement (to nearest 0.5cm) and other relevant information from each sea trout caught. 10 scales per fish, taken from the right flank, and placed in an individual scale envelope, were requested (Appendix 3.4). Regulations relating to catching sea trout at sea were issued to anglers to clarify issues around licensing (Appendix 3.5)

Adult scale samples from two rivers with trapping facilities, the River Dee in North Wales and the River Lune in southern England, were included in the sampling programme. The River Dee has been monitored since 1991 and has a substantial sea trout run numbering from 4,000 to 10,000 fish per annum (Harris, 2002). Summary descriptions of the partial trap on the Dee and the Lune trap are presented in Davidson et al (2006) (Dee) and Harris (2002) (Dee and Lune). Where annual or total targets set for anglers were not being achieved additional sampling was undertaken in some priority catchments by electrofishing. Spurious electrofishing surveys also provided some scale samples in some systems. In the River Fleet seine netting was carried out in freshwater to supplement rod caught scale samples while fish from the coracle fishery, which operates at the uppermost reaches of tidal waters in the Tawe and Teifi in Wales, were also included in the riverine samples.

3.6 Results of Freshwater Sampling

Juvenile Trout

Sampling was carried out in 84 river systems at 205 sites distributed throughout the project area (Figure 3.4.1). Table 3.6.1 presents summary data for this sampling effort. Details of systems sampled, sampling dates, GPS site locations and sample sizes are presented in Appendix 3.6.

An average of 1.77 sites per catchment (ranging from 1 to 8) were sampled for 0+ fry (Table 3.6.1). The maximum was in the Lough Currane/Waterville system which is a complex, highly structured system with numerous small lakes which required intensive sampling. Sampling intensity increased to achieve the target sample size in each catchment. For example, where one sample from 50 x 0+ fish in a spawning area in a given catchment was adequate only one site was sampled if the target sample size was reached. However, in some rivers multiple locations within a discrete spawning area had to be sampled to achieve the target. For the majority of systems only one sample of 50 x 0+ was collected but in larger or more diverse systems two or more discrete samples were taken. This varied depending on the number of important spawning sites.

An average of 2.47 sites was sampled per catchment for 1+ parr but this was biased by sampling of 30 sites on the extensive Border Esk system. Removing this outlier resulted in an average of almost 2 sites per system.

10,555 individual tissue samples were collected for the genetics workpackage. This comprised 5,358 0+ fry and 5,185 x 1+ parr samples. Median tissue sample size by system was 52 for 0+ and 50 for 1+ fish.

For the microchemistry baseline a total of 1138 trout parr were retained (Appendix 3.7) from 51 sites in 36 systems. Selection of samples for this task was based on a rationale detailed in Chapter 5. A total of 2,611 trout fry from 55 sites in 38 systems were retained for growth studies (Appendix 3.7).

Table 3.6.1 Summary of trout 0+ fry and 1+ parr sampling in river systems in England, Ireland, Northern Ireland, Scotland, Wales and the Isle of Man from 2008-2011 for the CSTP. All samples collected by electrofishing.

Country	River Name	No. sites sampled	Sampling Years	Total no. 0+ fry sampled	Total no. 1+ Parr sampled	Tissue sample storage
England	Calder	5	2009-2010	50	77	Individual vial
	Derwent	5	2009-2010	98	125	Individual vial
	Duddon	5	2010	52	50	Individual vial
	Eden	2	2009-2010	100	100	Individual vial
	Ehen	2	2009-2010	101	100	Individual vial
	Cumbrian Esk	7	2009-2010	119	100	Individual vial
	Irt	7	2009-2010	125	100	Individual vial
	Kent	4	2009-2010	101	100	Individual vial
	Lune	2	2010	100	98	Individual vial
	Ribble	2	2010	98	100	Individual vial
Ireland	Argideen	2	2011	110	94	Pooled*
	Avoca	2	2010	23	55	Pooled*
	Bandon	2	2011	37	104	Pooled*

	Boyne	2	2009	102	105	Pooled*
	Bride	2	2011	0	114	Pooled*
	Campile	1	2010	43	51	Pooled*
	Castletown	1	2010	32	42	Pooled*
	Colligan	1	2010	52	23	Pooled*
	Corock	1	2010	53	48	Pooled*
	Currane	8	2010	388	29	Pooled*
	Dargle	2	2009-2010	65	50	Pooled*
	Dee (White River)	1	2010	51	15	Pooled*
	Dodder	1	2010	50	13	Pooled*
	Duncormick	1	2010	52	47	Pooled*
	Fane	1	2010	42	4	Pooled*
	Flurry	1	2010	50	14	Pooled*
	Glashaboy	1	2011	66	53	Pooled*
	Glyde	1	2010	59	54	Pooled*
	Ilen	1	2011	52	34	Pooled*
	Inch	1	2010	50	50	Pooled*
	Inny	2	2011	103	27	Pooled*
	Liffey	3	2010	43	12	Pooled*
	Mahon	1	2010	53	50	Pooled*
	Nanny	1	2009	25	3	Pooled*
	Nore	1	2011	2	55	Pooled*
	Owenboy	1	2011	49	63	Pooled*
	Owenacurra	1	2010	39	50	Pooled*
	Owenduff	1	2010	51	41	Pooled*
	Owenavarragh	1	2010	54	6	Pooled*
	Potters	1	2010	52	52	Pooled*
	Redcross	1	2010	52	49	Pooled*
	Slaney	3	2009-2010	96	47	Pooled*
	Sow	1	2010	51	26	Pooled*
	Suir	1	2011	60	31	Pooled*
	Tay	1	2010	48	30	Pooled*
	Three Mile Water	1	2010	50		Pooled*
	Turvey	1	2010	10	35	Pooled*
	Vartry	1	2010	40	52	Pooled*
	Womanagh	1	2010	51		Pooled*
N. Ireland	Cooley	1	2009	53		Pooled*
	Ghan	1	2010	52	51	Pooled*
	Monecarragh	1	2009	0	41	Pooled*
	Moygannon	5	2009	58	58	Pooled*
	Ryland	1	2009	56	59	Pooled*
	Shimna	1	2008	48	45	Pooled*
	Strangford Blackwater	1	2008	24	24	Pooled*
Scotland	Annan	7	2008-2010	103	158	Individual vial
	Cree	3	2010-2011	87	33	Individual vial
	Border Esk	30	2009-2010	104	635	Individual vial
	Fleet	3	2009-2010	51	81	Individual vial
	Luce	2	2009-2010	50	89	Individual vial
	Nith	3	2009-2010	100	180	Individual vial
Wales	Aeron	2	2010	50	50	Individual vial
	Clwyd	1	2010	50	50	Individual vial
	Conwy	1	2010	50	50	Individual vial
	Dee(Wales)	4	2010	102	100	Individual vial
	Dwyfor	2	2010	50	53	Individual vial
	Dwyryd	1	2010	54	50	Individual vial
	Dyfi	1	2010	50	50	Individual vial
	Glaslyn	1	2010	50	50	Individual vial
	Llyfni	1	2010	50	50	Individual vial
	Loughor	3	2010	51	50	Individual vial
	Mawddach	1	2010	50	50	Individual vial
	Nevern	1	2010	50	50	Individual vial
	Ogwen	1	2010	50	50	Individual vial

	Rheidol	2	2010	53	50	Individual vial
	Taf	1	2010	52	50	Individual vial
	Tawe	1	2010	50	50	Individual vial
	Teifi	3	2010	61	113	Individual vial
	Tywi	1	2010	50	50	Individual vial
	Western Cleddau	2	2010	50	50	Individual vial
Isle of Man	Glass	6	2010-2011	100	27	Individual vial
	Neb	6	2010-2011	100	27	Individual vial
	Sulby	6	2010-2011	99	35	Individual vial
TOTAL		**205**		**5358**	**5187**	
* samples for genetics were taken on-site and pooled (by life stage) in large wide-mouthed vials						

Adult Trout

An estimated 34,000 scale envelopes were distributed to anglers over the course of the project. It was intended that the sampling target of 300 sets of scales for each priority system would be collected by anglers over a two year period commencing in 2010. To gauge angler feedback and the feasibility of achieving targets collection of samples was initiated in 2009 in several systems to maximise potential returns. Following a review of scale returns in early 2011 it was evident that targets were unlikely to be achieved in several priority systems and sampling was extended into 2012.

A total of 7,869 sets of scales were available to the project (Table 3.6.2). Between 2009 and 2012 a total of 7,789 samples were collected for the project and a further 80 sets from different catchments, dating from 2007 and 2008, were provided from previous studies (Appendix 3.8). The highest number of samples was collected in 2011 (45.2% of the 7,869 total).

Anglers contributed the majority with 5,775 samples (73.4%) of the total (Table 3.6.2). The remainder were sampled using different methods including electric fishing, which yielded 1,114 samples (14.2%). In-river seine netting was used to sample returning sea trout on the Fleet and provided almost 89% of the sample from the system. Sea trout from the coracle fisheries which operate in the uppermost tidal reaches of the Teifi and Twyi were sampled to supplement the scale sample from both systems. Fish were also sampled from the Dee and Lune Rivers traps. Scales were also collected from fish retained following some minor fish kills in five systems.

Table 3.6.2 Numbers of sea trout scales by system and by capture method 2007 to 2012.

System	Angling	Electric fishing	Fish Kill	Fish trap	Netting	Total	CSTP status
Annan	62	23			18	103	
Argideen	349					349	Priority
Artro	4					4	
Avoca	18	8				26	
Bandon	102					102	Priority
Blackwater		11				11	
Bladnoch	1					1	
Border Esk	415	119			4	538	Priority
Boyne	317					317	Priority
Broadmeadow		16				16	
Campile	1					1	
Castletown	608	4			2	614	Priority
Clwyd	90					90	Priority
Colligan	14	11			1	26	Priority
Conwy	81				1	82	Priority
Cree	89	1	1		1	92	
Currane	407					407	Priority

Dargle	15	114				129	Priority
Dee (White River)	604					604	Priority
Dee(Scotland)		21				21	
Dee(Wales)	16			112	2	130	Priority
Derwent		5				5	
Dodder	2	13				15	
Dwyfor	27	2				29	Priority
Dyfi	266				9	275	Priority
Eden					2	2	
Ehen	9	249				258	Priority
Fane	14					14	
Fleet	17	4			166	187	Priority
Glashaboy	4					4	
Glaslyn	13					13	
Glass	14	1	2			17	
Glyde	109	8				117	
Ilen					2	2	
Inch		12				12	
Kent	1					1	
Liffey	1	6				7	
Loughor	5					5	
Luce	235	2		15		252	Priority
Lune	149			245	38	432	Priority
Mahon	23	11				34	
Mawddach	77					77	
Monecarragh	15					15	
Neb	24	83	2			109	
Nevern					1	1	
Nith	111	193	20			324	Priority
Nore	1					1	
Ogwen	5					5	
Owenavarragh		15				15	
Owenduff		3				3	
Potters		18				18	
Redcross	4	9				13	
Rheidol	15					15	
Ribble	87					87	Priority
Shimna	689	1				690	Priority
Slaney	295	27				322	Priority
Sow		31				31	
Suir	3					3	
Sulby	14	58				72	
Tawe	40			22		62	Priority
Tay		4				4	
Teifi	56	1			74	131	Priority
Three Mile Water		2				2	
Turvey		3				3	
Tywi	251		1		239	491	Priority
Urr		1				1	
Vartry		23				23	
Western Cleddau	6	1				7	
TOTAL	5775	1114	26	394	560	7869	
% of total	73.4	14.2	0.3	5.0	7.1	100.0	

Scales were submitted from 68 catchments and the larger collections came from Priority Rivers (Table 3.6.2). Effort was focussed on these systems and the Isle of Man rivers by members of the project team who visited the majority of these catchments and made presentations to anglers about the project and requesting anglers to engage in sampling. Of the 25 priority systems identified 10 exceeded the target 300 sample threshold while two exceeded 250 samples (Figure 3.6.1). Samples from rivers on the Isle of Man (Neb and Sulby) were also prioritised. Scales were submitted from 43 other catchments which had not been listed as priority systems. This included approximately 100 sets of scales from each of three rivers: the Annan, Cree and Glyde while the remaining systems yielded <25 sets of scales each.

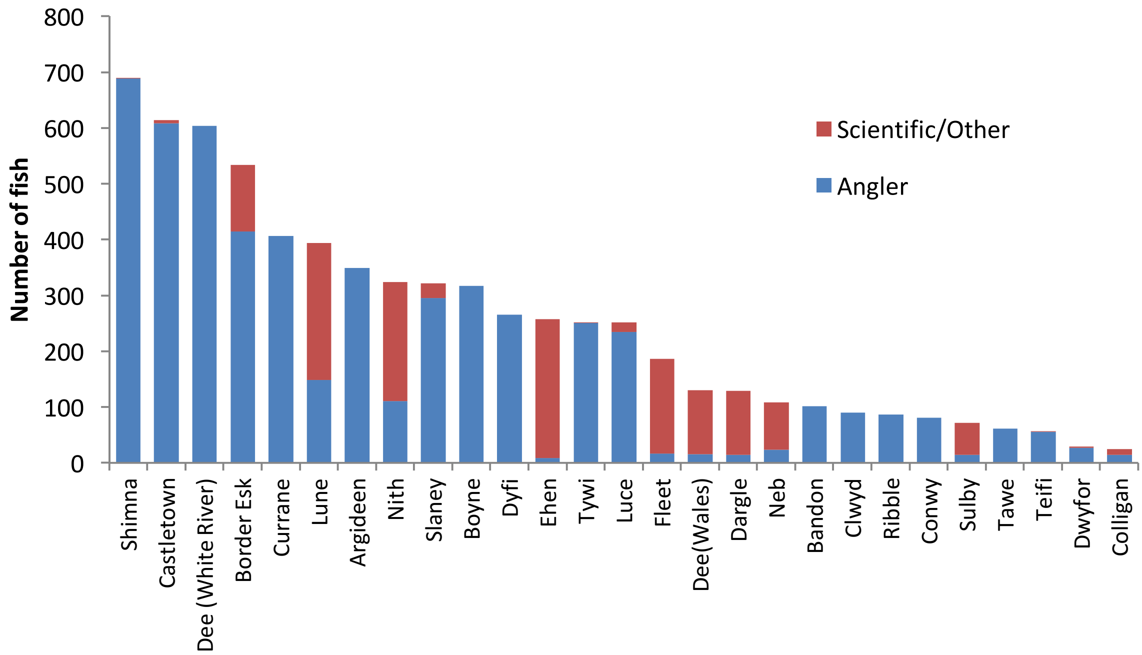

Figure 3.6.1 Sea trout scale sample returns by river for CSTP priority rivers 2007-2012 by anglers and by scientific/other sampling methods and programmes

July, followed by August, was the most productive months for scale sampling (Figure 3.6.2). A full breakdown of samples by river by month (all years pooled) is presented in Appendix 3.9.

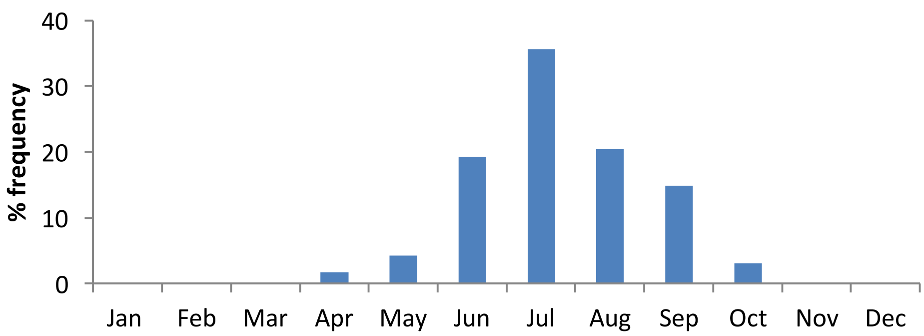

Figure 3.6.2 Angler sampled sea trout by month 2007 - 2012

The length (mm) frequency distributions in Figure 3.6.3 show the variation in size ranges across the river systems sampled. For example, systems like the Slaney, Shimna, Castletown, Boyne and Glyde were essentially unimodal and characterised by smaller sea trout whereas samples from rivers including the Dyfi, Tawe, Teifi and Twyi had more complex distributions which were dominated by larger fish. Smaller fish down to 12 cm were recorded from several systems suggesting that anglers sampled across all sizes, although these smaller fish are likely to have been resident brown trout.

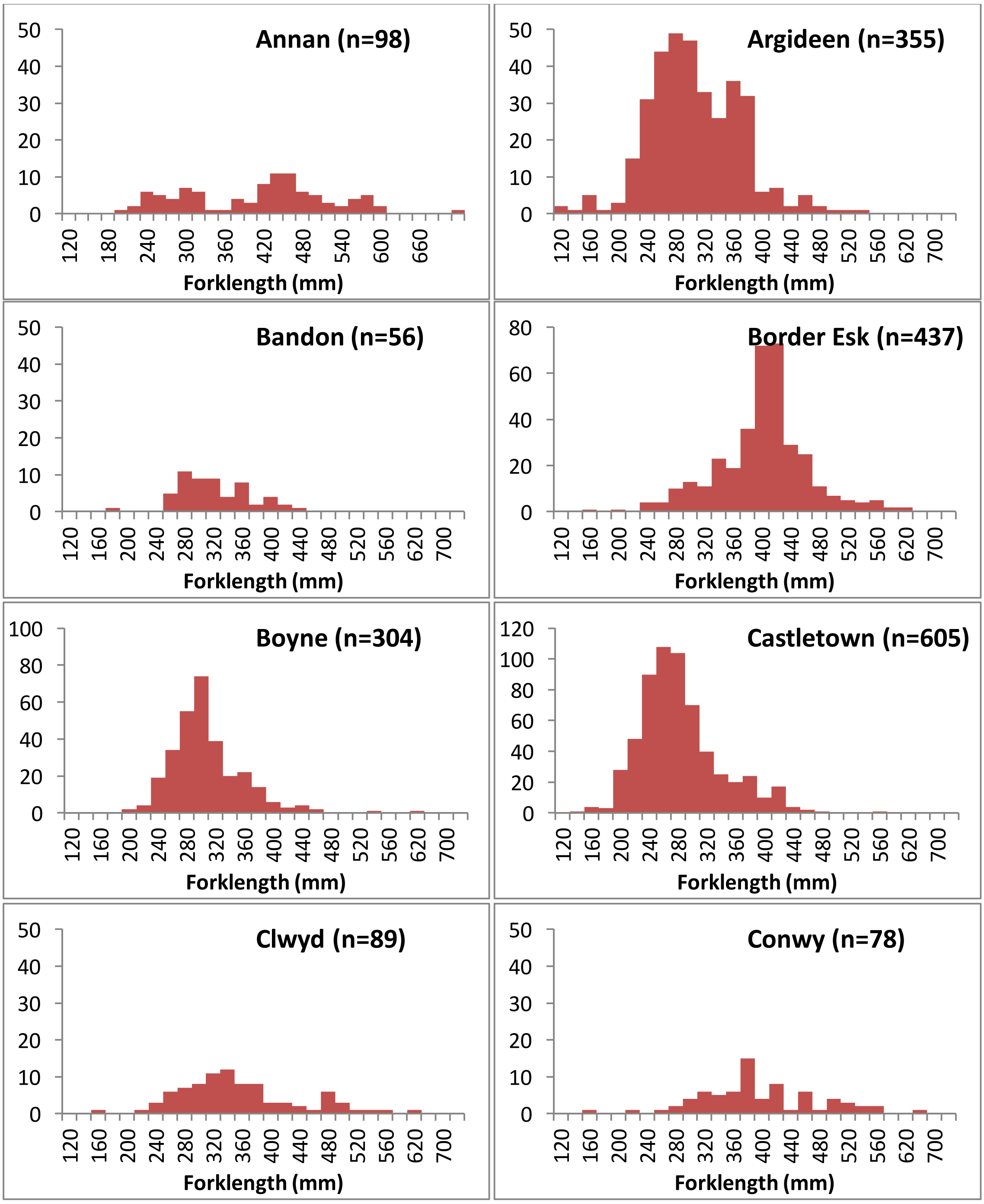

Figure 3.6.3 Sea trout length frequencies for systems where >50 sets of scale samples (with forklength mm values) returned by anglers. Supplementary samples provided by electrofishing, fish traps, netting and several small fish kills (see Table 3.6.2 for detail).

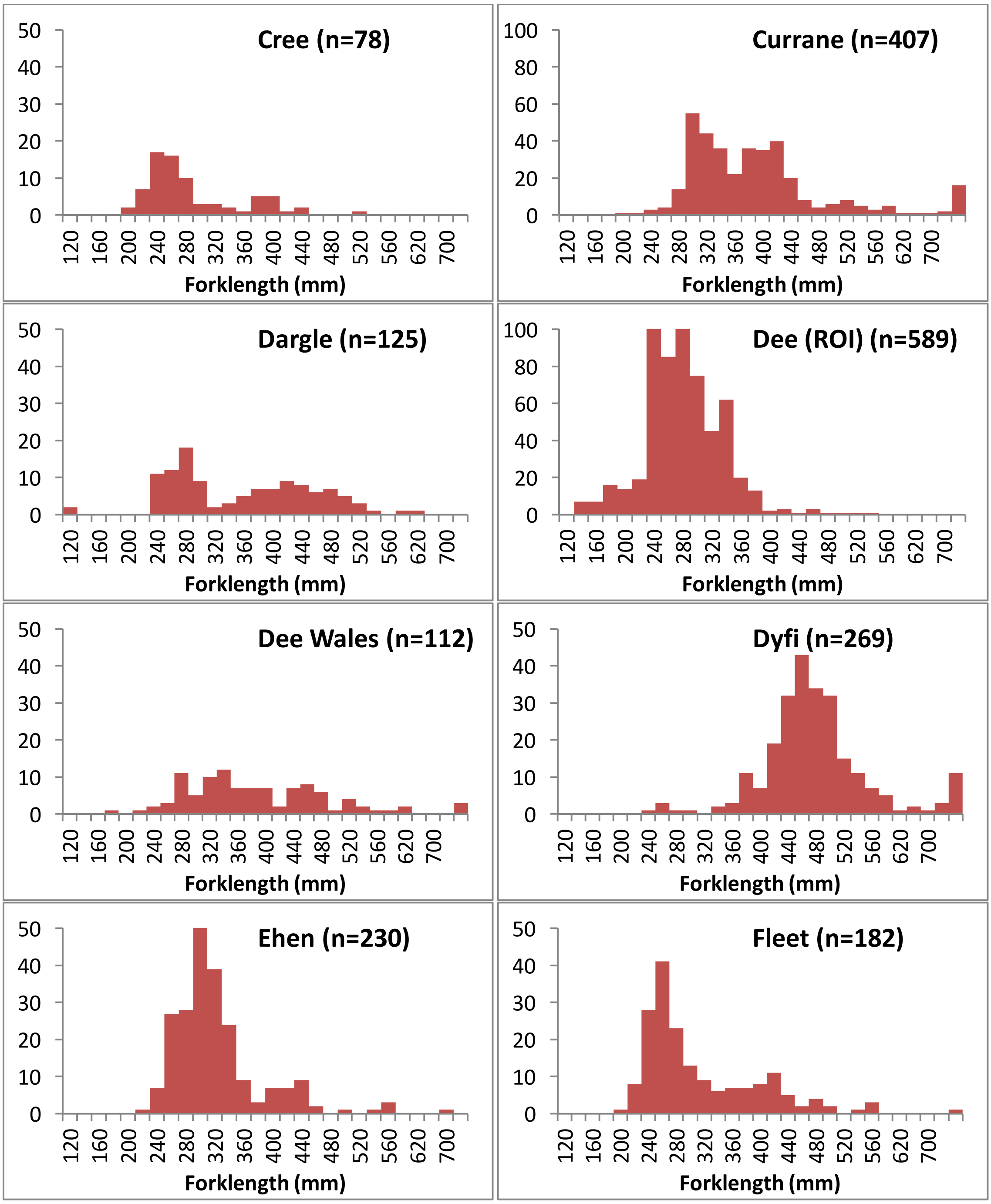

Figure 3.6.3 (contd) Sea trout length frequencies for systems where >50 sets of scale samples (with forklength mm values) returned by anglers. Supplementary samples provided by electrofishing, fish traps, netting and several small fish kills (see Table 3.6.2 for detail).

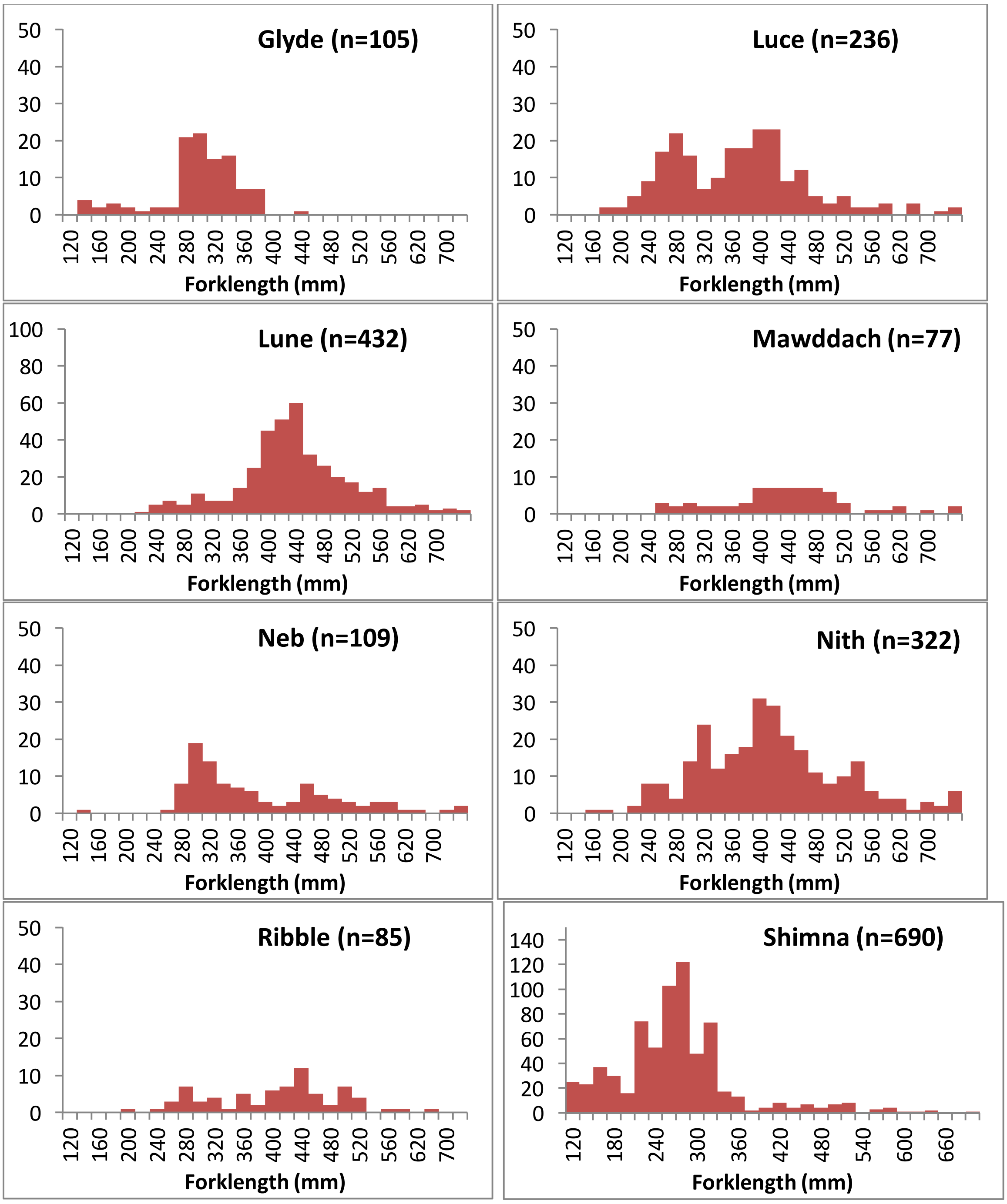

Figure 3.6.3 (contd) Sea trout length frequencies for systems where >50 sets of scale samples (with forklength mm values) returned by anglers. Supplementary samples provided by electrofishing, fish traps, netting and several small fish kills (see Table 3.6.2 for detail).

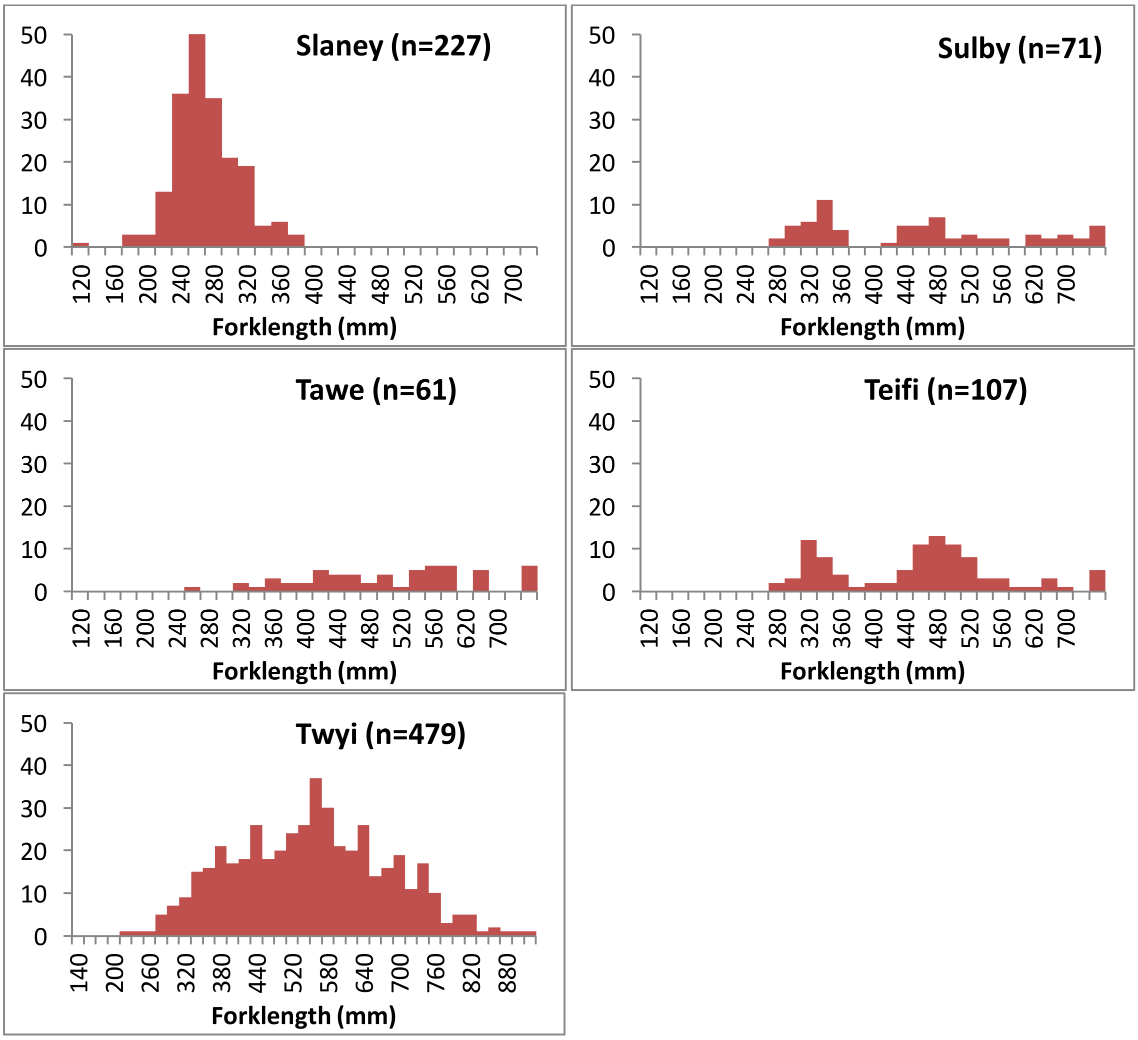

Figure 3.6.3 (contd) Sea trout length frequencies for systems where >50 sets of scale samples (with forklength mm values) returned by anglers. Supplementary samples provided by electrofishing, fish traps, netting and several small fish kills (see Table 3.6.2 for detail).

Median forklength (mm) of sea trout from each system sampled, where sample size exceeded 50 fish, was plotted (Figure 3.6.4). The lower median values, ranging from 279-330 mm, were a consistent feature of the majority of systems sampled in Ireland (Table 3.6.3). This tier also included the Rivers Fleet, Cree and Ehen. The higher median values, ranging from 425-542 mm were from rivers discharging into the Bristol Channel, including the Twyi and Tawe, and Cardigan Bay rivers such as the Teifi, Dyfi and the Mawddach. Further north, all of the inner Solway rivers sampled including the Nith, Border Esk and Annan Rivers were amongst this group with high median forklength values.

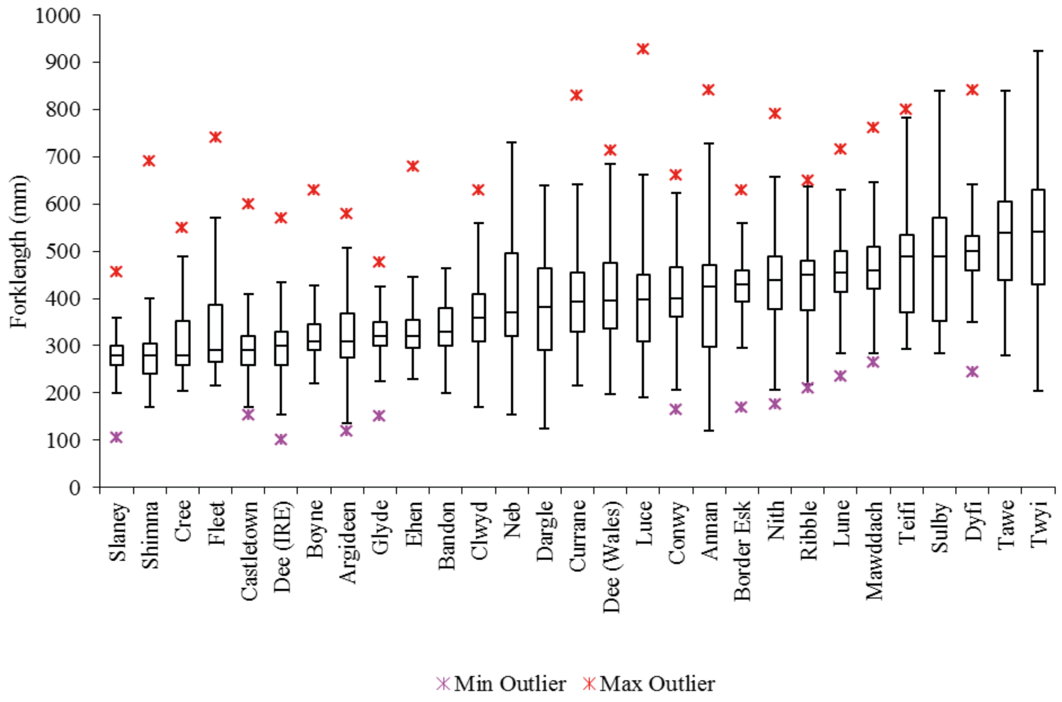

Figure 3.6.4 Ranked box-plots of median forklength (mm) of sea trout sampled in rivers where sample size exceeded 50 fish.

Table 3.6.3 Median, minimum and maximum forklengths (mm) of sea trout sampled from rivers where >50 fish sample size.

River	n	Median (mm)	Min	Max
Twyi	479	542	205	925
Tawe	61	538	280	840
Dyfi	269	500	245	840
Sulby	71	490	285	840
Teifi	107	490	292	800
Mawddach	77	460	265	760
Lune	432	456	234	716
Ribble	85	450	210	650
Nith	322	440	175	790
Border Esk	437	430	170	630
Annan	98	425	120	840
Conwy	78	400	165	660
Luce	236	398	190	927
Dee (Wales)	112	395	197	713
Currane	407	394	216	830
Dargle	125	382	125	640
Neb	109	370	154	730
Clwyd	89	360	170	630
Bandon	56	330	200	465
Ehen	230	320	230	680
Glyde	105	320	150	476
Argideen	355	310	120	580
Boyne	304	310	220	630
Dee (IRE)	589	300	100	570
Castletown	605	290	153	600
Fleet	182	290	215	740
Cree	78	280	205	550
Shimna	566	279	170	690
Slaney	227	279	105	457

3.7 Marine Sampling

3.7.1 Sampling Rationale

The extent of the coastline around the Irish Sea, which exceeds 6,500 km, presented many potential inshore survey sites in addition to the extensive area of offshore habitat. Division of the sampling area into zones identified specific areas where sampling would be conducted.

Sampling of marine zones was subdivided into two discrete activities. Inshore sampling would be primarily shore based or conducted from small boats by regional sampling teams familiar with each area or CSTP staff working with local teams or local individuals with expert knowledge. Sampling areas within these marine zones were prioritised based on the following criteria:

- Areas within zones where sea trout had previously been encountered by anglers or during previous sampling programmes, or where illegal netting activity was suspected, were to be sampled using CSTP survey nets or seine nets
- Areas within zones where sea trout had been taken on rod and line
- Areas adjacent to existing trap/net fisheries
- Areas within zones where experienced commercial net fishers operated, or had operated in the past, and were willing to provide samples or sample directly for the project

Regional crews selected sites based on these criteria harnessing all local knowledge in order to maximise sampling success. Any inshore marine sampling which necessitated deployment of nets was required to focus on the Irish Sea where the freshwater resource would have been intensively sampled in order to provide samples to develop stock discrimination tools.

Target sample was 100 sea trout per inshore marine zone within the Irish Sea. With 14 such zones (MZ05-MZ17 and MZ23 inclusive) (Figure 3.4.1) the overall target was 1400 fish from the inshore sampling effort.

The original CSTP project proposal identified four main netting methods that would be used to sample sea trout in the marine environment: coastal sampling using multi-mesh survey gill nets, trawling, draft netting (including haaf netting) and beach seining.

Offshore, surface trawling, which had been previously been successful in other salmonid coastal sampling programmes (Rikardsen et al., 2004; Sheehan et al., 2011), was the only nominated sampling method. Due to limits within the project in relation to available trawling sampling time and budget, potential areas for trawling were reduced by discounting Marine Zones over the deep central trough in the Irish Sea (ICES VIIa) which meant that sampling would be conducted in zones over relatively shallow water to maximise likely success. Despite the success of other trawl sampling programmes, notably Rikardsen at al., 2004 trawling was regarded by CSTP as an exploratory technique which would test the efficiency of the surface trawling technique with the aim of investigating the distribution of sea trout in specific areas.

Trawl sampling areas were restricted by limitations of dispensations from regulatory authorities on English and Welsh coastlines in the Irish Sea. Sampling from a large vessel (>10m) is confined to marine areas outside the 6 nautical mile (nm) fisheries limit and SACs are also deemed exclusion zones. Trawl sampling off the Welsh coast was carried out using a 10 m vessel which can operate inside the 6 nm limit.

Table 3.7.1 Marine net sampling methods used to collect sea trout samples for CSTP

Net type (general)	Specific type	Scientific or commercial sample	Sampled in	Description	Fishing method
Draft net Type 1	Ring haul net	Scientific	MZ06	Site specific net. 3" full stretched monofilament mesh x 60md x 100yds Up to 2010 the mesh size was 3.5" and a nylon mesh net was used.	Deploy from boat and fish perpendicular to shore (ends held by boat crew and shore crew) from point A to point B with the tide. Close draft at point B by rowing ashore and hauling. Night sampling.
Draft net Type 2		Scientific	MZ01 & 04	40 m draft net, 3.5" fsm.	Operated by 2 staff walking beach with net perpendicular to shore. Draft closed and hauled. Dusk/night sampling.
Draft net Type 3		Scientific	MZ08	Commercial salmon draft net – 4" fsm. Seasonal.	Deploy from boat encircling fish, row to shore and haul. Usually operated in daylight at traditional netting stations.
Draft Net Type 4		Scientific	MZ07	Draft Net, 80m 4.5" mesh	
Drift net		Scientific	MZ07	Site specific net 180m x 2.5", 3", 3.5" fsm mono, 1.5 m deep.	Deployed from boat at mid-tide. Attended drift to high water. Dusk/night fishing.
CSTP Gill net - 60m - 120m - 180m	CSTP survey multi-mesh	Scientific	MZ01, 04 – 10, 11 – 18, 22, 23, 29 & 30	6 x 10m panels of 0.4 mono (2.25", 3", 3.5", 4 ",4.75", 5.5" fsm) of monofilament totalling 60m (mounted length). All 30.5 meshes deep except 2.25" at 40.5 meshes deep. Floating and benthic type produced.	Deployed from shore usually at low water. Fished perpendicular or parallel to shore. Usually fished overnight but restrictions of netting license applied to sampling in Wales.
Gill net Type 2		Scientific	MZ06	Site specific net 70m 2.75", 3", 3.5", 4" fsm , 2m high	Deployed by boat; fished flooding tide over shallow water. Dusk/night fishing
Gill net Type 3		Scientific	MZ06	Site specific net 70m 3.5" fsm, 2m high	Deployed by boat; fished flooding tide over shallow water. Dusk/night fishing.
Gill net Type 4		Scientific	MZ16 & 18	Site specific net 200m x 60md x 100mm fsm floating gill net	EA Llandarcy exploratory survey for CSTP
Gill net Type 5		Scientific	MZ10 & MZ12	30m multi mono panel mesh	Deployed from RIB
Gill net Type 6		Scientific	MZ14	150m 4" mesh monofilamement	
Gill net Type 7 - A - B - C - D - E		Scientific	MZ12	a- 100m, 3 ½" mesh b- 200m, 3 ½" mesh c- 300m 4"mesh d- 400m, 4x100m, 300x4", 100x3 ½" e- 700m 4"mesh	Set from boat; short soak time 1-2 hrs for majority of settings

Haaf net	Scottish waters	Commercial	MZ10	The Haaf (or sea net) is mounted on a rectangular frame 5m long by 1 – 1.5 m high, supported by three legs.	Traditional method of fishing for salmon and sea trout on the rivers of the North West, notably the Lune, Ribble and Solway. Frame is placed across the current by a fisherman. Fish entering net are enveloped and net is lifted (Galbraith et al, 2004).
Seine net Type 1 - A - B	Single mesh	Scientific	MZ13-15	Type 1 a = 20m length and and Type 1 b= 60m length small meshed seine used by Bangor University.	
Seine net Type 2		Scientific	MZ16 & 17	45m seine net, mesh 20mm wing, 5mm centre 30m seine (same configuration)	EA Strategic survey
Seine net Type 3		Scientific	MZ12	60 m seine (same configuration)	EA Strategic survey
Stake net	Stake net used in Scottish waters	Commercial	MZ10	Net is 400m long and mesh size is ≥ 90mm stretched mesh. Consists of a long net of heavy twine, suspended on tall stakes, which extends seaward for a prescribed distance (often referred to as the long arm). The long arm is semi-permanent in that it remains in situ throughout the fishing season. Net is set at right angles to the beach and gets flooded out twice per day by the tidal flood. Set into the long arm are a number of pockets (fish courts) designed to trap fish as they migrate along the coast, coming up against the long arm, they are trapped as they swim seaward to deeper water.	Traditional form of fishing exercised in Scottish coastal waters to capture migrating salmon and sea trout. Permanently deployed for season. Netsman in attendance as net is uncovered by the receding tide and any fish captured are dispatched. All nets operate within season i.e. on the Nith 25th Feb – 9th September but generally fishing does not commence until April.
Trammel net 1		Scientific	MZ10	50m, 2m deep multi mono	
Trammel net 2	Coracle fishery - Welsh artisan fishery	Commercial	MZ16, 17	Net is a single walled trammel restricted to 12 metres wide with an opening of 45cm. The legal minimum mesh size for a coracle net is 10cm. 2 types of nets used depending on season. In spring the mesh size is usually 15cms because the fish are generally larger. In early summer the mesh size is changed to the legal minimum.	Traditional form of fishery only permitted in the specific tidal areas of the rivers Taf, Tawe and Teifi. (COUNCIL REGULATION (EC) No 510/2006 on protected geographical indications and protected designations of origin "West Wales Coracle Caught Sewin"). Sea trout from the Tawe and Teifi sampled by this method were included in the river scale sample total for both.
Trawl net 1	SALSEA	Scientific	MZ05-08, 22, 23, 29 & 30.	SALSEA salmon smolt trawl – surface fishing	8 day CSTP sampling cruise in 23m trawler
Trawl net 2	Modified S net	Scientific		77m length, 9m wide pelagic trawl, modified for surface fishing by addition of plastic floating collar	5 days of targeted sampling off Welsh cost in <10m trawler
Fish screen	Heysham 2 power plant	Scientific	MZ12	A cooling water intake of 50 m3s-1 operates at this plant and has screens with 10 mm spacings.	Samples of fish trapped on the intake were periodically available to the survey team.

3.7.2 Sampling Methods

Inshore sampling

For inshore sampling standardised CSTP survey gill nets, based on standard gill net design (Potter and Pawson, 1991), were distributed to all sampling teams. Benthic multi-mesh survey nets were the preferred option as they would be capable of capturing sea trout across the full size range of the population from post-smolts (>18cm) up to larger multi-spawners. O'Grady (1981) has shown that a gang of gill nets incorporating a range of mesh sizes from 52mm to 127mm (stretched mesh) is effective at capturing brown trout ranging from 19.8 to 48 cm in Irish lakes. CEFAS studies have shown that mesh sizes ranging from 53mm to 139mm can capture sea trout in the range 25 to 65cm (Potter *pers. comm*). A multipanelled monofilament net based on these considerations was designed for the CSTP project (specification in Table 3.7.1) and it was envisaged that this would be the main sampling methodology for all teams. Standardised sampling would facilitate spatial and temporal CPUE comparisons.

Deployment areas were selected by the teams and all were requested to sample regularly throughout the year, at least on a seasonal basis, in order to collect different life stages (pre-adult and adult) and to determine temporal fish distribution patterns. Survey data were collected on a CSTP survey sheet (Appendix 3.10). The low CPUE values recorded in 2010 from CSTP survey gill nets resulted in teams investigating and adapting complementary sampling methods, particularly existing or previously used commercial methods, and identifying supplementary sources of sea trout, as the primary objective was to obtain samples for the various tasks. This process resulted in site specific netting techniques including variants of gill netting, draft netting and drift netting being used in some areas, with local expert input, where the preferred standard approach was shown to be unlikely to yield sufficient samples. Greater emphasis was also placed on sourcing samples from commercial sources and the broadening of sampling approach resulted many different gears and approaches being used.

The multiplicity of sampling gears used to sample sea trout (whole bodies and scales) at sea are presented in Table 3.7.1. A total of 28 different gears were utilised; all are grouped by general net type (i.e. draft, drift. gill, seine etc) and the marine zone in which it was used is identified. Gear specification and, where provided by survey teams, method of deployment is described. Sea trout were also collected from fish screens at Heysham 2 Power station in Lancashire.

Offshore sampling

Offshore sampling was conducted using a modified mid-water trawl (Swan Net Gundry Ltd), loaned to the project by the Marine Institute, which had previously been used for the SALSEA project to sample salmon smolts. The headline was fitted with a plastic floating collar and the trawl was fished at surface level. A transducer mounted to the headline monitored fishing depths and general net activity. Trawl dimensions and specifications are illustrated in Appendix 3.11. The trawl was operated by a single 23 m trawler (500 KW), Naomh Iuda, and maximum trawl speeds were up to 5 knots depending on tidal conditions and wind speed. At trawl start and end points GPS locations, time and trawl speed were recorded together surface temperature, salinity and water depth.

Following on from experimental trawling for sea trout in the Irish Sea (ICES Division VIIa) in August 2011, a second series of tows were conducted in several areas off the south Wales coast in 2012. Sampling was conducted using a mid-water sprat trawl [77 m (250') long x 9.2 m (30') deep] in September and October 2012. The net was modified for the second set of trawls (21/9, 22/10, 23/10 and 30/10) by fitting a plastic floating collar to try to fish the trawl at surface level. The trawl was operated by the 9.93 m Emily Rose (LT70). At trawl start and end points GPS locations and time were recorded together surface temperature and salinity. In addition the range of water depth fished during the trawl was recorded.

The catch was transferred to a holding tank and sorted to species level. All species other than sea trout were discarded as per conditions of various derogations. Sea trout were measured, individually bagged, labelled and stored on ice in the hold (4°C).

3.8 Marine Zones Sampling Results

The total number of marine sea trout available to the CSTP from all sources was 1367 (Table 3.8.1). This total includes 132 additional samples (mainly scales) from sites within the project area which were collected in 2001 and 2006-2008 and donated by various fisheries agencies.

Samples were collected from sites in all inshore zones sampled in the Irish Sea and from offshore sites in MZ29 and 30 (Figure 3.8.1). Targeted (scientific) sampling by regional sampling teams, CSTP officers and other surveys yielded 750 samples (54.9%) of the total (Figure 3.8.2), followed by 391 fish from commercial sources (28.6%) (Table 3.8.2) and 103 (7.5%) from anglers. Rod caught fish contributed significantly to catches in some locations; rod catch comprised 89% of the total sample in MZ13 (north Wales) (Table 3.8.1). Samples from the fish screens at Heysham Power Station (106 fish) and a small number of fish kills were combined to provide 123 fish of the total (9.0%)

Sampling locations (scientific and other netting), sampling dates, catches of sea trout and the most commonly recorded fish species are presented in Appendix 3 (Section 3.13)

Table 3.8.1 Numbers of sea trout sampled in CSTP Marine Zones (all methods)

Marine Zone	Sample Year								
	2001	2006	2007	2008	2009	2010	2011	2012	Total
MZ01		1						3	**4**
MZ03	1					1		2	**4**
MZ04				1	9	16	1	14	**41**
MZ05						35	74	9	**118**
MZ06				1		29	72	114	**216**
MZ07		7			37	35	32	11	**122**
MZ08			5	12	1	1	31	39	**89**
MZ09					20	52	19	12	**103**
MZ10				89	72	91	37	21	**310**
MZ11							9	12	**21**
MZ12							13	107	**120**
MZ13					2	6	22	5	**35**
MZ14						3	20	18	**41**
MZ15				2			2	3	**7**
MZ16			12			1	3		**16**
MZ18				1			4		**5**
MZ23						14	24	14	**52**
MZ29							16		**16**
MZ30							47		**47**
Total	**1**	**8**	**17**	**106**	**141**	**284**	**426**	**384**	**1367**

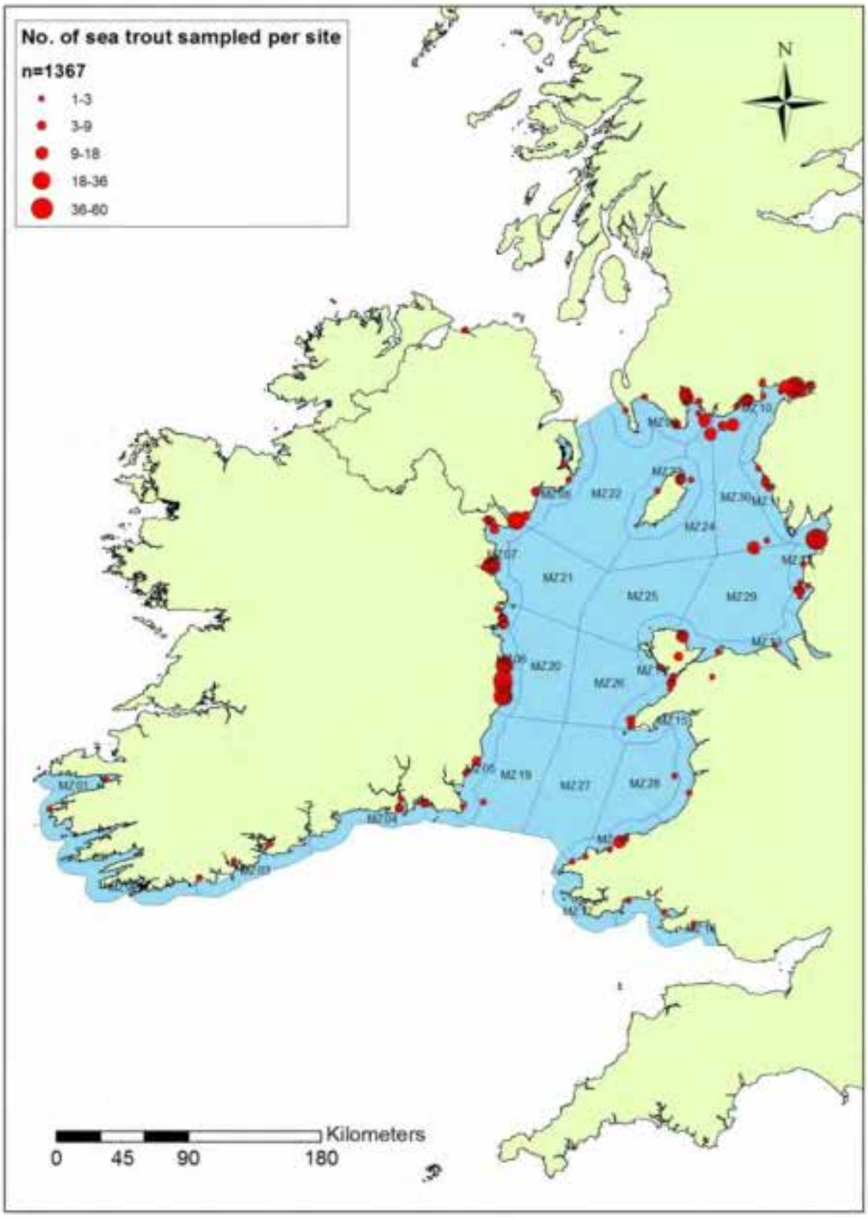

Figure 3.8.1 Numbers of sea trout sampled in Marine Zones by site (all methods)

Sea trout were captured in 19 marine zones and the sample target of 100 fish per zone was achieved from six of these. The greatest numbers of samples were obtained in 2011, followed by 2012 and 2010. Large samples sizes were taken from inshore zones on the east coast of Ireland, the Scottish coast and MZ12 (Heysham site). Low sample sizes were recorded for zones in Wales (MZ13 to MZ18 inclusive despite intensive targeted sampling in several of these zones.

The largest number of samples was recorded from MZ10 (Solway) and was dominated by samples from the commercial catch which contributed 91% of samples for the zone (Figure 3.8.2), primarily from the stake net and haaf net fisheries. Samples from the commercial catch also dominated in MZ09 where the stake net fishery contributed the majority (Table 3.8.3). Scientific targeted sampling contributed the majority of samples along the east coast of Ireland (MZ05-MZ08), and MZ14 (North Wales), MZ23 (Isle of Man) and while samples from MZ29 and MZ30 came from CSTP trawling. Angling contributed the majority of samples in MZ04 (south coast of Ireland) and MZ13 (north-Wales).

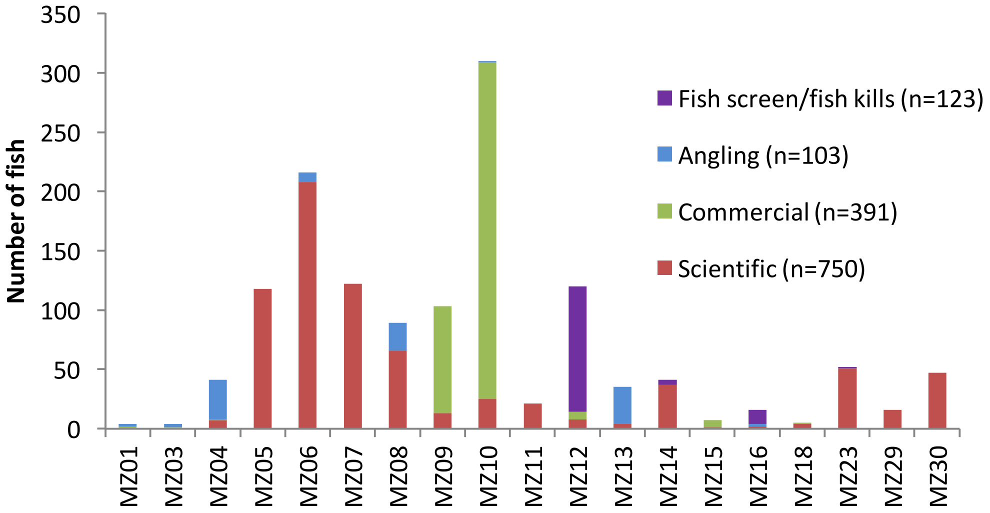

Figure 3.8.2 Numbers of sea trout available to CSTP (n=1367) for each Marine Zone by grouped generalised sampling method

Table 3.8.2 Numbers of sea trout sampled by commercial engines in Marine Zones for CSTP

Marine Zone	Method	2001	2006	2008	2009	2010	2011	2012	Total
MZ01	Drift Net		1					1	**2**
MZ03	Unknown	1							**1**
MZ04	Drift Net			1					**1**
MZ09	Coastal Net					4			**4**
	Cobble Net				1		2		**3**
	Gill Net						2		**2**
	Seine Net					2			**2**
	Stake Net				19	45	6	8	**78**
	Unknown					1			**1**
MZ10	Coastal Net						1		**1**
	Gill Net						10		**10**
	Haaf Net				23	43	4	7	**77**
	Stake Net			89	49	48	10		**196**
MZ12	Gill Net							6	**6**
MZ15	Gill Net			2					**2**
	Unknown						1	3	**4**
MZ18	Unknown			1					**1**
Subtotal		**1**	**1**	**93**	**92**	**143**	**36**	**25**	**391**

Table 3.8.3 Numbers of sea trout sampled by anglers in Marine Zones for CSTP

Marine Zone	**Sample Year**						
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**Total**
MZ01						2	**2**
MZ03				1		2	**3**
MZ04			9	9	1	14	**33**
MZ06		1		3		4	**8**
MZ08	5	12	1	1	3	1	**23**
MZ10					1		**1**
MZ13			2	4	20	5	**31**
MZ16					2		**2**
TOTAL	**5**	**13**	**12**	**18**	**27**	**28**	**103**

A total of 382 individual scientific sampling events were conducted between 2009 and 2012 which provided 689 sea trout for the project (Table 3.8.4).

Table 3.8.4 Number of scientific (targeted) sampling events conducted between 2009 and 2012 and associated CPUE values. Net type includes all variants of the specific netting methodology carried out during the project. CPUE is expressed as catch per unit sampling event.

Net type	No. sampling events	Total catch	CPUE	SD	Min. no. captured	Max. no. captured
Draft Net	63	449	7.1	8.2	0	36
Drift Net	4	7	1.8	2.2	0	5
Gill Net	207	146	0.7	1.2	0	7
Seine Net	66	13	0.2	0.7	0	5
Trammel Net	5	4	0.8	1.1	0	2
Trawl Net	37	70	1.9	4.2	0	16
Total	**382**	**689***	**1.8**			

*61 fish not included as survey data details were incomplete.

Inshore Sampling

Survey teams (both project-specific and teams from other agencies) used the preferred standard CSTP multi-mesh survey net in inshore zones but low catches in many areas resulted in teams investigating complementary sampling methods (Table 3.7.1).

The total effort for inshore sampling (i.e. all targeted sampling events less trawl sampling) was 345 sampling events contributing 619 samples (Table 3.8.4). Similar gear types are grouped to facilitate a comparison of efficiency. Gill nets were the most frequently deployed net type with 207 deployments (54% of all netting effort) (Table 3.8.4). This netting group type comprises five different gill net designs including the standard CSTP multi-mesh survey net. CPUE of 0.7 sea trout per sampling trip was the one of the lowest for this type of net despite the high relative sampling intensity. Draft nets accounted for the highest CPUE of 7.1 sea trout and the highest maximum of 36 fish. Four draft netting methods were used over the course of the project; the most productive was the ring haul method described in Table 3.7.1. Drift netting was productive off the north-east coast of Ireland where four individual sampling efforts were carried by the CSTP team. Seine netting was the least successful. Variability in CPUE was a feature of the results and was reflected by high standard deviation values for all methods.

Inshore net sampling (all net types, varying soak times and effort) was carried out in all months except December (Figure 3.8.3 A). Sampling activity peaked in the March to September period to coincide with periods when sea trout were expected to be available at sea. Particular life stages targeted were kelts in early Spring, smolts in April and May, and post-smolts, maidens and older sea trout thereafter. Exceptionally low numbers of sea trout were captured over the course of the targeted inshore netting sampling programme. Median values of zero sea trout per sampling effort were recorded for all months except August where a value of 1 sea trout was recorded (Figure 3.8.3 B). 75th percentile values were extremely low and the maximum value of 2 was recorded in March, May, August and September. The results were characterised by high value outliers – these were one-off values from samples collected using draft net type 1 (ring haul net) at sampling sites on the east coast of Ireland.

Analysis of pooled data (i.e. net servicing and retrieval time (h)) showed that the highest level of inshore net sampling activity was undertaken at night and particularly between 20.00 hr and 02.00 hr throughout the 2010-2012 sampling period Figure 3.8.3 C. In terms of catches no particular pattern was evident but zero values were the most frequently recorded. Where sea trout were captured values were generally < 5 fish, with some outliers, and up to 36 fish being captured in one event. Sampling in daylight hours (08.00 hr to 18.00 hr) yielded few samples and although the majority of night sampling yielded zero sea trout these data suggest that night sampling is likely to be more successful. In several instances sampling teams observed sea trout becoming more active when light levels decreased (i.e. nightfall).

Length (mm forklength) frequency distribution for all marine samples combined (Figure 3.8.5) indicated that sea trout populations within the project area were dominated by larger fish (mode 440 mm; range 140 – 840 mm). Examination of the length frequency distributions for all sea trout (all methods combined) in individual marine zones (Figure 3.8.9) demonstrate total sample size by zone and, importantly, identify fish length bias for some zones. While sample size reflected sampling frequency and fish availability, the length frequency bias evident in some zones was in large part a function of the dominant sampling methodology. In Ireland, where the commercial fishery for sea trout (and salmon) is closed, the larger samples on the east coast (MZ05, MZ06 and MZ07) were taken by former commercial net operators using traditional draft netting methods (Table 3.7.1) where the mesh size was 8.89 cm (3.5”). Large sea trout (>42 cm) predominated in MZ08 on the north coast of Ireland where a large mesh salmon draft net was used. On the Scotland coast fish were sampled from several stake net fisheries and dominated samples taken in MZ09 and MZ10 with the majority of fish exceeding >36cm forklength. On the east coast of England (MZ11) CSTP survey nets yielded a small sample across a broad size range. Smaller sea trout 14-18 cm dominated samples from MZ12 which were provided by EA personnel sampling the drum screens at Heysham Nuclear Plant and one of the few sites where smaller sea trout were taken at sea. Thirty one (89%) of the 35 fish sampled in MZ13 (north Wales coast) were provided by angling despite extensive sampling by the CSTP team using many different methodologies.

Trawl-caught sea trout off Morecambe (Marine Zone 29) on 13/8/2011

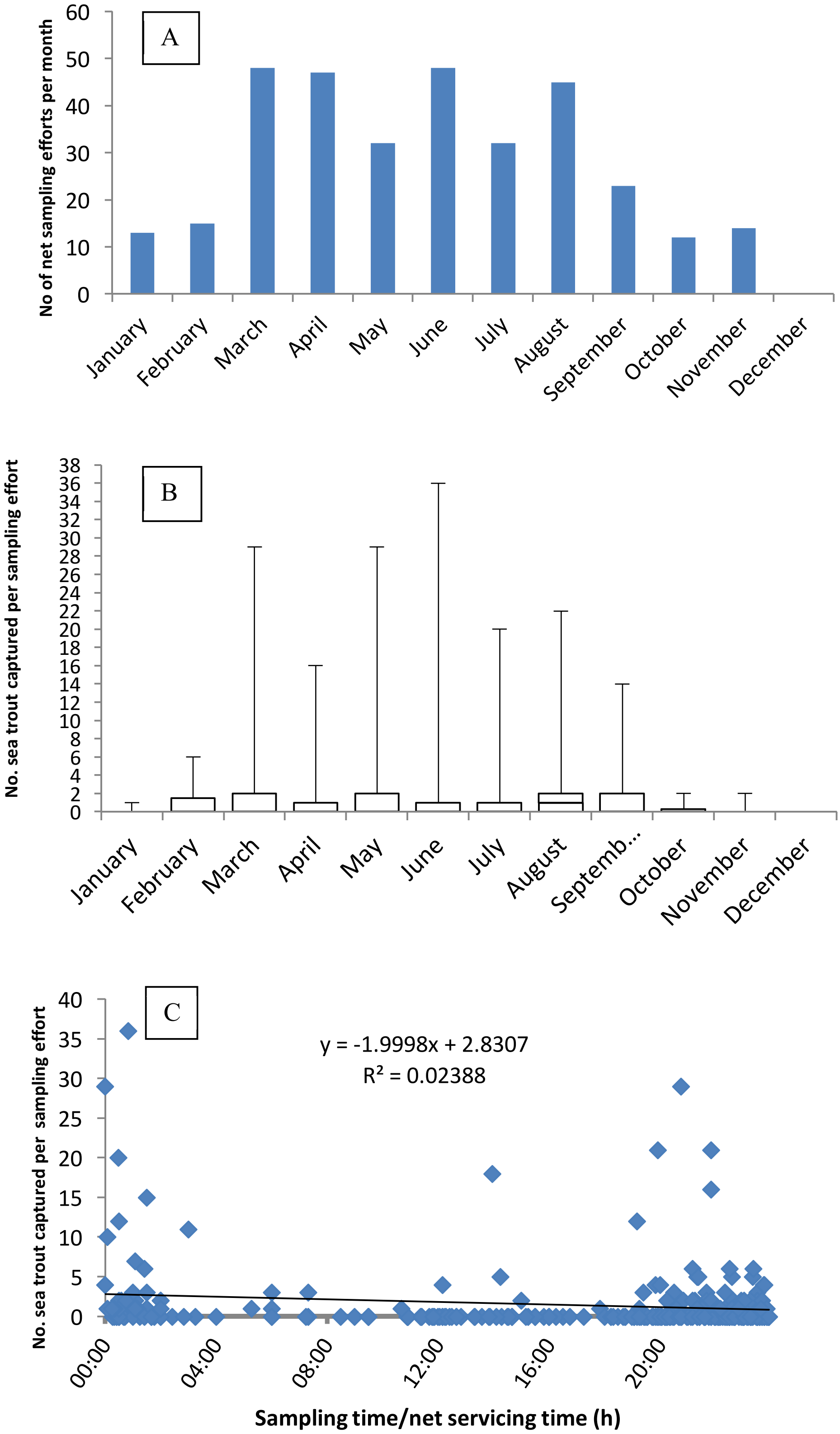

Figure 3.8.3 A – C. Inshore net sampling statistics for all years combined (2010-2012): A - sampling efforts by month; B - box plot of sea trout captured per sample effort; C – sea trout catch by time of day

A fish kill at sea in 2007 was the primary source of samples in MZ16. No samples were recorded for MZ17 where trawling and two inshore netting surveys were conducted. Five fish were sampled in MZ18. Marine Zone 23 referred exclusively to the Isle of Man where 40 sampling surveys using CSTP survey nets yielded 52 sea trout from 24 to 70cm in length.

Table 3.8.5 details the results of sampling in each zone by specific method. Scientific or targeted sampling with customised site-specific nets was the most effective and efficient sampling gear (Table 3.8.5). Examples include high CPUE values in MZ05, MZ06, MZ07 and MZ08 where site-specific draft nets were used.

CSTP standard nets were fished extensively and intensively in the majority of Irish Sea inshore zones during the sampling programme. Analysis of catches for standard 60m CSTP multimesh nets shows consistent CPUE values of approximately 1 sea trout per sampling event in four of the seven marine zones this method was used (Table 3.8.5 and Figure 3.8.4). Even in MZ23 around the Isle of Man where 38 individual sampling events were conducted and where sampling intensity was highest for this method, the CPUE was similar. Lower CPUE was recorded in the remaining zones (MZ10 - Solway and two zones in Wales (MZ13 and 14). Although sampling intensity was high in both zones in Wales, where 12 and 21 individual deployments of the standard CSTP net were undertaken respectively, low fish numbers combined with the conditions of the sampling permission (i.e. hourly servicing and re-setting) impacted on sampling success.

In several zones in England, Wales and the Isle of Man CSTP nets were extended by joining two or three nets so as to deploy 120m or 180m sampling gears. With the exception of a CPUE of 6 fish/sampling trip for MZ23 (Table 3.8.5 and Figure 3.8.4) for a 120m net, CPUE for extended gear was less than 0.5 fish and several sites recorded zero values. CPUE for the 180m net were also low. It was evident that the preferred standard sampling methodology (i.e. 60m CSTP multimesh net) or variants of it would not deliver the 100 sea trout per zone sample target within the available sampling window. Furthermore, the sampling effort required to attempt to achieve the target would be prohibitive for all sampling teams. The multiplicity of gears used in some zones reflected the low catches recorded generally and the attempts to identify the most effective sampling methodologies which would yield sufficient samples for the project.

Table 3.8.5 CPUE for net sampling undertaken for CSTP. Number of netting surveys and total number of sea trout captured in each Marine Zone is presented. Samples from spurious sampling included**.**

Marine Zone/ Method	No. surveys by method	No. sea trout captured	CPUE	CPUE SD	Min no. captured	Max no. captured
MZ01	**3**	**0**				
Draft Net Type 2	2	0	0.00	0.000	0	0
MZ04	**10**	**6**				
CSTP multi mesh 60m	4	0	0.00	0.000	0	0
Draft Net Type 2	4	0	0.00	0.000	0	0
Waterford Drift	2	6	3.00	2.828	1	5
MZ05	**23**	**136**				
CSTP multi mesh 60m	11	12	1.09	1.578	0	4
Draft Net Type 1	11	123	11.18	10.722	0	36
MZ06	**45**	**212**				

CSTP multi mesh 60m	2	2	1.00	1.414	0	2
Draft Net Type 1	18	170	9.44	9.805	0	29
Gill net Type 2	22	37	1.68	1.524	0	6
Gill net Type 3	1	3	3.00	n.a.	3	3
Trawl net Type 1	2	0	0.00	0.000	0	0
MZ07	**32**	**95**				
Draft net Type 4	21	81	3.86	3.410	1	13
Drift net	4	7	1.75	2.217	0	5
Trawl net Type 1	7	7	1.00	1.826	0	5
MZ08	**7**	**68**				
Draft net Type 3	5	68	13.60	5.899	8	22
Trawl net Type 1	2	0	0.00	0.000	0	0
MZ09	**13**	**14**				
CSTP multi mesh 60m	13	14	1.08	1.115	0	3
MZ10	**26**	**5**				
CSTP multi mesh 60m	5	1	0.20	0.447	0	1
Haaf net	1	0	0.00	n.a.	0	0
Gill net Type 5	15	0	0.00	0.000	0	0
Trammel	5	4	0.8	1.100	0	2
MZ12	**17**	**2**				
Gill net Type 5a -100m	1	0	0.00	n.a.	0	0
Gill net Type 5b - 200m	1	0	0.00	n.a.	0	0
CSTP multi mesh 120m	1	0	0.00	n.a.	0	0
Gill net Type 5c - 300m	3	0	0.00	0.000	0	0
CSTP multi mesh 180m	4	1	0.25	0.500	0	1
Gill net Type 5d - 400m	2	0	0.00	0.000	0	0
Seine Type 1a	2	0	0.00	0.000	0	0
Gill net Type 5 e- 700m	3	1	0.33	0.577	0	1
MZ13	**25**	**2**				
CSTP multi mesh 60m	12	0	0.00	0.000	0	0
CSTP multi mesh 120m	9	1	0.11	0.333	0	1
Seine Type 1b 60m	3	0	0.00	0.000	0	0
MZ14	**100**	**29**				
CSTP multi mesh 60m	21	6	0.29	0.717	0	2
CSTP multi mesh 120m	20	8	0.40	0.681	0	2
CSTP multi mesh 180m	1	0	0.00	n.a.	0	0
Seine Type 1a 60m	52	7	0.13	0.345	0	1
Gill net Type 6 150m	2	3	1.50	0.707	1	2
Seine Net Type 3 – 60m	1	5	5.00	n.a.	5	5
Seine Net Type 1a 20m	3	0	0.00	0.000	0	0
MZ15	**6**	**0**				
CSTP multi mesh 120m	3	0	0.00	0.000	0	0
Seine Type 1b 60m	2	0	0.00	0.000	0	0
Seine Net Type 1a 20m	1	0	0.00	n.a.	0	0
MZ16	**8**	**1**				
Seine Net Type 2 - 30m	1	1	1.00	n.a.	1	1
Trawl net Type 2	3	0	0.00	0.000	0	0
Gill net Type 4	4	0	0.00	0.000	0	0
MZ17	**4**	**1**				
Seine Net Type 2 - 45m	1	1	1.00	n.a.	1	1
Trawl net Type 2	3	0	0.00	0.000	0	0
MZ18	**15**	**4**				
Trawl net Type 2	5	0	0.00	0.000	0	0
Gill net Type 4	10	4	0.40	0.966	0	3

MZ22	**3**	**0**				
Trawl net Type 1	3	0	0.00	0.000	0	0
MZ23	**44**	**51**				
CSTP multi mesh 60m	38	45	1.18	1.522	0	7
CSTP multi mesh 120m	1	6	6.00	n.a.	6	6
Trawl net Type 1	4	0	0.00	0.000	0	0
MZ29	**3**	**16**				
Trawl net Type 1	3	16	5.33	5.859	1	12
MZ30	**4**	**47**				
Trawl net Type 1	4	47	11.75	3.500	8	16
Grand Total	**384**	**689**				

Nith Stake Net No. 2

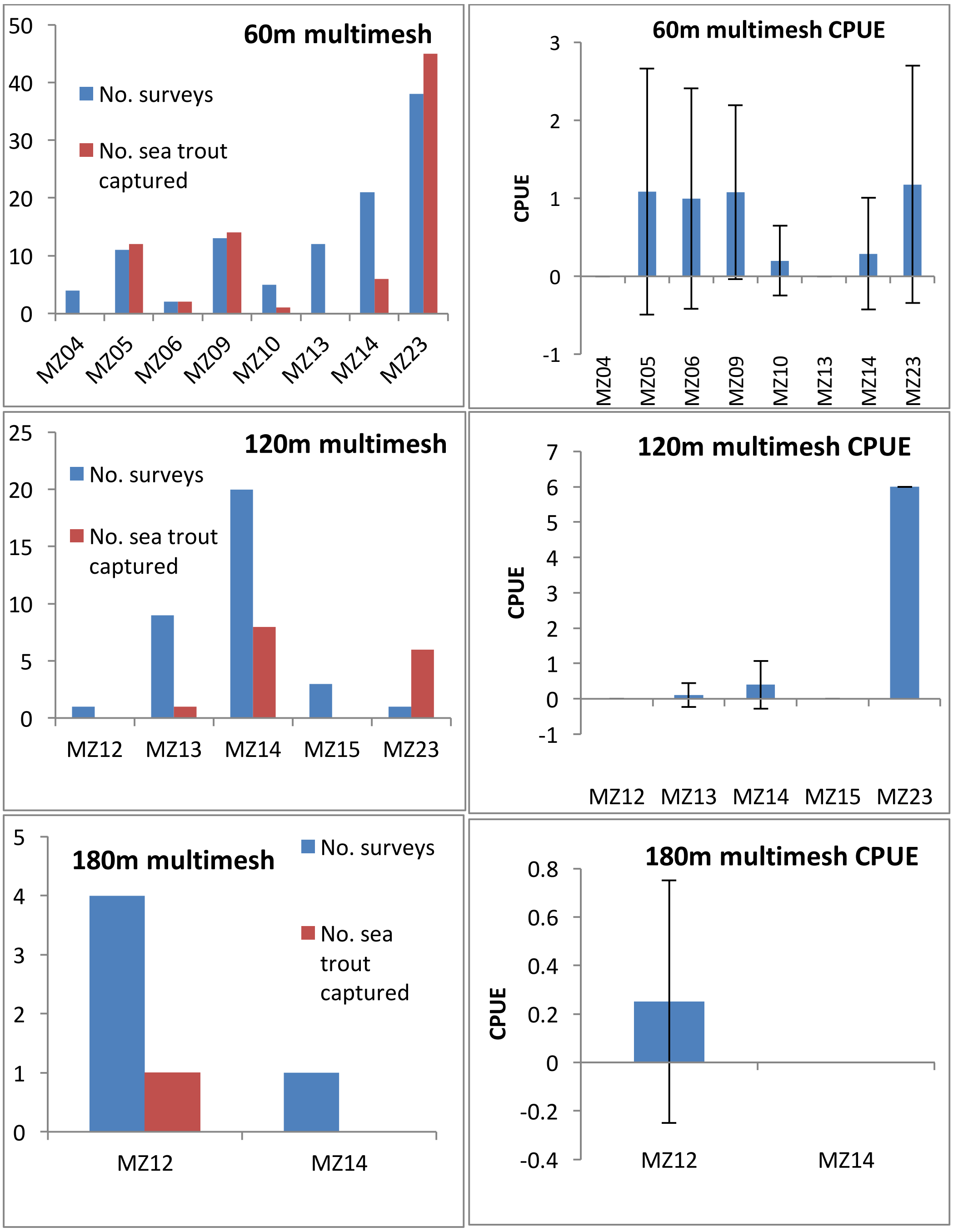

Figure 3.8.4 Sampling frequency, sea trout catch numbers, and CPUE (catch of sea trout per sampling event) for CSTP standard 60m monofilament multimesh nets. 120m and 180m settings were two and three nets combined. NB - sampling effort duration was variable.

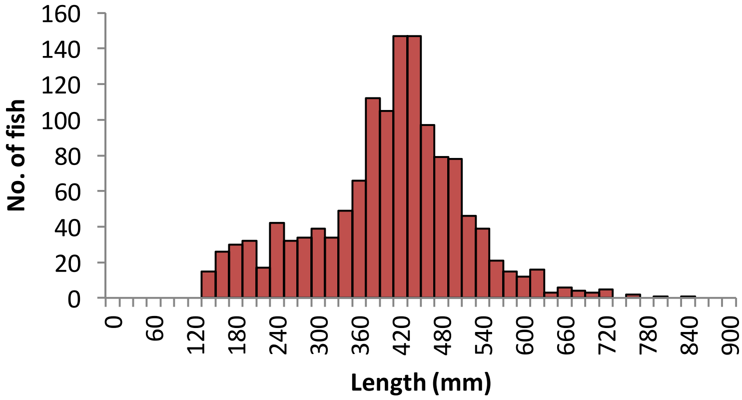

Figure 3.8.5 Length(cm) frequency of marine caught sea trout available to the CSTP 2009-2012 (n=1355). Additional samples from 2001, 2006-2009 from other programmes included

Offshore Sampling

Two periods of intensive trawl surveys were undertaken over the course of the project. Period 1 in August 2011 focussed on the northern portion of the Irish Sea. Trawl tracks are shown in Figure 3.8.6 and survey details, including catches for this survey, are presented in Table 3.8.6. The sampling route followed a course northwards from Dublin along the coast, then east sampling through MZ09 and, and south into Isle of Man waters. Subsequently outer Solway (MZ30) was sampled followed by Morecambe Bay and a return to the east coast of Ireland.

A total of 24 surface trawls were made over the duration of the survey undertaken between 8-14 August 2011 inclusive. 9 hauls contained sea trout and a total of 69 were captured. Sea trout were recorded outside Solway, off Morecambe gasfields and Dundalk Bay (Figure 3.8.6). All sites which produced sea trout were relatively shallow (<40 m) and were situated in extensive depositing areas with sand dominated substrate outside significant river estuaries. No sea trout were recorded in any other habitat type.

The mean CPUE over the survey was 1.0 fish/hr trawling (range 0 - 5.3). Sea trout ranged from 19-30 cm in length with a mode of 24 cm (Figure 3.8.7). Jellyfish dominated the bycatch, with sprat also very common (recorded in 75% of all trawls), followed by small numbers of sandeel (25% occurrence) and herring. Small numbers of various other species were recorded also (Table 3.8.6).

For Period 2, where a 9.9 m trawler was utilised for the second experimental surface trawling in September/October 2012, the target sampling areas were Turbot Bank (near Milford Haven), Carmarthen Bay and Cardigan Bay (Figure 3.8.8). In total, 7 trawls were made over the duration of this survey: 3 in Turbot Bank, 4 in Carmarthen Bay and 2 in Cardigan Bay (Table 3.8.7), with tows (where the net fished properly) ranging from 1 – 2.5 hr duration. The catch was very limited. No sea trout were caught and bycatch consisted of juvenile sprat plus a few juvenile mackerel (Table 3.8.7).

In comparison to other generalised sampling methods utilised over the course of the CSTP trawling was relatively successful yielding almost 2 fish per trawl event (Table 3.8.4) but the high standard deviation observed for all netting types demonstrated the variability in sampling success.

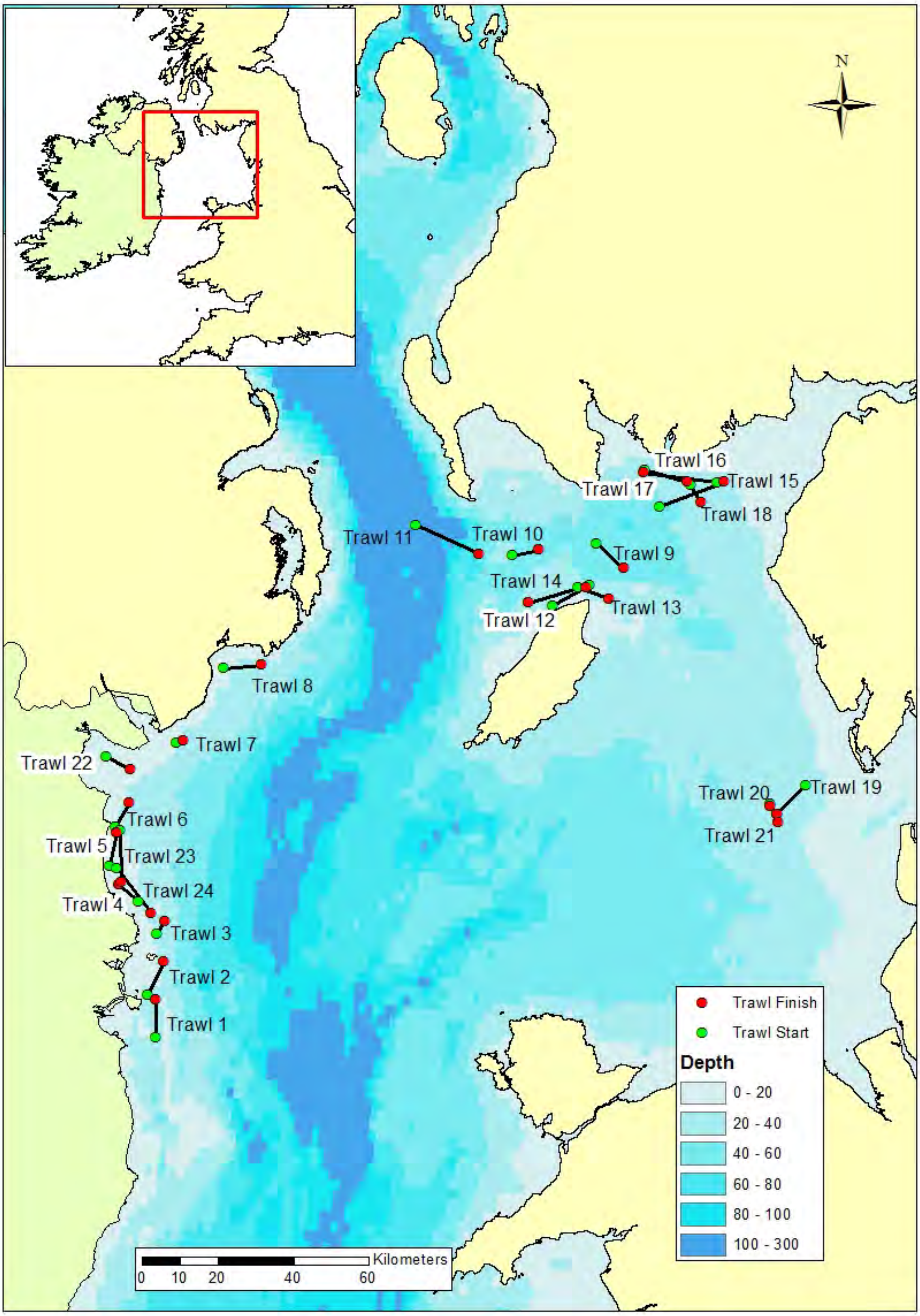

Figure 3.8.6 CSTP surface trawling tracks, August 2011.

Table 3.8.6 Details of CSTP trawling survey – 8/8/2011 to 14/8/2011

Area	Marine Zone	**Code**	**Date**	**Start GPS - Trawler N**	**Start GPS - Trawler W**	**End GPS - Trawler N**	**End GPS - Trawler W**	**Av. Trawl Speed (knots)**	**Trawling time (hr)**	**ST catch**	**ST CPUE no. fish/hr trawling**	**By-catch volume (bin)**	**Main bycatch species**
Ireland - north east - north of Howth	MZ06	Trawl 1	08/08/2011	53.18.00	05.58.45	53.23.32	05.59.20	3.5	1.50	0	0.0	1.0	J, S, W, Wh, M
Ireland - north east - north of Howth	MZ06	Trawl 2	08/08/2011	53.23.98	06.01.23	53.28.86	05.58.05	2.8	2.00	0	0.0	1.2	J, S
Ireland - north east - north of Howth	MZ06	Trawl 3	08/08/2011	53.32.69	06.00.13	53.34.61	05.58.50	2.4	1.00	0	0.0	1.0	J, S
Ireland - north east	MZ07	Trawl 4	09/08/2011	53.37.06	06.05.12	53.39.22	06.10.25	2.9	1.25	0	0.0	0.8	J, S
Ireland - north east	MZ07	Trawl 5	09/08/2011	53.41.84	06.12.83	53.46.58	06.11.82	2.5	1.17	0	0.0	0.5	J, S, Sa, H
Ireland - north east	MZ07	Trawl 6	09/08/2011	53.47.47	06.12.25	53.50.97	06.09.44	2.8	1.75	0	0.0	0.6	J, S, Wh
Ireland - north east	MZ07	Trawl 7	09/08/2011	54.00.17	05.59.32	54.00.60	05.57.60	3.0	0.67	0	0.0	0.5	J, S
Ireland - north east	MZ07	Trawl 8	09/08/2011	54.11.33	05.49.40	54.12.34	05.40.21	3.0	2.00	0	0.0	0.1	J, S
Scotland - south west coast	MZ09	Trawl 9	10/08/2011	54.33.25	04.20.71	54.29.90	04.13.60	3.6	1.00	0	0.0	0.5	J, H, Sa
Scotland - south west coast	MZ09	Trawl 10	10/08/2011	54.30.65	04.41.02	54.31.77	04.34.71	2.0	2.50	0	0.0	1.0	H, J, Sa
Scotland - south west coast	MZ09	Trawl 11	10/08/2011	54.33.96	05.05.33	54.30.60	04.49.24	2.0	2.67	0	0.0	0.5	J, S
Isle of Man - North	MZ23	Trawl 12	11/08/2011	54.23.86	04.30.37	54.26.82	04.22.55	1.5	4.50	0	0.0	0.1	Sa, H, J, octopus
Isle of Man -	MZ23	Trawl	11/08/2011	54.26.82	04.24.57	54.25.46	04.16.85	3.0	4.00	0	0.0	0.1	Sa, H, Wh

North		13											
Isle of Man - North	MZ23	Trawl 14	11/08/2011	54.27.26	04.21.68	54.24.09	04.36.34	3.4	3.00	0	0.0	0.1	W
Scotland - Solway	MZ30	Trawl 15	12/08/2011	54.39.04	04.05.61	54.43.14	03.50.10	4.0	3.00	16	5.3	0.5	S
Scotland - Solway	MZ30	Trawl 16	12/08/2011	54.43.00	03.51.75	54.43.73	04.10.14	3.8	2.67	13	4.9	0.2	J, G
Scotland - Solway	MZ30	Trawl 17	12/08/2011	54.44.04	04.09.91	54.42.82	03.59.13	2.1	3.00	10	3.3	0.5	S, J, Sa
Scotland - Solway	MZ30	Trawl 18	12/08/2011	54.42.34	03.58.20	54.40.02	03.55.60	2.3	2.50	8	3.2	0.6	S, J, Sa
England – east coast - Morecambe Bay	MZ29	Trawl 19	13/08/2011	54.00.51	03.26.33	53.56.15	03.33.01	2.5	3.00	3	1.0	0.8	S, J, G
England – east coast - Morecambe Bay	MZ29	Trawl 20	13/08/2011	53.56.21	03.33.01	53.57.22	03.34.76	3.8	3.00	1	0.3	0.5	S, J
England – east coast - Morecambe Bay	MZ29	Trawl 21	13/08/2011	53.57.51	03.34.65	53.54.93	03.32.53	2.6	3.75	12	3.2	0.7	S, A
Ireland - north east	MZ07	Trawl 22	14/08/2011	53.57.32	06.16.14	53.55.86	06.09.96	2.8	1.25	5	4.0	0.6	J, S, Sa, G,
Ireland - north east	MZ07	Trawl 23	14/08/2011	53.46.91	06.11.04	53.39.70	06.09.86	3.0	2.33	1	0.4	0.6	S, J
Ireland - north east	MZ07	Trawl 24	14/08/2011	53.41.55	06.11.10	53.35.61	06.01.87	3.6	2.25	0	0.0	0.5	S, J
		Totals						2.87	2.32	69	1.07		

J=Jellyfish, S=Sprat, SA=Sandeel, H= Herring, W=Weever, Wh=Whiting, M=Mackerel.

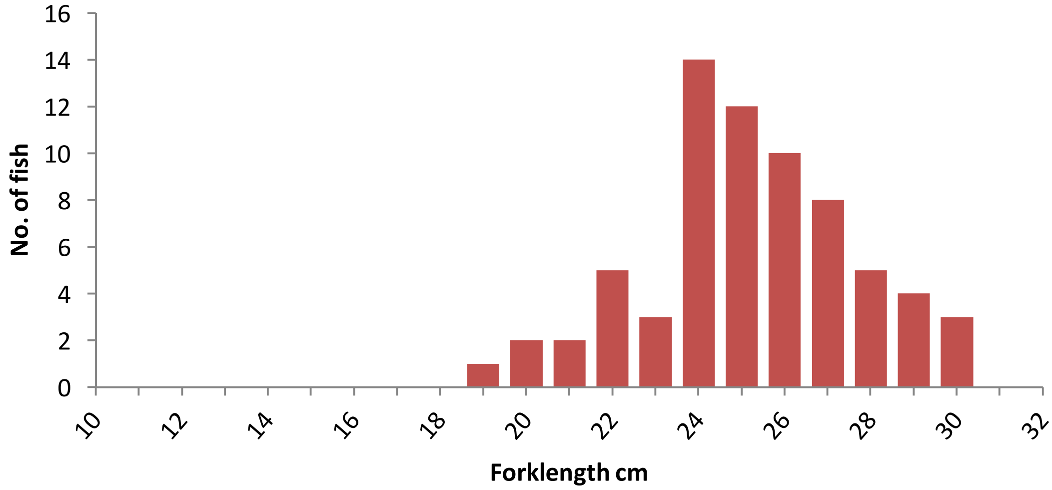

Figure 3.8.7 Irish Sea Trawling 2011 – Sea Trout length frequencies (n=69)

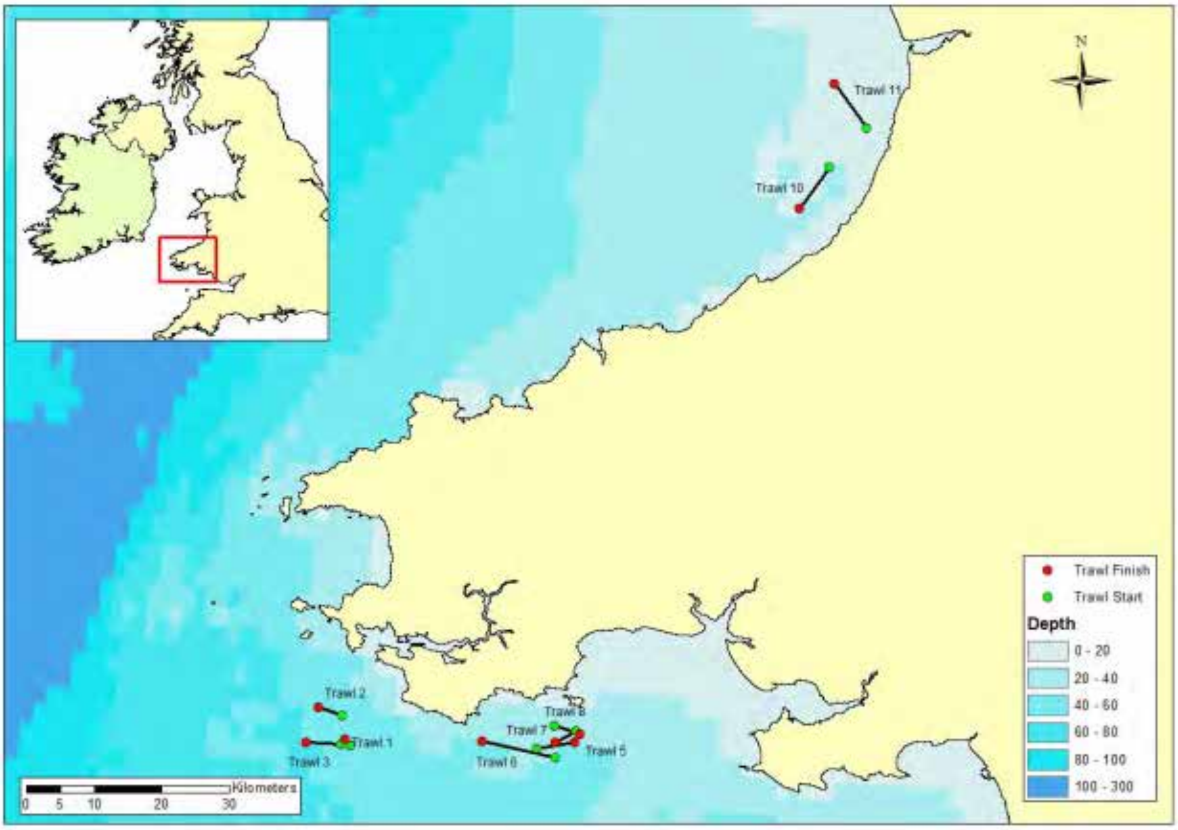

Figure 3.8.8 CSTP surface trawling tracks, Sept/Oct 2012.

Table 3.8.7 Details of CSTP trawling survey results in Welsh waters – September/October 2012

Code	Date	Location	Start GPS N	Start GPS W	End GPS N	End GPS W	Depth	Trawl Time	ST catch	By catch
Trawl 1	03/09/2012	Turbot bank	51 33.402	05 09.811	51 33.861	05 10.559	3 - 12 m	9 mins	0	0
Trawl 2	04/09/2012	Turbot bank	51 35.720	05 11.165	51 36.218	05 14.236	4.5 - 14 m	67 mins	0	100 sprat
Trawl 3	06/09/2012	Turbot bank	51 33.436	05 11.027	51 33.351	05 15.513	6 - 15.5 m	60 mins	0	0
Trawl 4	07/09/2012	Carmarthen Bay								
Trawl 5	08/09/2012	Carmarthen Bay	51 34.239	04 45.976	51 34.938	04 41.248	9 - 18 m	157 mins	0	1000 sprat
Trawl 6	08/09/2012	Carmarthen Bay	51 33.605	04 43.577	51 34.452	04 53.078	3 - 12 m	120 mins	0	500 sprat, 10 mackerel, 3 jellyfish
Trawl 7	21/09/2012	Carmarthen Bay	51 35.837	04 41.200	51 34.832	04 43.753	0 - 9 m	28 mins	0	0
Trawl 8	21/09/2012	Carmarthen Bay	51 36.127	04 43.974	51 35.610	04 40.546	1.5 - 10.5 m	111 mins	0	6 mackerel, 5 sprat, jellyfish
Trawl 9	22/10/2012	Cardigan Bay								
Trawl 10	23/10/2012	Cardigan Bay	52 22.100	04 12.908	52 18.600	04 16.472	2 - 11 m	157 mins	0	1 (gutted) mackerel
Trawl 11	30/10/2012	Cardigan Bay	52 25.360	04 08.320	52 28.718	04 12.870	3 - 12 m	120 mins	0	1 - 2 cm sprat

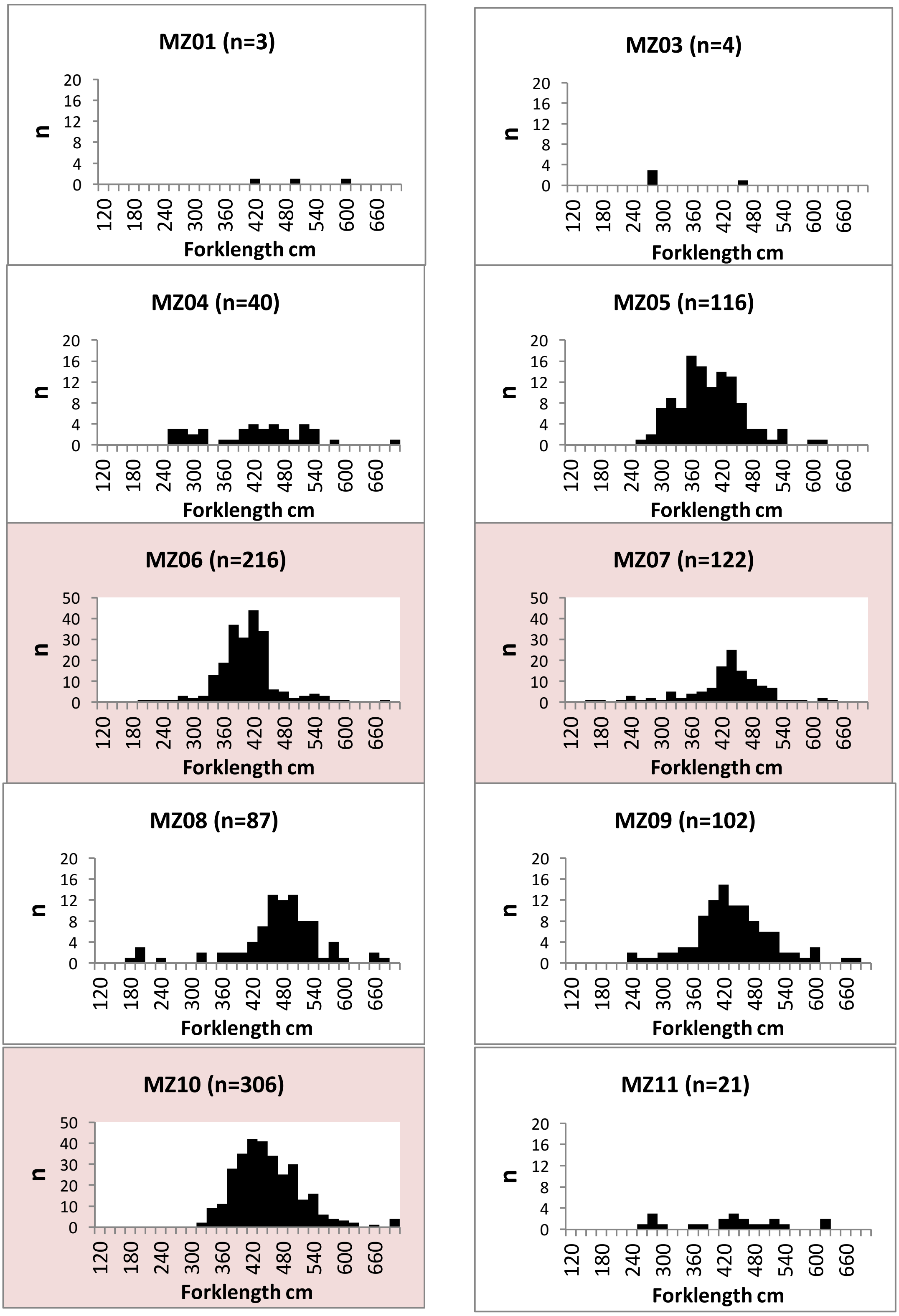

Figure 3.8.9 Length frequency distribution (forklength cm) of sea trout sampled in Marine Zones in Ireland (MZ01 – MZ08), Scotland (MZ09 & MZ10) and North England (MZ11). Vertical scale is 0 to 50 in coloured panels.

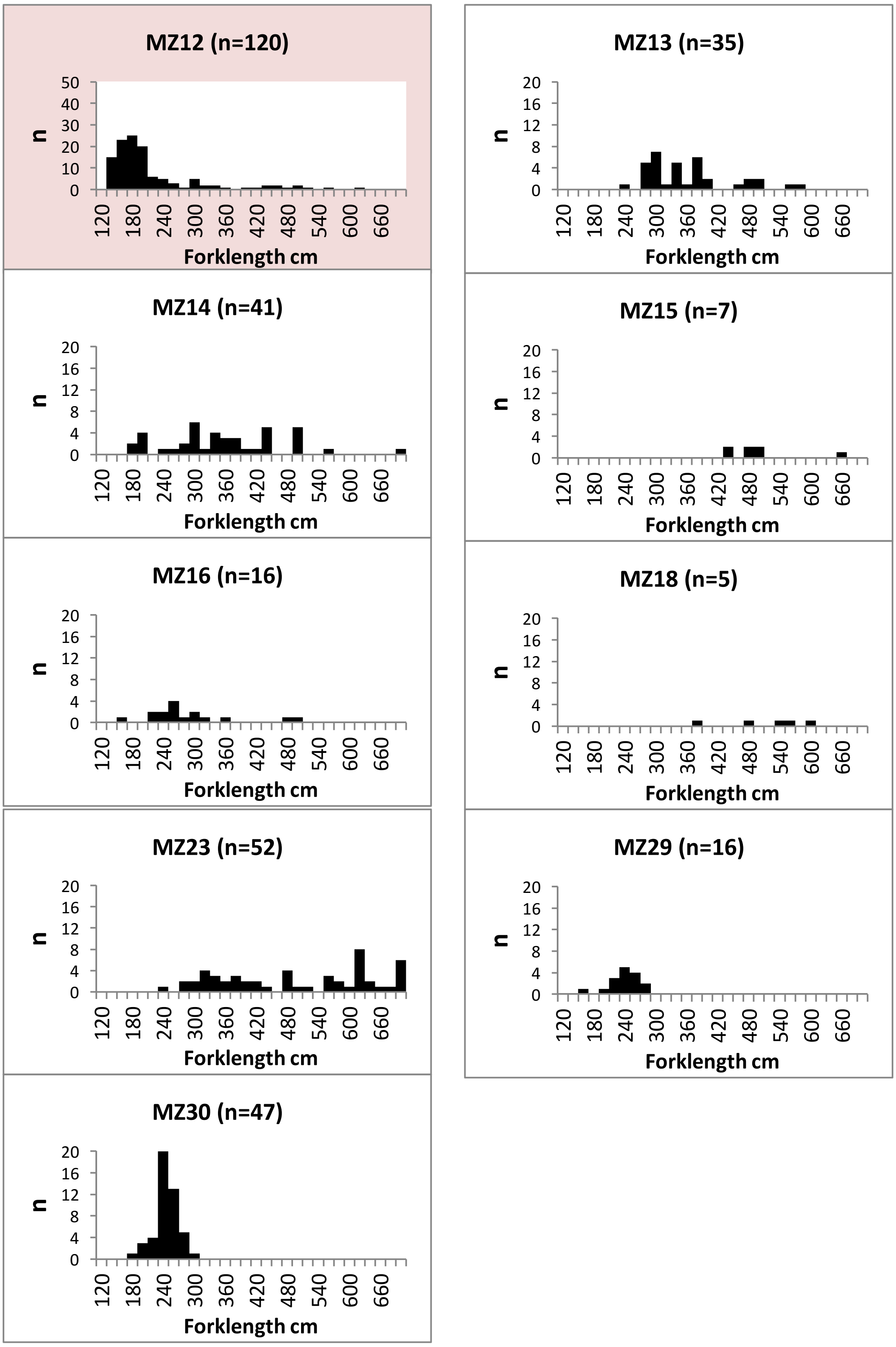

Figure 3.8.9 contd Length frequency distribution (forklength cm) of sea trout sampled in Marine Zones in England (MZ12 & MZ13, MZ29 & MZ30), Wales (MZ14 – MZ18) and Isle of Man (MZ23) . In coloured panels vertical scale is 0 to 50.

Sample types

A total of 981 whole sea trout bodies were available to the project and these were provided by direct sampling, fish screen/fish kills and from the commercial fishery, from across the marine zones sampled (Figure 3.8.10). 18 additional samples of sea trout tissue (head and gut only) were provided by fish dealers in Wales (MZ13). Scale samples were provided from 366 fish from many different zones. The majority came from previous sampling programmes in the stake net fisheries in MZ09 and MZ10 which commenced in 2008 with anglers providing the remainder. When the CSTP project sampling effort increased from 2010 onwards greater numbers of bodies were retained (Table 3.8.8).

Table 3.8.8 Sea trout sample type available to CSTP project by year

	Year								
Sample Type	**2001**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Total**
Head & Gut						4	11	3	18
Scale & Genetic Sample								2	2
Scale Packet Only	1	8	5	103	141	56	32	20	366
Whole Body			12	3		224	383	359	981
Total	**1**	**8**	**17**	**106**	**141**	**284**	**426**	**384**	**1367**

March to August were the peak months for samples (Figure 3.8.10) reflecting a combination of high sampling activity levels and the operation of the commercial fishery (in the UK).

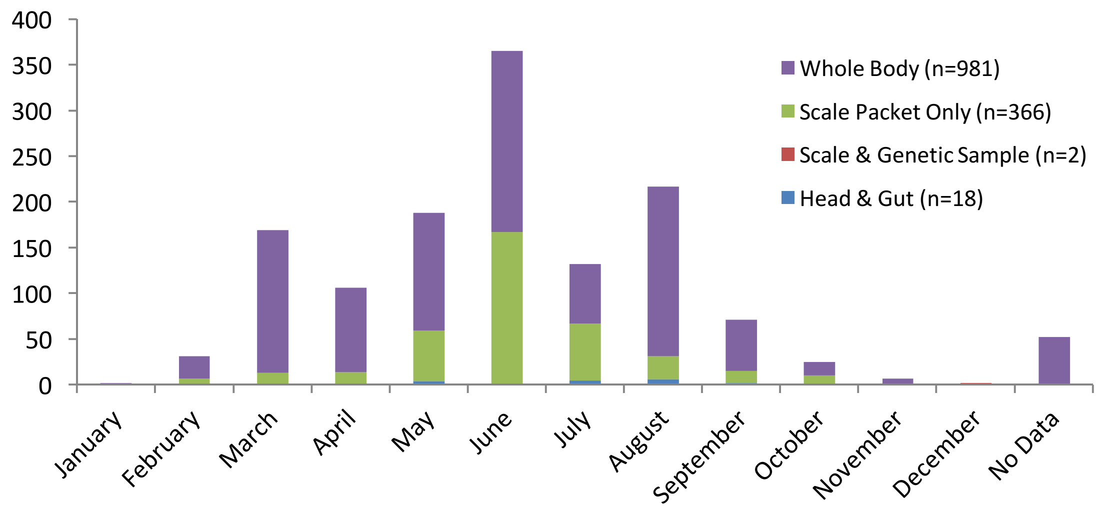

Figure 3.8.10 Sea trout sample type available to CSTP project by month (n=1367) – all years pooled.

3.9 Sample Storage and Handling

To provide high quality samples for the various project tasks all target fish being retained by CSTP personnel were dispatched using fish handling techniques approved by the relevant authorities in the United Kingdom or the Republic of Ireland. In the freshwater environment fish > 8cm (FL) were individually bagged or wrapped in clingfilm, labelled and frozen locally at -20°C (if necessary) and transported on ice in cooler boxes to the relevant laboratory (Ireland – Inland Fisheries Ireland, Dublin; Wales - School of Ocean Sciences, Bangor) for storage at -20°C (Ireland) and -30ºC (Wales) until processed.

Fish < 8cm (i.e. trout fry) were dispatched and fish being retained for aging or microchemistry tasks were transported and stored as described above. In Ireland, trout fry were sampled *in situ* and the tissue sample (tail clip/rear body section) was removed and stored in ethanol in a bulk sample (target of 50 samples per spawning site) for the genetics task. Fish >8cm FL were anaesthetised and a 2mm tail clip sample was removed and the fish was returned alive to the water following recovery from the anaesthetic. Individual tissue samples for trout try and 1+ trout parr were collected in the Bangor laboratory and stored in ethanol in 2ml screw cap tubes for this task.

In the marine environment all sea trout captured by CSTP personnel were killed as above, and stored at -20°C in the Dublin, or -30ºC in the Bangor, storage facilities or retained in suitable storage by other fisheries agency staff before collection/shipment to the relevant laboratory. Any commercially caught fish collected on-site from fishermen by CSTP personnel or project associates were similarly handled. Other commercially caught fish supplied by the sector were presented as dead animals and in a small number of cases were presented as a frozen bagged sample containing several fish.

3.10 Sample Processing and Database

Sample Processing

Samples were processed between the laboratories at Bangor University and Inland Fisheries Ireland.

All fish (whole bodies or head/gut samples) and scale samples were assigned a code to ensure optimum recording, storage, retrieval and analysis of data. The elements of the code were as follows:

i. Country Code/Abbreviation
ii. Sampling Environment/Location
iii. Year
iv. Fish Number

Marine Code	Freshwater Code
Example 1	***Example 1***
I-MZ05-10-001	**W-TEIF-10-002**
Describes	**Describes**
Ireland-Marine Zone 5-Year 2010-Fish No 1	Wales-River Teifi-Year 2010-Fish No 2

The code was used on individual scale envelopes, bags, sample bottles and database entries pertaining to each fish to ensure full traceability.

Whole body samples received were processed as per summary Table 3.10.1; all laboratory protocols are presented in Appendices 3.12 to 3.17. All samples were distributed to primary tasks for further processing or analysis. In addition to collecting standard measurements of individual fish, tissue and scale samples for Task 4, otoliths and scales for Task 5 and scales for Task 7, external and internal parasites and other tissues were sampled, data on sex and fecundity and sea trout feeding were also collated.

Table 3.10.1 List of samples taken from each marine caught sea trout body

Sample type	**Sample detail**
Photograph	Digital image, with individual fish reference no, left side and right side
Scale loss	Percent scale loss by section and side
Sea lice count	Scan with binocular microscope and count sea lice (0 if absent)
Sea lice collection	Remove visible sea lice – adults only
Length	Fork length in cm (precision 1 mm)
Whole weight	Weight (g) (precision 1 g)
Presence of scars	Note type of scar, location, comments on sampling form
Scale sample for ageing	Note on sheet, location scales removed
Scale sample for SIA	Note on sheet, location scales removed
Tissue for genetics	Small piece of pectoral fin
Sex determination	Male, female, unknown (if not identifiable)
Gonad weight/maturity status	Total weight of both gonads/classify maturity per Kestevan scheme
Stomach	Cut at the sphincter muscle beside pyloric caecae
Hindgut for parasites	Remove hindgut
Stable isotope tissues	Liver - small plug, lower tip
Stable isotope tissues	Dorsal muscle - small plug just below dorsal fin, no skin
Stable isotope tissues	Adipose tissue - if present, 2 mm section
Stable isotope tissues	Heart
Stable isotope tissues	Caudal fin - upper clip or punch
Viscera for parasites	Remove all gills, and retain remaining viscera
Individual nematodes in viscera/swim bladder	Harvest nematodes from viscera/organs
Gutted weight	Weight (g)
Lipid condition	Remove about 1 cm wide strip of muscle middle of dorsal fin, down to vertebral column, along ribs, from left side, starting at dorsal fin down to ventral incision
Head	Remove head for otoliths
Otoliths	Dissect out both otoliths
Eye parasites	Dissect out both eyes
Carcass - parasites	Retain and place in plastic bag and freeze

Scale samples were collected, stored and processed as detailed in the CSTP scale methods manual which was developed in the early stages of the project (CSTP, 2010). The manual, compiled and edited by Dr Russell Poole, was developed to manage consistency in scale sample collection, preparation and analysis, and to provide guidance on the use of image analysis software and data handling. The methodology is briefly summarised in Appendix 3.20. See Section 7.3.1 for additional detail on scale reading and interpretation.

All scales collected for sea trout from rivers sampled in the UK, which were presented with fish length data, were read and analysed. In Ireland, where sample size from some rivers exceeded 300, a sub-sample was randomly selected from the population within each 1 cm length interval. All scales with fish length data from the marine zones were read.

Scale reading: interpretation of first post-smolt annual checks & designation of Indeterminate Mark (IM)

The majority of scales aged over the course of the CSTP conformed to standard interpretations and were characterised by distinct annuli. Difficulties arising from inconsistencies in interpretation of the first post-smolt annual check were identified early in the extensive scale reading programme. Variously, the annual check/marks were taken to represent:

1. checks in winter growth of fish which remain at sea over their first sea winter, or which return to their natal river or its estuary, but do not spawn.
2. genuine spawning marks of fish that have entered the river and spawned.

For CSTP these marks were termed ‘finnock marks’ because they were often manifested in fish that were returning to the rivers as finnock (aka whitling) but were also observed in scales of older fish. The characteristic of these marks was a mild degree of erosion and loss of a small number (e.g. <10) of circuli. The number of circuli lost was variable which could lead to interpretational inconsistency. This feature does not affect ageing because, irrespective of cause, it was regarded as an annual check. Nevertheless the distinction was important because:

- the timing of maturation and first spawning is a key variable in determining a population’s growth rate and “fitness”, and is crucial in life history analysis and life cycle modelling.
- the selection of maiden fish was a prerequisite to back-calculation of size at age for growth studies.

It was hypothesised, but not unequivocally demonstrated, that the first spawning check of any sea trout is the least distinct of its lifetime, because the degree of erosion is less than in the spawning marks of older fish, which classically are very distinctive. The degree of erosion in the older (larger) fish may be greater because:

- they tend to return to the river earlier in the year and therefore experience a longer period of fasting and living in the freshwater hypotonic environment;
- they experience a relatively greater gonadal development (compared to young small fish);
- the process of scale formation and its relation to metabolic/catabolic processes may vary systematically with age.

No studies have investigated the relationship between fasting, maturation and scale resorption in sea trout. To formalise the discrimination between annual checks and spawning marks for CSTP a catalogue of typical examples, showing the continuum of appearance from clear winter checks to clear spawning marks, was compiled to support rule-based decisions on check type. This process resulted in the assignment of 'Indeterminate Mark' (IM) to the age of a fish where mild erosion was observed in its scales as described above. It denotes an annual check but does not necessarily assign it to any specific life history event.

Approach to classification of check types and nomenclature

Freshwater, up to smolt stage

Problem 1: to identify genuine annual checks (as narrowing of circuli, contrasting with the wider circuli of putative summer growth).

Solution: label as age 1, 2, 3 or x (if uncertain)

Problem 2: to recognise the point of smolting, in order to back-calculate size at that point. May be very distinctive, may merge gradually into faster marine growth (end of FW phase not distinguishable), or may display an identifiable phase of intermediate growth (termed B growth or runout).

Solution: identify and label measurements to (a) end of freshwater winter and (b) to end of B Growth)

Marine phase, 1st post smolt marks (finnock marks)

Problem 1: apparent checks show continuum of erosion and circuli loss that can be interpreted as

1. Typical sea winter (SW) checks (narrowing of circuli, taken as winter growth, no loss of circuli)
2. "Indeterminate Mark" (IM), in which some circuli loss apparent (up to 10, but not characterised by extensive lateral or posterior erosion)
3. Classical Spawning Mark (SM), in which substantial erosion (>10 circuli lost)is evident on both laterals and often around posterior margin.

Solution: label as SW, IM or SM. Where IM labelled note if preferred interpretation is SW or SM.

Problem 2: Often typical SWs show no clear start/end points, but may be characterised by an extended phase of narrower or disturbed, erratic circuli. This can result in difficulties in identifying a point for back-calculating 1st yr marine growth.

Solution: identify and label measurements to start and end of best estimated winter check, then each value or an average can be used later for back-calculation.

Scale reader variation and inclusion of Indeterminate marks (IM):

To assess the accuracy and reproducibility of the scale reading process several quality assurance exercises were trialled: sets of scale images from different rivers were circulated among all CSTP scale readers. The scale interpretations were subsequently compared and sources of discrepancy discussed. The two primary sources of discrepancy were (a) the number of years a trout resided in freshwater before migrating out a sea and (b) the level of erosion considered to be sufficient to differentiate between a sea winter (SW) and a spawning mark (SM).

The discrepancy of freshwater ageing was mainly caused by the variance in freshwater growth patterns between British rivers Fig. 3.10.1., where scales from trout collected from rivers draining into the Solway Firth show particularly tight and narrow circuli hindering the distinction of summer and winter growth during the fresh water phase. Two different approaches were used to interpret freshwater age of scales from the UK:

1) Assigning a freshwater winter only when the thickness of summer and winter circuli was clearly different. Potentially leading to underestimation of parr age.
2) Assuming that most parr will smoltify at 2 years of age and accept any indication of variance in circuli thickness as the difference in summer/winter growth. This methodology introduced an expectation bias into the data but produced results which were more in agreement with previous published for the region (Harris, 2002)

Two different datasets were produced by a single reader for scales from UK fish following each protocol, but only those from the second protocol are reported here. Nall (1930) refers to potential for growth and potential age discrepancies in freshwater in temperate regions which may lead to incorrect aging. For freshwater age for sea trout in Ireland no interpretational difficulties were encountered. Two readers analysed the scales and each was assigned a system or marine zone. QA cross-checking was carried out on an ongoing basis.

Sea Winter (SW) and Spawning Mark (SM) assignment discrepancies among CSTP readers were referred to other scale reading experts from different part of the UK and Ireland. From the referral exercise it was evident that interpretation of difficult scales was variable. Some scales show wide spaced circuli, followed by a tightening of the circuli before becoming spaced again without any evidence of scale edge erosion, which is interpreted as a SW, while other show very clear signs of missing sections of circuli and a disruption in shape of the scale, which is interpreted as a SM Fig. 3.10.1. However, many scales show mild erosion around the lateral margins Fig.3.10.1. leading to a variety of interpretation of such scale features among scale readers and experts: sea winters, migration to estuaries, migration to rivers but not spawning, and actual spawning events. This ambiguity in interpretation was acknowledged: the inclusion of Indeterminate Marks (IMs) in the nomenclature allowed the reader to indicate that the mark is ambiguous/unclear/incomplete and cannot be confidently assigned to either SW or SM and thus could represent either of the two life strategy stages.

Furthermore, the migratory patterns, suggested by a limited ICPMS based exploratory study of microelemental traces, in the scale profile of marine-caught sea trout with IMs, included both residencies at sea and return to fresh water during the IM winter mark. This provided further evidence that IMs cannot be reliably interpreted as either SWs or SMs. The inclusion of IMs into the interpretation of scales allows management of such ambiguity and reduces the error introduced by reader into the data.

Scale reading data can be used for several purposes (patterns of growth modelling, reconstruction of migration patterns, population dynamics modelling…), and the inclusion of the IMs needs to be adapted depending on the purpose of the analysis:

1) For the analysis of patterns of growth, IMs indicate the possibility of a return to fresh water and the potential loss of circuli, thus invalidating back-calculation of size at previous ages, and should thus be discarded as potential previous spawners.
2) In the reconstructions of migration patterns they could be included as either SW or SM, so long as the ambiguity is reported.

3) For population dynamics modelling IMs can be regarded as a mixture of non-spawning and reduced-spawning individuals. Accordingly they can be managed by either setting their fertility to zero or a small fraction of the fertility of true spawners (fraction of true spawners per IMs times the fertility of a true spawner at IM age).

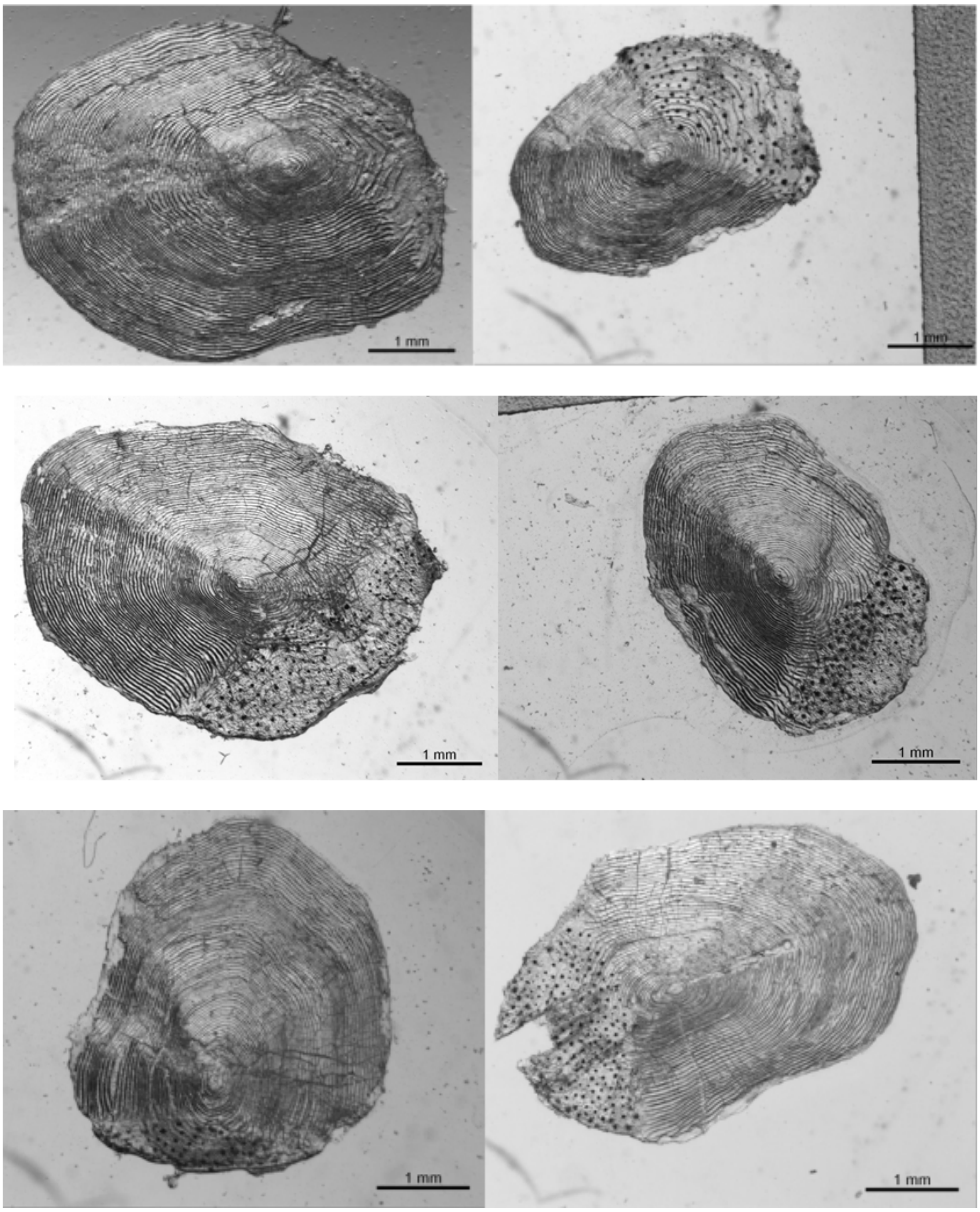

Figure 3.10.1: Scale features from various rivers (a) variance in freshwater scale features from the River Tawe (top left) and River Nith (top right), (b) scales with a sea winter (centre left) and spawning mark (centre right) from the River Nith, (c) Scales from the River Nith with indeterminate marks (IM)

Acknowledging and managing the ambiguity in interpretation of mild-erosion on scales avoids introducing errors into the analysis of scale-derived age data, and should lead to higher reliability of the scale data. If scale image-libraries have been created (such as for CSTP), then IM scales can also be revisited by future researchers and reclassified as SW or SMs should the researcher require further information from an individual. Exploring the potential application of ICPMS techniques to investigate and validate scale based life history analysis is a logical progression.

Growth measurement:

Scales are commonly used to estimate fish age, growth and to determine life history characteristics. Where scale radius is proportional to fish length, size at age can be determined from back-calculation by applying scale measurements.

For the CSTP back-calculation to determine growth, with a particular focus on marine growth, was limited to whitling (finnock/0+ sea age) and maiden fish (1/1+ sea age) as the growth of sea trout with these life histories would represent absolute marine growth. This approach was consistent with the methodology detailed in the CSTP scale reading manual (CSTP, 2010) which cautions against using scales from previous spawners to determine growth due to these scale being comprised due to scale erosion arising from spawning or prolonged freshwater residency (i.e. overwintering).

Individual sets of sea trout scales from river and marine sites were selected for growth studies. All maiden fish were sampled as the numbers of maidens was limited in the majority of sites. All whitling were sampled from UK sites but a representative subsample was selected from a number of Irish river systems where sample size was excessive.

Scales were cleaned according to the CSTP (2011) protocol. In the Inland Fisheries Ireland laboratory cleaning was substantially enhanced by using a fine chamois to remove any finer traces of loose material. Scale measurements were captured electronically following the protocol, although in some cases a fine scale ruler was used to manually measure scale radius and incremental distances on digitally captured scale images. Radial and incremental measurements were made from the focus to the anterior edge of the scale. Growth data recorded as incremental measurements were converted to radial measurements for back-calculation of fish length.

For back-calculation the body proportional hypothesis (BPH) Francis (1990) was selected as being most appropriate to provide growth data for comparative purposes between sea trout from various systems and areas (both local and regional).

The model (assuming a linear scale-length relationship) is:

$$L_i=L_c(c+dS_i /c+dS_c)$$

where L is fork length (mm) and S is scale radius. L_c and S_c are the forklength and total scale radius at capture and L_i and S_i are forklength and scale radius at age $_i$. Constant c is the intercept of the forklength-scale regression (one per fish). For a given sample the linear BPH back-calculation model produces multiple linear relationships (one per fish) which have an intercept of $cL_c/(c+dS_c)$ and pass through each observed (S_c,L_c) point (Ogle, 2012).

Mean population and standard deviation of back-calculated length at age is computed from BPH back-calculated lengths.

Database
All survey, sampling and fish data were uploaded into an MS Access database developed within the project. Appendix 3.19 details database tables, queries and field definitions.

3.11 Discussion

The aims and objectives of the sampling programme were delivered for juvenile fish within the CSTP. Samples were collected from all rivers prioritised by the project team; in the UK all of the major sea trout systems, all significant watercourses, were sampled. In Ireland sampling was conducted in all identified sea trout systems (Mc Ginnity et al, 2003) discharging into the Irish Sea irrespective of catchment size. A broad geographical area with 1-2 putative spawning sites per system was sampled – because sea trout spawning areas are more disparately distributed, given their capacity to spawn in smaller channels (including 1st order) (Whelan, 2014), more detailed individual catchment studies may be required to improve precision. Previous studies by IFI on two mixed salmon/sea trout catchments in Ireland, the Erriff (Gargan and Roche, 1991) and Feale (Holmes et al., 2014), found that juvenile trout were poorly represented in main channels and dominant in catchment extremities. The large number of samples collected across a large network of freshwater systems, discharging into an extensive, but relatively discrete marine ecosystem, provided the basis for development of genetic and microchemistry baselines within the project which will contribute to improved understanding and further conservation and management of sea trout.

Sampling of in-river returning adult sea trout to provide scales was identified primarily as a task for public participatory sources (i.e. anglers) as sampling coverage would be widespread and continuous over the angling season. The 300 sets of scales sampling target was achieved for 44% of the 25 priority rivers with returns ranging from very high (> 300 sets of scales) to low (circa 50 sets). Harris (2002) recommended that the inclusion of rivers for citizen science sampling, that would provide statistically robust samples (i.e. sufficiently large and representative of the stock), should be conditional on local angling community support. As the project progressed it became evident that the majority of samples from individual rivers were being collected by one or two dedicated individual anglers, or a small group of anglers within a club, who had taken responsibility for the task and this generally led to achievement of the target sample size.

Through Task 7 baseline data on stock structure and composition are available from freshwater systems where anglers provided a complete sample of scales. Low returns of scale samples from some priority rivers meant that a comprehensive overview of stock structure and composition was not undertaken. Nonetheless, the samples represent the best available data to generate some stock descriptions for these rivers given that little, if any, scientific data were available previously. The data collection process also increased awareness of the importance of sea trout and identified a significant role in sample and data collection by anglers. Increasing the profile of sea trout was an important output from the sample collection process as it served to highlight their presence, particularly in mixed salmonid fisheries, and heightened awareness of their recreational, socio-economic and biodiversity value.

In the marine environment the sampling objective was achieved with varying levels of success. Sea trout were captured using many different methods in the various marine zones. Samples were collected in all inshore sampling zones within the Irish Sea. Originally, dedicated survey nets (i.e. CSTP multimesh survey net) were deployed exclusively by survey teams in inshore waters but limited success and logistical issues, arising from the large scale of the sampling programme, resulted in adopting variations of site-specific nets in several zones. The logistical challenge of structured sampling posed by sampling sites being distributed along the extent of the Irish Sea coastline, and the possibility that insufficient samples would be collected, meant adopting a pragmatic approach whereby samples were collected by any means possible. This introduced unavoidable sampling bias. Catches in some inshore Welsh zones were lower than average but, in general, this adaptive sampling approach satisfied the primary objective of providing adequate numbers of samples of marine caught sea trout from inshore areas around the Irish Sea. Furthermore, the project identified a number of netting methods that could be refined for use in future sea trout sampling programmes. For scientific sampling, passive netting (e.g. gill netting) was relatively effective in some areas, but active netting using larger meshed draft nets generated the highest CPUE values and appear to offer an efficient sampling gear for sea trout in littoral zones.

In 2001 surface trawling had been successful for salmon smolts and yielded adult sea trout by catch (Gargan, *pers. comm*). Rickardsen at al., 2007 showed that sea trout occupied the upper 3m layer for > 90% in a Norwegian fjord in summer. Sampling this stratum in summer 2011 proved successful over shallow depositing habitat areas for the project despite sampling being restricted to waters outside a 6 nm exclusion zone in England and Wales. No sea trout were recorded during a similar trawling of sites with high quality sea trout habitat characteristics off the Welsh coast in late autumn; no exclusion applied as the vessel was <10 m. The majority of sea trout may have already migrated from the sea into the rivers but the complete absence of sea trout was unexpected.

The scale of the CSTP marine sampling programme was ambitious as it sought to sample a large water body for all sea trout life stages with a consistent methodology to provide directly comparable samples from all sites. Future sea trout sampling programmes in larger water bodies may benefit from identifying a series of priority inshore marine locations where consistent sampling methods would be used regularly rather than attempting to deliver a comprehensive sampling programme over extensive areas. Complementing this approach with surface trawling of long sections of the coastline over suitable near shore and offshore habitat, over a series of seasonal sampling trips, would offer a robust sampling strategy.

For the purposes of the CSTP the sampling programme delivered the required samples to the other tasks with the co-operation of many individuals, clubs, organisations and agency staff within the project partnership grouping. Target sample sizes were not achieved for all tasks for all locations but an abundance of samples was collected across the project to enable delivery of high quality samples to all Workpackages. The sampling programme provide a solid basis for advancing future freshwater and marine sampling programmes for sea trout, particularly with regard to the use of trawling.

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4 Genetic Stock Identification of Sea Trout in the Irish Sea

4.1 Summary

In order to have an understanding of the marine ecology of trout in the Irish Sea, which can be reliably employed for management and conservation, it is essential to acquire stock specific information on their biology and distribution. Genetic stock identification (GSI) is now recognised as a cost effective and reliable method of acquiring such knowledge of the migration and geographical distribution patterns. Microsatellites, currently the main tool for GIS analysis, were used for the construction of a sea trout genetic baseline for the Irish Sea. The trout multiplex marker system developed at Queen's University was considered as the best starting point for the selection of useful candidate microsatellite markers. Following preliminary screening of a test sample data set, which included cross-calibration and testing for genetic data consistency and reliability among the three participating laboratories, 22 markers with sufficient variation to resolve stock structure and enable population discrimination were chosen. Sampling design included the collection of 5,500 juvenile fish, from 111 sites in 99 individual river systems. DNA extracted from these specimens was genotyped to produce a baseline consisting of approximately 120,000 novel pieces of genetic information. Following quality control these data, for which there were very few calibration errors, were incorporated into the Celtic Sea Trout Project's ecological and genetic database. The comprehensive sampling programme of Irish, Welsh, Scottish, English and Manx rivers, was designed to attempt to include the majority of the potentially contributing rivers to the sea trout stock in the Irish Sea. The resulting genetic baseline is the largest and most comprehensive assembled for the study of sea trout in a defined ecosystem. Analysis of genetic data revealed strong statistical support for nine major genetically distinct regional and putative phylogeographic groups within the British and Irish database. Sampling efforts at the Irish Sea secured 1,232 adult sea trout. Genomic DNA was successfully extracted from 1099 (89%) specimens and following genetic analysis they were assigned to the 99 rivers in the baseline. This represents an exponential increase above previous sea trout tagging experiments in the number of fish i.e. 100s of informative individuals rather than 10s, for which population specific marine data are available. As an outcome of the analyses, all marine captured fish have been given assignment probability scores and baseline quality evaluations attached. Microchemistry and ecological profiling provided additional estimates of reliability of genetically based assignments and provide strong corroborating support for the veracity of the microsatellite (GSI) based designations. The genetic data show that sea trout in the Irish Sea originate from a large number of rivers and constitute a substantially mixed stock; however it is possible within these data to discern some novel insights into stock specific distribution patterns. Although the inferred movement patterns are region specific it appeared that majority of the fish occur in the proximity of their natal river, nevertheless, a substantial and hitherto unsuspected proportion made large scale migrations traversing the Irish Sea. Long range migrations up to 300Km were recorded. As an added component to the project, an initial evaluation of new emerging molecular methodologies for future GSI analysis was also considered. The nuclear SNP analysis revealed a nearly identical structure to that revealed by microsatellites, separating Great Britain from Ireland samples along the first principal component, and segregating latitude along the second principal component. A genome-wide inbreeding coefficient was calculated for each individual in PLINK: inbreeding coefficients were generally low; however, inbreeding was much more prevalent in the Currane Lake sample. The nSNPs analysis identified a number of markers as potentially being associated with parr growth rate (*Gdist.S165925_1807* and *Gdist.S331452_3731* as the most significant ones). The random jungle analysis revealed a larger list of SNPs (*Gdist.S94599_4328, Gdist.S259989_7655, Gdist.S49472_3963* among others) and two environmental variables potentially associated with parr growth, namely latitude, a surrogate for river temperature, and river

length, which could be associated with river productivity and intra and interspecific competition. A novel panel consisting of 152 mtSNP markers have been developed within the project for and are readily available for future brown/sea trout studies. It is anticipated that both nuclear and mtDNA SNP marker will provide a valuable addition to the molecular toolbox for the monitoring of sea trout.

This report* [Section 4 Genetic Stock Identifiaction) *is based on a preliminary interpretation of genetic data and may be subject to change with subsequent analysis.

4.2 Background

In contrast to many other vertebrates, a large proportion of the total genetic, phenotypic and life history variation observed in brown trout/sea trout (*Salmo trutta*) is distributed among populations (Ferguson 1989, 2004). It is now largely recognized that much of this phenotypic and life history variation has both an adaptive and phylo-geographic basis. Thus, proper identification and characterization of population units is fundamental to ensuring informed management and the long term viability of the species. Sea trout in the Irish Sea are unlikely to be a single homogenous group, but rather be comprised of a multitude of genetically different contributing populations, each uniquely adapted to exploit their environment. For example to maximise their fitness, individuals belonging to each distinct population might be expected to vary, for example, in the distance and duration of their migrations; the timing of their return from the sea, their growth trajectories, and their maturation schedules. As recently suggested by Hilborn *et al*. (2004) and Schindler *et al*. (2010), this complexity in life-history strategies plays a pivotal role in the long-term resilience and productivity of sea trout in the Irish Sea. This is of particular relevance in the context of climate change, increasing fishing pressure, ecosystem fluctuations and other natural and/or anthropogenically mediated alterations. In order to have an understanding of the marine ecology of the trout in the Irish Sea, it is essential to acquire genetic stock specific information on their geographical distribution and the way they exploit the marine resource. Genetic stock identification is now acknowledged as a very useful, reliable and cost effective method of acquiring data on migration and geographic distribution patterns and, hence, has been deployed successful for the study both salmon and trout in the sea. Among the major advantages of genetic methods over other conventional tagging methods are: 1) the ability to identify all the fish sampled and not just those that have been previously tagged; 2) there is no physical marking involved, hence, there is no additional mortality due to handling of fish; 3) there is less reliance on hatchery tagged fish as surrogates of wild populations.

In many respects the Irish Sea is an ideal location to conduct a genetically based study of the ecology of sea trout. Compared to more open oceanic scaled ecosystems it is relatively small in size. Furthermore, since it is geographically well defined, the Irish Sea is likely to be, predominantly, an independently functioning ecological unit. Basically, it provides an ideal model from a genetic stock identification perspective, because there is a high expectation that most contributing sea trout populations (i.e. baseline data) can be sampled and genetically characterised. Genetic stock identification and individual assignment reliability are fundamentally influenced by the comprehensiveness and quality of the baseline data.

The objectives of Workpackage 4 were to describe the extent of genetic population structuring of sea trout in the rivers flowing into the Irish sea and to develop a genetic methodology for the assignment of trout caught in the Irish Sea to their geographical region and possibly their specific river of origin, which could be used subsequently, in combination with biological profiles and oceanographic and marine environment data, to provide new insights into the marine ecology and behaviour of sea trout in the Irish Sea. In addition, the potential of new emerging molecular methodologies, specifically nuclear and mitochondrial single locus polymorphisms (SNPs) were investigated both for genetic stock identification and to provide additional insights into the biology of sea trout.

4.3 Methods, Results and Outputs

4.3.1 Database on Genetics of Sea Trout in the Irish Sea Established

A review and compilation of existent genetic data on sea trout populations in Ireland, Wales, Scotland and England was proposed in the project application. However, it was apparent early on during the project planning stages that there has been relatively little work carried out previously, in particular focusing on the population genetics of sea trout (see review in Ferguson 2006 and other specific studies listed within). More significantly there are no genetic data, at least from recent studies, on sea trout populations that are native to the Irish Sea. Nevertheless, a substantial body of literature is readily available on the genetic diversity of brown trout. Much of the most recent published work has been undertaken using microsatellite markers and these include a number of studies focusing on Irish and British populations. The project team considered the trout micro-plex recently developed at Queen's University Belfast and reported in Keenan et al. (2013) as the best starting point for the selection of useful candidate microsatellite markers for sea trout genetic studies. As QUB are a sub-contracting partner, the project was fortunate to have direct access to the newly developed panels and as then unpublished material. This represented a very considerable saving to the project in resources and time. As a consequence it was possible to considerably shorten the review process. Also fortuitously, prototype testing by Keenan et al. (2013) in the development of their microplex panel was carried out on a subset of trout specimens collected in rivers and lakes throughout Britain and Ireland and provided an accurate indication of the likely levels of total diversity present at each locus tested.

There are a large number of salmonid derived microsatellites available in the published literature, many of which have been found to cross amplify in *S. trutta* (Scribner *et al.* 1996; Paterson *et al.* 2004; King *et al.* 2005; Vasemägi *et al.* 2005). In all, 150 candidate salmonid microsatellite primer sets of sequences, which were obtained from the previously published literature, developed from in house cloning and designed *de novo* from sequences sourced from GenBank, were evaluated by Keenan *et al*. 2013 with respect to a number of criteria relevant to their suitability for trout population genetics studies. These criteria were as follows: 1) reliability of amplification; 2) consistency of automated allelic calls; 3) sufficient polymorphism (≥2 alleles); and 4) allele size range. Loci with very large size ranges were excluded as they were unsuitable for size based multiplexing. Keenan *et al*. (2013) selected 38 markers on the above criteria which could be amplified on four panels. These 38 loci provided a valuable starting point for the commencement of the genetic element of the project.

4.3.2 Production of Standard Cross Laboratory Protocols for Analysis/Interpretation and Optimisation of Molecular Markers for the Study of Sea Trout in the Irish Sea

As a result of new technological advancements in genetic analyses there has been a proliferation of new markers and platforms e.g. SNPs (see section 4.4). Despite these advances it was decided early in the project, consistent with the view that had been outlined in the project proposal, that microsatellites, as a well proven and mature screening methodology, would be the principal marker system for the construction of a sea trout baseline in this project. Notwithstanding, to account for new developments in screening methodologies, some development and testing was undertaken to assess the potential of the previously untried nuclear and mitochondrial DNA SNP (single nucleotide polymorphisms) marker systems for stock discrimination and the results of these efforts are presented in section 4.4.

As different microsatellite alleles are sized relative to internal size-standards, different laboratories must calibrate and standardize allelic designations when exchanging data and the interchange of microsatellite data can often prove problematic (Ellis *et al*. 2010). Since there were three laboratories involved in the genetic analysis for the project and with the intention of incorporating their data into a common baseline, the provision of a fully calibrated and standardized inter-laboratory methodology was essential for accurate trans-regional assignment. To enable the cross calibration exercise and the selection of the best markers, a control panel of 96 samples was produced with 48 fish from British and 48 fish from Irish rivers, which were expected to be representative of the main geographical regions within Britain and Ireland. In addition to regular contact by email and Skype, representatives from the three research groups met on a number of occasions to discuss the outputs of the exercises in Belfast, Dublin and Cork. The labs used similar sequencing and genotyping platforms (i.e. ABI3730XL 96 capillary system in QUB/UCC and the ABI 3130XL in Bangor). While different array lengths were used at QUB/UCC (50cm) and Bangor (36cm) the same polymer (Pop7) and size standard (Liz600) were used in both instances. Differences in arrays size were not found to be relevant following calibration exercise. DNA extraction techniques and marker primers were standardised as far as was possible. At QUB/UCC genomic DNA was extracted from biopsy tissue samples (adipose fins) using the Promega Wizard 96 kit following manufactures instructions. At BU genomic DNA was extracted from fin clips using a plate-wise optimised hi-salt extraction method (Aljanabi and Martinez 1997). From the initial 38 markers assessed, a panel consisting of 22 marker loci (Table 4.3.1). The number of markers (22) deployed in the project were considerably higher than the 15 that were envisaged at the commencement of the programme. Given the implementation of a robust protocol for sampling processing and calibration, there were a relatively small number of inconsistencies observed among laboratories in genotype calls for the 22 loci. Thus, for most of the markers, genotypic calls generated in the British and Irish laboratories were identical, though for a few there were consistent differences which could be easily corrected by either shifting alleles calls by a set number of base pairs or adjusting the bin edges to accommodate both Irish and British data. These corrections were included in the bin panel construction state before calling genotypes. All labs used the same bin panel for all markers to achieve allele-call consistency.

Table 4.3.1 Marker information for the two anadromous *S. trutta* MicroPlex panels used in this study, including primer sequences (with ABI labelled primer). Loci names prefixed with 'm' have been modified in this study from their original sources for use in *S .trutta* (see Keenan *et al*. (2013) for additional details). All unlabelled primers are 'pig tailed' (i.e. prefixed with "gttt").

Sea-trout-Panel-1		
*Ssa*85	NED-AGGTGGGTCCTCCAAGCTAC	gtttACCCGCTCCTCACTTAATC
m*One*102a & b‡	NED-GGGATTATTCTTACTTTGGCTGTT	gtttCCTGGTTGGGAATCACTGC
*Ssa*406UoS	NED-ACCAACCTGCACATGTCTTCTATG	gtttGCTGCCGCCTGTTGTCTCTTT
CA054565a & b‡	PET-TCTGTGGTTCCCGATCTTTC	gtttCAACATTTGCCTAGCCCAGA
CA053293	PET-TCTCATGGTGAGCAACAAACA	gtttACTCTGGGGCATTCATTCAG
*Str*2QUB	PET-CTGGGGTCCACAGCCTATAA	gtttGAGCTACAACCTGATCCACCA
m*One*108	PET-GTCATACTACTCATTCCACATTA	gtttACACAGTCACCTCAGTCTATTC
*Ssa*416UoS	FAM-TGACCAACAACAAACGCACAT	gtttCCCACCCATTAACACAACTAT
m*One*101	FAM-TGCTAAATGACTGAAATGTTGAGA	gtttGAGAATGAATGGCTGAATGGA
*Ssa*D48	FAM-GAGCCTGTTCAGAGAAATGAG	gtttCAGAGGTGTTGAGTCAGAGAAG
Cocl-Lav-4	VIC-TGGTGTAATGGCTTTTCCTG	gtttGGGAGCAACATTGGACTCTC
*One*µ9	VIC-CTCTCTTTGGCTCGGGGAATGTT	gtttGCATGTTCTGACAGCCTACAGCT
CA048828	VIC-GAGGGCTTCCCATACAACAA	gtttGTTTAAGCGGTGAGTTGACGAGAG
Sea-trout-Panel-2		
BG935488	gttTGACCCCACCAAGTTTTTCT	NED-AAACACAGTAAGCCCATCTATTG
*Ssa*D71	NED-AACGTGAAACATAAATCGATGG	gtTTAAGAATGGGTTGCCTATGAG
Sasa-TAP2A	gtttGTCCTGATGTTGGCTCCCAGG	NED-GCGGGACACCGTCAGGGCAGT
MHC-I	PET-AGGAAGGTGCTGAAGAGGAAC	gtttCAATTACCACAAGCCCGCTC
*Ssa*410UoS	gtttGGAAAATAATCAATGCTGCTGGTT	PET-CTACAATCTGGACTATCTTCTTCA
*Str*3QUB	FAM-CTGACCGCTGCACACTAA	gtttGGCTCTAATCGACTGGCAGA
CA060177	FAM-CGCTTCCTGGACAAAAATTA	gtttGAGCACACCCATTCTCA
*Ssa*197	VIC-GGGTTGAGTAGGGAGGCTTG	gttTGGCAGGGATTTGACATAAC

‡ Amplifies two independently segregating loci, although CA054565b is not used in anadromous S. trutta (see main text for additional information)

4.3.3 Sampling Juveniles for the Baseline

One hundred and eleven (111) sites in 99 individual river systems were sampled for genetic analysis and construction of the baseline (Figure 4.3.1). This comprehensive sampling programme of Irish, Welsh, Scottish, English and Manx rivers was designed in an attempt to capture all of the major contributing rivers to the sea trout stock in the Irish Sea. The sampling design for the baseline rivers involved collection of two co-occurring cohorts from the extant river population i.e. 0+ fry/parr from the previous winter's spawning and 1+ parr from the spawning the year prior to that. The target sample size was to capture 50 of each 0+ and 1+ parr cohorts. An adipose fin clip was recovered from the 1+ parr, preserved in ethanol and the fish returned alive to the river. 0+ parr were killed and the whole body or part of the body stored in ethanol. It was not possible at all sites to achieve the numbers set out and also at some locations it was only possible to collect fry/parr from the most recent spawning event as in many instances no 1+ fish were encountered (a summary table of details of samples collected and location is provided in Appendix 3). Within rivers, areas with suitable spawning habitats were preferentially targeted for sampling as these are the most likely focus for discrete population spawning aggregations. Based on local knowledge of the distribution of sea trout populations in large river catchments, sampling was also prioritised in the lower tributaries. There was some concern that the progeny of resident trout in the baseline i.e. fish that would make no contribution to fish in the sea, might affect the quality of the baseline and subsequent interpretation of the population structure of sea trout in the region. This was likely to be particularly problematic for large catchments. The sampling programme undertaken in this study was the largest and most comprehensive (high resolution) sampling programme carried out to date for sea trout in a single marine ecosystem.

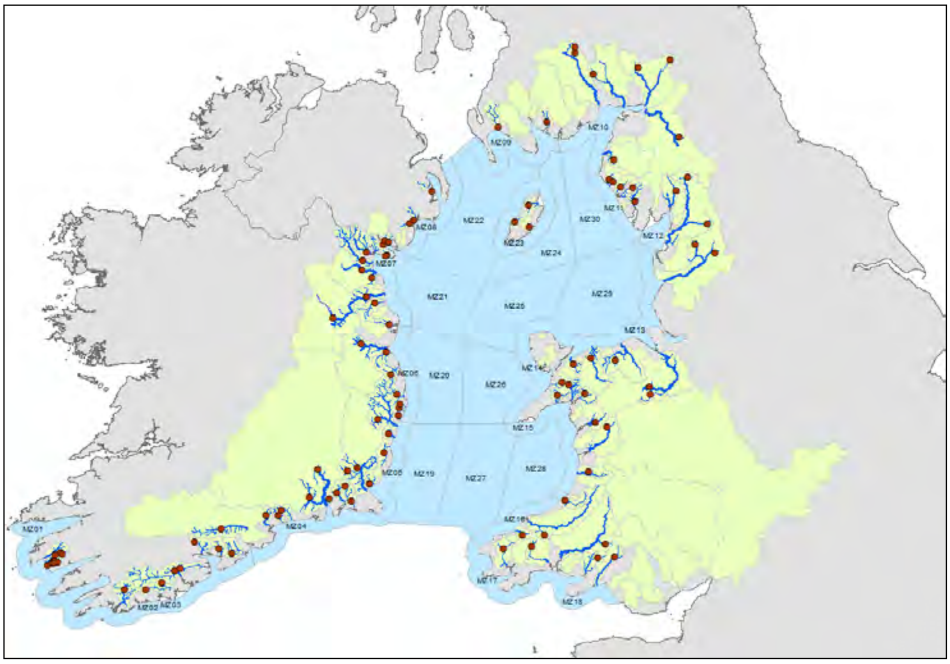
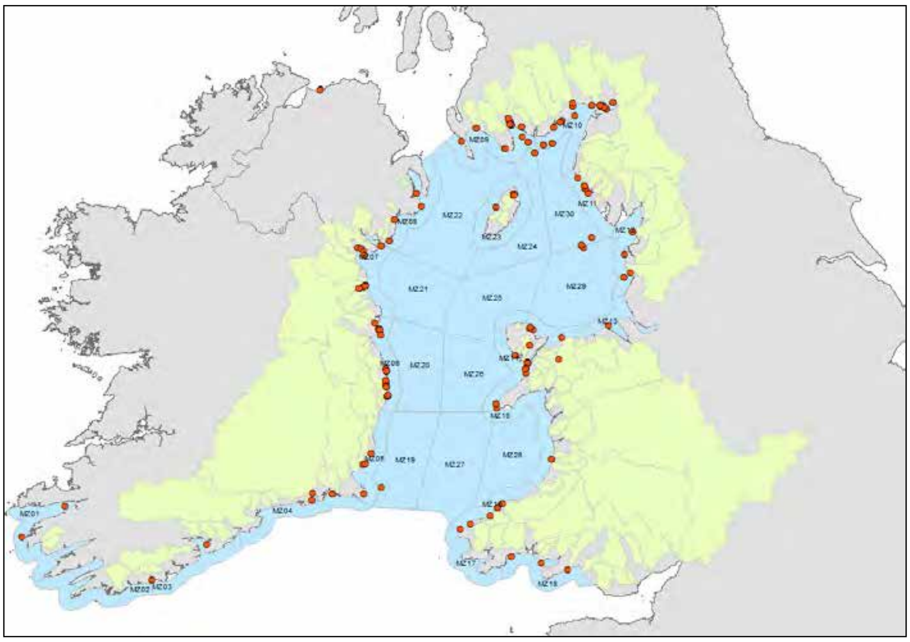


Figure 4.3.1 River sampling locations of genetic baseline for the Celtic Sea Trout Project

<u>**A**</u>



B

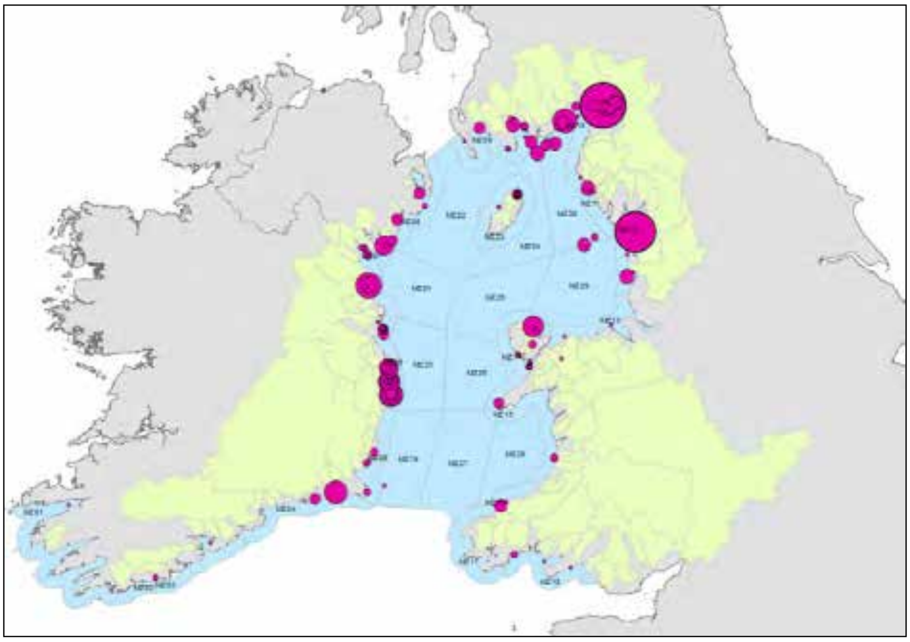


Figure 4.3.2 (A) Sampling location of adult sea trout captured at the Celtic Sea for this project; (B) sampling location of adult sea trout captured at the Celtic Sea for this project including quantitative data (i.e. size of pies are proportional to number of fish captured in a given location).

4.3.4 Sampling Adult Sea Trout

1,232 marine caught sea trout, from across the project area, were sampled using various methods. The majority were from inshore locations (Figure 4.3.2A). Numbers of samples by location is detailed in Chapter 3. Sample sizes were very variable (Figure 4.3.2B) with substantial bias in areas like the east coast of Ireland and Solway due to greater availability of fish, higher sampling frequency and, in some cases, opportunistic sampling which yielded bonus samples. Genomic DNA was successfully abstracted from 1099 individuals.

4.3.5 Novel genetic information on sea trout genetics added to the database

Deploying the marker panel consisting of 22 microsatellites, 5,500 juvenile fish were genotyped from 111 sites representing the majority of sea trout rivers debouching into the Irish Sea (n=99) to provide approximately 120,000 novel pieces of genetic information. Quality control for these data indicated only very few calibration errors in the order of less than 1%. This figure is similar to the value reported by Ellis et al. (2010) for the high quality SALSEA Atlantic salmon genetic database. The final data were incorporated into the Celtic Sea Trout Project's ecological and genetic database after checking for the presence of individuals with family ties within given population samples (i.e. family over representation) that are known to bias genetic analysis. This was done by systematically checking each of the 111 population samples using the Sibling-Group Partitioning Program (Almudevar and Field 1999). In samples where family over-representation was found, the bias was also observed as departures from Hardy Weinberg expectations. The effect was minimised by consecutively removing individuals from the largest families until genotype frequencies where within Hardy Weinberg expectations in order to maintain the greatest number of individual within samples (i.e. unbiased population sample). The genetic component of the database is the largest and most comprehensive assembled for the study of sea trout in a defined ecosystem. The genetic data assembled is of sufficient resolution to provide information on fine scale population genetic structuring capable of delivering both medium and fine scale regional assignment, in some instances down to individual river level, and for the majority of fish with a high degree of accuracy. The data have been incorporated into a bespoke database (see Section 3.10 for details of database). Excellent support for the design and construction of the database was provided by Dr John Gilbey, Marine Scotland, who with Dr Bernt Drange, Institute of Marine Research in Norway, was responsible for the design of the SALSEA database. Efficient, user- friendly data entry protocols were implemented, encompassing data quality control procedures to ensure accurate genotypes, river ID, sample history and source laboratory. The database allows data searching by loci, regions, countries, rivers, sample sites, and data extraction in formats required for genetic assignment programmes (e.g. GENECLASS, ONCOR, C-Bayes) as well as data export in standardized or laboratory specific nomenclature in spread sheet format.

4.3.6 Report on levels /extent of genetic population structuring at local/regional scales for sea trout populations in the region using microsatellites

As part of the data exploration exercise, a variety of different methodologies for identifying regional groupings were compared – BAPs (Corander et al. 2008), STRUCTURE (Pritchard et al. 2000), multivariate analysis such as Correspondence analysis and principal component analysis (Jombart 2008, Jombart et al. 2010), phylogenetic and individual distance trees (Wilkinson et al. 2011) and GENELAND (Guillot et al. 2005). While each of these procedures had their own strengths and weaknesses, a consensus was reached among the genetics group that STRUCTURE in conjunction with Evanno et al. (2005) would be the most practical approach for establishing the number of stocks or population clusters revealed by the data.

In order to identify the most basic level of genetic partitioning within the data, STRUCTURE was applied initially to the entire dataset using a hierarchical approach that was intended to identify major genetically defined groups among sea trout from the Irish Sea and subsequently refine these down to sub-geographical groupings and eventually to the population level. STRUCTURE analysis was carried out using the admixture model with correlated allelic frequencies. Simulations were run for 100,000 interactions following a burn-in length of 100,000. For each run, the following parameters were employed: USEPOPINFO=0, *K* (number of populations) ranged from 1 to 10. For each value of *K*, 20 iterations were carried out to ensure data concordance and reliability of results. The program CLUMPP v 1.1.2 (Jakobsson & Rosenberg 2007) was used to consolidate membership coefficients for the 20 iterations for each *K* estimate. Given the large data set, the "greedy" algorithm within CLUMPP was used, with 1000 repeats. The number of clusters present in the dataset was inferred using the Evanno method (Evanno et al. 2005).

Results of the hierarchical STRUCTURE analyses are summarised as follows: in the first hierarchical level, sea trout from the Irish Sea was broadly divided into three major groups: 1) West of Ireland/Currane; 2) Ireland and 3) Britain including the Isle of Man (Figure 4.3.3). Each of these major groups can be further partitioned into a number of genetic sub-groups following subsequent hierarchical STRUCTURE/CLUMPP analyses. In each of these, in order to find the most appropriate level of relevant genetic partitioning (i.e. sub-groups) within these broad regional groups; *K* was run for values ranging from 1 to 10 using identical parameters as above. Thus, for the identification of each genetic sub-grouping within each higher level hierarchy, the first *K* break was taken as the starting point. On those few instances where the first *K* break was considered not to be particularly informative, this was due to bias caused by one or two highly divergent samples within a group. In these cases the most divergent samples were removed and STRUCTURE was re-run on both of the partitioned sample groups. The rationale for this approach is that the STRUCTURE algorithm performs better when samples have similar levels of genetic divergence. Furthermore, unusual highly divergent samples are likely to be associated with contemporary random factors (e.g. population bottlenecks), which tend to bias results of analysis. This hierarchical process was continued until no further sub-division was supported by the Bayesian algorithm. The final supported reporting group is represented by nine groups mostly comprising of population samples related by geography. When this was not the case, the grouping most likely reflects the phylo-geographic history of sea trout in the Irish Sea.

Analyses of genetic data provide good evidence for the following regional groupings for the trout in the Irish Sea:

Level 1 (Figure 4.3.3): L1.1) West of Ireland (Currane - orange), L1.2) most of Ireland (green) and L1.3) Britain (including the Isle of Man and a region in the west coast of Ireland - red);

Level 2 (Figure 4.3.4): L2.1 & L2.2) West of Ireland (Currane splits into two groups – light pink and brown); L2.3) South of Ireland/Celtic Sea (blue); L2.4) Southeast Ireland green); L2.5) Northeast Ireland (pink); L2.6) a discontinuous group distributed in an “inverted U fashion” comprising regions in East and North of Ireland, Isle of Man and Britain (red); L2.7) remaining samples from Britain (yellow

Level 3 (Figure 4.3.5): in addition to groups identified at Level 2 (i.e. L2.1 – light pink & L2.2 – light brown, L2.3 - blue, L2.4 – green and L2.5 - pink), the other two groups (i.e. L2.6 – red and L2.7 - yellow) are further partitioned as L3.1) East of Ireland (orange), L3.2) Isle of Man (dark green); L3.3) a discontinuous group distributed in an “inverted U fashion” comprising regions in North of Ireland and Britain (dark pink), L3.4) Britain 1 (light blue) and L3.5) Britain 2 (yellow).

Close inspection of the data (i.e. genetic differences among regional samples) suggests that group L3.3 can be incorporated in a regional context without the loss of assignment power. To facilitate subsequent data analysis this strategy was deployed but with the safeguard that results of all subsequent analysis was to be examined in detail to identify any possible bias for this “subjective” approach. In summary, the results of the hierarchical STRUCTURE analyses provide good evidence for the presence of nine major regional groupings that tend to follow a clear geographical pattern around the Celtic Sea (Figure 4.3.6). These nine groups (1- West Ireland, 2- South of Ireland, 3- South East Ireland, 4- North East Ireland, 5- North Ireland, 6- Isle of Man, 7- Solway/Morcambe; 8- West Wales, 9- South Wales) were subsequently used for individual assignment analyses.

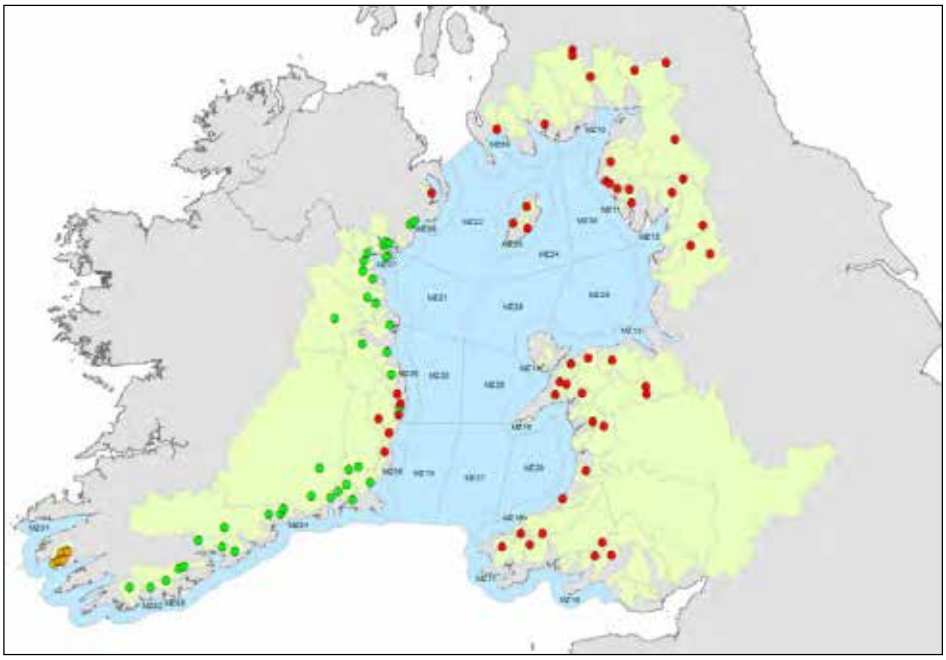


Figure 4.3.3 Level 1 hierarchical structuring of sea trout from the Irish Sea.

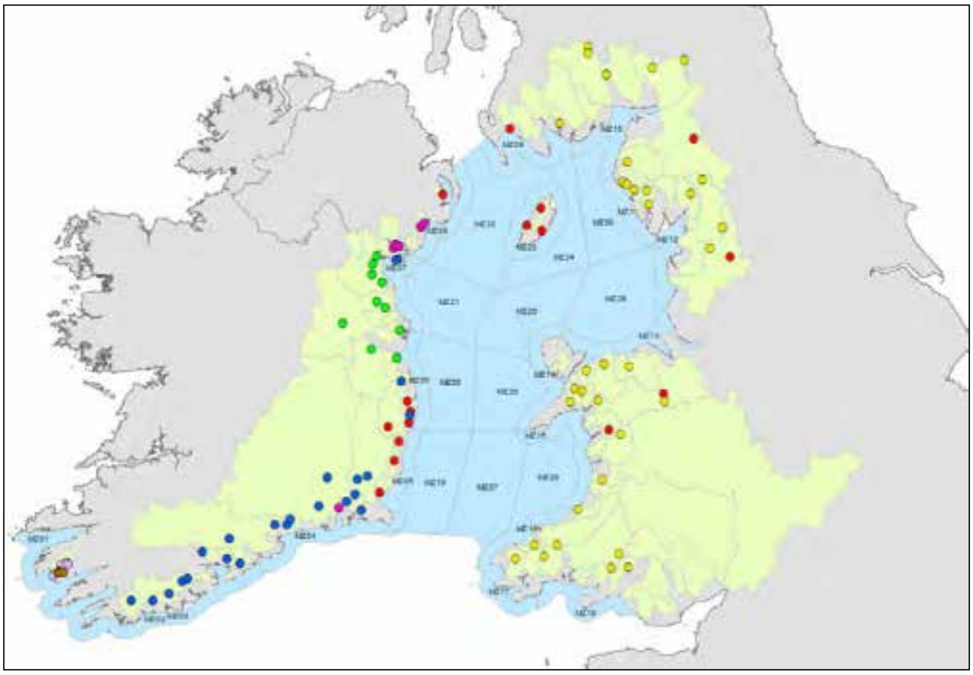


Figure 4.3.4 Level 2 hierarchical structuring of sea trout from the Irish Sea.

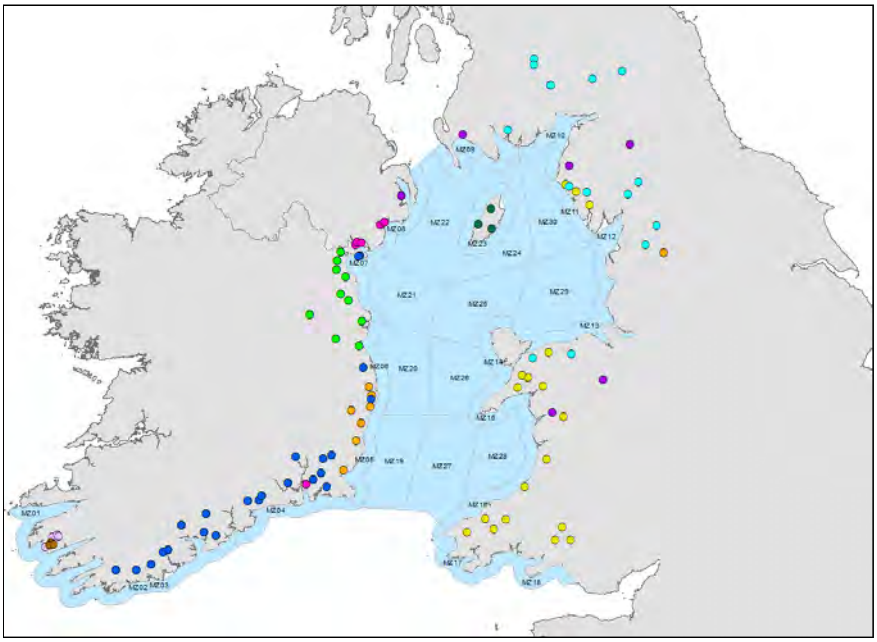


Figure 4.3.5 Level 3 hierarchical structuring of sea trout from the Irish Sea.

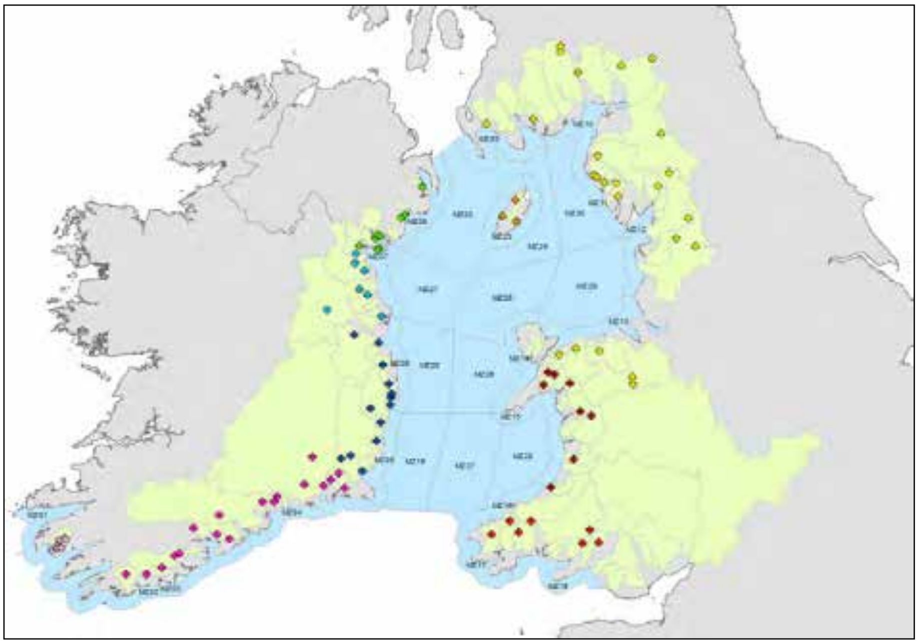


Figure 4.3.6 Final nine reporting groups identified from the hierarchical STRUCTURE analyses that were used in subsequent individual assignment analyses.

4.3.7 Report on the quality of the baseline (testing and verification)

In addition to the standard and common practice of using assignment probability scores (i.e. probability for a given assignment score), it is relevant to provide some level of error estimation (both Type I and Type II errors). For this this reason a supplementary analysis was adopted to assess the reliability of individual assignments by considering them in the context of the quality of the baseline samples (i.e. river samples). This was based on the 'ad-hoc' approach reported recently in Magee et al. (submitted) and it is linked to both adequate baseline sampling and the level of genetic differentiation between and among populations (explained below). This statistic is derived from the results of a combination and self-assignment/population re-sampling exercises. Briefly, the accuracy of assignments scores provided by algorithms such as those implemented in Geneclass and ONCOR (used in the particular study) depend ultimately on the quality of the baseline samples. Therefore, there are a number of interlinked elements contributing to the confidence that can be placed on a given assignment, which is most importantly related to the “quality” of the baseline. In the context of this study, “quality” is defined as how well the baseline reflects those “true” populations which are contributing to the mixture. Thus, the quality of the baseline to a large extent will be a function of the sampling design (e.g. its comprehensiveness). Thus it is important to ensure that all potential contributing rivers-populations are sampled. Allied to this is the accuracy (or adequacy) of the sampling. For example, if samples from a particular river were erroneously taken from non-migratory non-resident brown trout rather than sea trout, that particular river-population would not be contributing to fish in the sea.

The level of inherent population genetic differentiation is also relevant for the assessment of the quality of the baseline. Thus, confident and reliable individual assignments can only be carried out if contributing baseline populations are sufficiently genetically differentiated from each other. The level of genetic differentiation will be invariably a function of geographical proximity, population size and the interplay of genetic drift, natural selection and levels of gene flow between populations from different rivers.

The phylogeographic history (i.e. historical colonization patterns) of the populations comprising the baseline is also important. As suggested from the results of the hierarchical STRUCTURE analyses, there appears to be good evidence for phylogeographic signals within the data set. Thus, Welsh and Irish rivers are likely to have been geographically proximate for long periods and the genetic signature of this proximity is apparent in the genetic make-up of contemporary populations (Figure 4.3.6)

An assessment of the quality of the baseline for individual assignment was carried out both by simulation of theoretical populations and by undertaking self-assignments with genotypes from fish of known provenance removed from the baseline put into a new mixture and reassigned against the baseline. From the results, it is possible to determine how readily an individual of known provenance is assigned to: 1. its natal river, 2. a neighbouring river in the same region or to 3, neither. From this exercise, it is possible to estimate areas where assignment has better confidence to particular baseline river (i.e. highly differentiated populations) or to region (weakly differentiated populations within a given region).

The quality assessment exercise was carried out with both ONCOR (Anderson et al. 2008) and GENECLASS (Piry et al. 2004). These programmes implement different algorithms from which a model of the best fit between an individual and a particular reference sample within the baseline can be determined. Each model has advantages and disadvantages. To account for these, in the present study both models were used. GENECLASS is based on the likelihood of a genotype occurring in a particular river sample i.e. that genotype has a higher probability or likelihood that it belongs or is a better match to the sample of “population A” rather than the sample of “population B”. It is relevant to emphasise, however, that the genotype does not actually have to derive from “population A”. While similar in context, ONCOR attempts to learn from the mixture proportions in a given sample and corrects assignments accordingly. This accounts for the fact that fish are invariably not moving alone but in some biologically relevant aggregation. Best confidence in assignment is often derived when both models are in agreement. In general, 65% of the baseline samples (n=788) have an ‘ad-hoc’ quality score of 0.7+ (scale ranges from 0 to 1) clearly indicating the usefulness of the baseline for individual assignment.

Of all of the sea trout captured in the Irish Sea, and successfully genotyped for microsatellites during the Celtic Sea Trout Project (n=1213) individual assignments derived from both GENECLASS and ONCOR were in agreement for 928 (77% samples for individual rivers and 1028 (85%) for regions respectively. Consistency in assignments both to individual rivers and/or regions from multiple methods provides additional confidence in the assignments. GENECLASS and ONCOR provided each individual that was captured at sea an assignment with a given probability score or P value. However, unlike in many published studies where a given P value (e.g. 80%) is provided as an acceptable measure of assignment quality, it does so without consideration for the quality of the individual components of the baseline as discussed above. In this analysis the quality of the baseline sample itself becomes an additional and equally important element of the assignment process. All fish have assignment probability scores and baseline quality evaluations attached. When considering the inclusion of a specific fish in an ecological assessment such as for example mapping migration and distribution patterns (see Section 7.7.1), reference can be made to both these P assignment scores and the baseline quality scores. It is interesting to note that there is no major correlation between baseline quality and the *P* scores generated either by GENECLASS or ONCOR. Thus, a high P score is not always associated with a high quality baseline and vice-versa. This suggests that care should be taken when using P scores only to identify the origin of an individual captured at sea. Additional analysis taking in consideration other biological and/or ecological data will be useful in trying to validate both approaches (i.e. P v.s. quality scores). Which samples to include in subsequent analysis is still based on a subjective assessment by the ecologist of the level of faith they have in a particular assignment. Coughlan et al. (submitted) have considered some strategies to support decisions of what fish, which have been genetically assigned, to include, which try to balance confidence metrics such as those described above i.e. achieving the highest quality assignments, while at the same time attempting to maximise the number of samples available for use in a biological study. It is important to remember that genetically based assignments are not absolutes as would be obtained from tagging, but rather are based on statistical outputs derived from a probabilistic framework. Where this might be considered a limitation, the advantages of acquiring data for large numbers of wild fish from many rivers far outweighs any apparent disadvantages.

It was possible in this project also to integrate other valuable information such as microchemistry data (see Chapter 5 for further details) and ecological profiling data such as a fish's date and location of capture, its sea age on capture and its size in order to confirm and to increase the reliability of the genetic assignments. To assess the level of agreement between regional assignments suggested by microchemistry profiles and genetic profiles, 80 otoliths acquired from sea trout captured in Marine Zone 6 (MZ6) and 80 otoliths from individuals caught in Marine Zone 10 (MZ10) were selected. MZ6 was chosen because of the large numbers of fish captured there assigning to English and Welsh rivers. Both MZ6 and MZ10 were chosen as they had the largest sample sizes and from the preliminary genetic data had a range of interesting regional assignments both suspected long and short distance migrants as well as individuals that assigned to regions with the poorest quality baseline and consequently the least confidence in their putative assignment. It is suspected that the quality of the baseline in the Wales and Morecambe Bay regions and the Southeast of Ireland may be affected by a shared phylogeographic history, possibly dictated by the pattern of the retreat of the ice following the last glaciations, which has led to a more than passing similarity in the genetic profiles of these rivers. The results of the microchemistry confirm/, at least to region (see Section 5.4.8) the region of origin indicated by the genetic analysis. Some preliminary exploration of the micro-chemistry data (using a genetic approach) it would appear that assignments based on individual river data can be highly accurate, unfortunately regional assignments are poor. It appears that the microchemistry works best at the individual river level, irrespective of region, and there are only 34 of the 99 rivers profiled for micro-chemistry in the baseline.

In addition to the microchemistry the ecological profiling of captured sea trout undertaken in the project presented a further valuable method for determining the dependability of an assignment. For example a sea trout post smolt of say 17cm assigned to a river that was 200km away might not be classed as a trustworthy assignment, in contrast a fish of 30 or 40cm located the same distance away from its assigned river might be more readily believed. The results of the ecological profiling combined with the genetically based assignments will add substantial diagnostic capacity to the analysis. One further strategy for determining the soundness of the baseline upon which the assignments were founded deployed in the project was to determine genetically the origin of returning adults in four British and four Irish rivers (e.g. Boyne), with the expectation that these adult fish were native to the river and the region within which they were captured. There always remains the possibility that the fish were strays from other rivers. Nevertheless an assignment of an individual adult to the river or region of its capture would be fairly solid evidence of the capacity of the genetic method to determine the river of origin of fish captured offshore. The results of the assignment exercise carried out on a small sample of adult fish substantially improved assignment rates to those rivers.

4.4 Report on New Information Brought to the Project Via nSNPs and mtSNP Analysis

4.4.1 Nuclear SNP genotyping and analysis

The individual choice of a *Salmo trutta* to remain in fresh water as a brown trout or migrate to sea before coming back as a sea trout is a critical question in *S. trutta* conservation, as it has impacts on their population dynamics, ecological role, ecosystem service, and management plans. There is wide variance in the propensity towards anadromy among rivers, and such individual choice is believed to be determined by a combination of biotic (food availability, population density, inter and intra-specific competition) and abiotic (river size, latitude, temperature) factors which must interact with many genetic traits throughout the genome. Novel genetic techniques such as single nucleotide polymorphism (SNP) chip, which include several thousand coding SNPs, allow us to explore the interactions between genome, environment and outcome. Given the high amount of biological, ecological, and environmental data collected about the *S. trutta* in the CSTP, the latter offers a unique setting for testing hypothesis of local adaptation and the importance of structured variance of ecologically relevant SNPs.

Growth during the freshwater phase could potentially be a critical factor determining the fate of individuals as brown trout or sea trout; hence here we aim to investigate the extent to which SNPs and environmental variables are associated with growth patterns across the sampling range covered by CSTP. Such information can reveal insights into the genetic component growth patterns in different environments.

4.4.2 Methods

4.4.2.1 Selection of individuals for SNP analysis

Six individuals in each of 32 rivers (192 individuals) were chosen as a good balance between broad spatial coverage of sampled rivers and within-river sample size. These sample sizes allow the genetic diversity within each sample to be estimated across the SNP panel. Although 6 individuals limits the power of detecting selection within a river, the replication of rivers within reporting groups or environmental conditions should increase the testing power. Simulations have shown that selecting fewer individuals from many populations is a better strategy than using larger samples from fewer populations for detecting selection to environmental gradients (de Mita *et al.* 2013).

Rivers were selected based on their spatial distribution around the Irish Sea and availability of individuals on certain life stages, sampling times and sizes. Parr (2+) captured between June and October were at the life stage/sampling time with the widest coverage of samples suitable for genomic DNA extraction (Figure 4.4.1) Individuals were chosen based on their length (cm) at capture time: the three largest and three smallest individuals were included as potential representatives of within-river/population fast and slow growers (Figure 4.4.2). Parr raw lengths were converted into categorical values (Case/control: Large Vs. Small) or standardised scores either within river (Null hypothesis: no variable is associated with relative length within populations) or as part of the whole dataset (Null hypothesis: no variable is associated with length throughout all populations). The first approach assumes that the differences in within-river mean parr length are due to non-genetic variables, but there may be genetic influences that affect size within population. The second assumes that genetic variables affecting parr length are independent/correlated with population structure.

4.4.2.2 Source of SNP Loci and Genotyping Method

The CSTP was fortunate to gain access to a trout specific SNP chip developed by the Centre for Integrative Genetics (CIGENE) in Norway and the Danish Technical University in Denmark which covers 6000 SNP loci. Of these, ~4200 SNPs produce reliable genotypes (Dorte Bekkevold - Living North Sea Project personal communication).

4.4.2.3 DNA Extraction

High coverage genetic tools such as the SNP chips require high quality un-degraded DNA, which proved to be impossible to obtain from any samples that had been frozen at any point in the past. Hence, only samples that were processed and preserved in ethanol immediately after capture (namely 1+ parr prior to release back to the river) were available for genomic analysis. DNA was extracted using QIAGEN® DNA extraction columns. Elutes were checked for DNA degradation in agarose gels (Figure 4.4.3) and genomic DNA quantified with QuBit® Fluorometric quantitation. Only extractions with a minimum of 20ng/ul of DNA were considered satisfactory. If after a second extraction DNA concentration was still insufficient, a different individual (the next in the largest or smallest scale) was chosen. Samples were then sent to CIGENE to be genotyped with the trout SNP chip.

4.4.2.4 Data Analysis

The quality of the SNP data was checked with PLINK, a whole-genome association (WGA) analysis toolset (Purcell *et al.* 2007). The samples performed very well with an average call rate of 99.4%, only three individuals had a call rate lower than 97% (Figure 4.4.4). SNPs and individuals with more than 10% missing information were removed from further analysis. SNP with very low minor allele frequency (MAF) can produce false positives in association studies, hence a cut-off value of MAF > 1% was applied. Conformity to Hardy-Weinberg expectations (HWE) was tested on the remainder SNPs.

One SNP, *SalarSNP:ESTNV_36823_515*, had low genotyping success (79% missing) and was removed from analysis. Of the remainder SNPs, only 10 had between 3% and 7% of genotypes missing. 111 SNPs with a MAF below 1% were also removed. One individual W-TAWE-10-041 was missing 25.9% of the data and removed from further analysis. 45 SNPs were outside of HWE and removed when analysing the whole dataset when assuming response variable as a quantitative trait (i.e. length or z-scores). When data was divided into case/control data (i.e. size class: large vs. small), 14 SNPs were removed from cases and 18 from controls. Infiles were created with the clipped data for further analysis in PLINK and other analysis platforms (3940 SNPs and 191 individuals).

4.4.2.5 Population Structure

The population structure of trout using the SNP data was visualised using principal component analysis in ADEGENET (Jombart 2008), a package in R (R Development Core Team 2014). The PCA (Figure 4.4.5) revealed a nearly identical structure to that revealed by microsatellites, separating Great Britain from Ireland samples along the first principal component, and segregating latitude along the second principal component (Figure 4.4.5). A genome-wide inbreeding coefficient was calculated for each individual in PLINK: inbreeding coefficients were generally low (mean = 0.048 ± 0.052), however inbreeding was much more prevalent in the Currane sample (mean=0.226 ± 0.027) (Figure 4.4.6)

4.4.2.6 Whole Genome Association between Body Size and SNP Frequencies

Associations between SNPs and 1) case/control data (large vs small individuals); 2) within-population z-scores; and 3) overall z-scores, were tested both on the whole dataset and within population using PLINK. For categorical data (large vs. small) the Cochran-Mantel-Haenszel (CMH) test statistic was used for testing for SNP-case/control association conditional on population clustering. For quantitative data (length z-scores) association conditional on population was tested by permuting phenotypic values 5000 times within population.

4.4.2.7 Detection of Outliers

Markers under differential selection may exhibit elevated levels of differentiation between case and control individuals compared to genomic average differentiation. Such behaviour can be exploited to find SNPs potentially under selection (Beaumont & Balding 2004). In-files clipped for data quality (see PLINK) divided into two clusters (large vs. small) were analysed in LOSITAN (Antao *et al.* 2008) with 500k simulations.

4.4.2.8 Random Jungle

Random Forest are powerful machine learning methods capable of estimating variable importance (Strobl et al. 2007) and imputing missing values among other features. Recursive binary classification of the data is achieved through, first, testing for independence between the covariates and the response; second, if dependence is found, determining the best split value for the covariate with the strongest effect on the response; and third, repetition of the first two steps with each of the branches until independence cannot be rejected (Hothorn et al. 2006). Random forest improves the prediction accuracy by first generating bootstrap sub-samples of the original data with a reduced number of predictor variables, and then growing un-pruned binary classification trees for each subsample. Prediction is then based on majority vote from the whole forest (Breiman 2001).

The capability of *random forest* to evaluate the importance of each variable on the response is improved by *Random Jungle*, a particularly effective algorithm of random forest. *Random jungle* is thus suited to the study of genome wide association where there may be many thousand variables (SNPs) and combinations of different types of variables (genetic and environmental variables).

Although random jungle does not make any assumption of the data, the clipped SNPs dataset (see PLINK) was used so that results could be compared among methods. There are a number of parameters that need to be optimised in a random forest analysis: The number of randomly selected variables in every bootstrap tree was optimised with the the *mtry* command (theta=0.01, iterations =100, size of jungle =10000). The inclusion of more than 600 variables per tree did not improve the out-of-bag error, and hence 600 variables were included in all remaining analyses.

Random Forest techniques cannot accommodate missing data: missing values need to be either removed (individual or variable) or imputed. Given the dimensions of data (192/191 individuals and 4068/3940 SNPs) removal of all markers and individuals with at least one missing value would greatly reduce the dataset, hence missing values were imputed. *Random jungle* can impute and analyse the data simultaneously, however the SNP data needed to be treated as a categorical variable with only three values (0,1,2 – depending on how many minor allele counts an individual has at a particular locus), while environmental variables could have more than three categories or be continuous. This posed a problem for simultaneous imputation of SNPs and environmental variables. SNP missing values (0.16% of data) were thus imputed prior to evaluating variable importance on the SNP data alone (rjunglesparse, GWA settings, iterations=100, size of the jungle =10000). The imputed file was then employed for all subsequent *random jungle* analyses.

Random jungle was employed to evaluate associations between 1) length class (large vs. small), 2) within-population z-score, and 3) total z-score and independent variables: SNPs, population membership, and geographical variables (river, reporting group, island, latitude and longitude). Environmental variables were only available for the rivers in England and Wales and hence their interaction with the SNP data was only evaluated in the England and Wales rivers.

4.4.2.9 Results of SNP Association with Parr Size

The WGA and the outlier method for the data structured by size class (largest vs. smallest) and population Z-score, all identified the same SNPs as potentially being associated with parr growth rate (*Gdist.S165925_1807* and *Gdist.S331452_3731* as the most significant ones). The random jungle analysis revealed a larger list of SNPs (*Gdist.S94599_4328, Gdist.S259989_7655, Gdist.S49472_3963* among others) and two environmental variables potentially associated with parr growth, namely latitude, a surrogate for river temperature, and river length, which could be associated with river productivity and intra and interspecific competition (Figure 4.4.7)

The agreement between two of the methodologies is encouraging and the different results from the random jungle analysis are not necessarily unexpected as it included environmental variables and random jungle also considers interactions between the variables analysed. The particular roles of the SNPs included in the SNP chip has not been published yet, so it is not possible to comment on the consequences of the functional roles or allelic distribution of said SNPs. Nevertheless, the findings identify not only some key environmental proxies strongly associated with growth pattern variance, but the SNP data discloses the likely importance of local adaptation on shaping patterns of growth in this species.

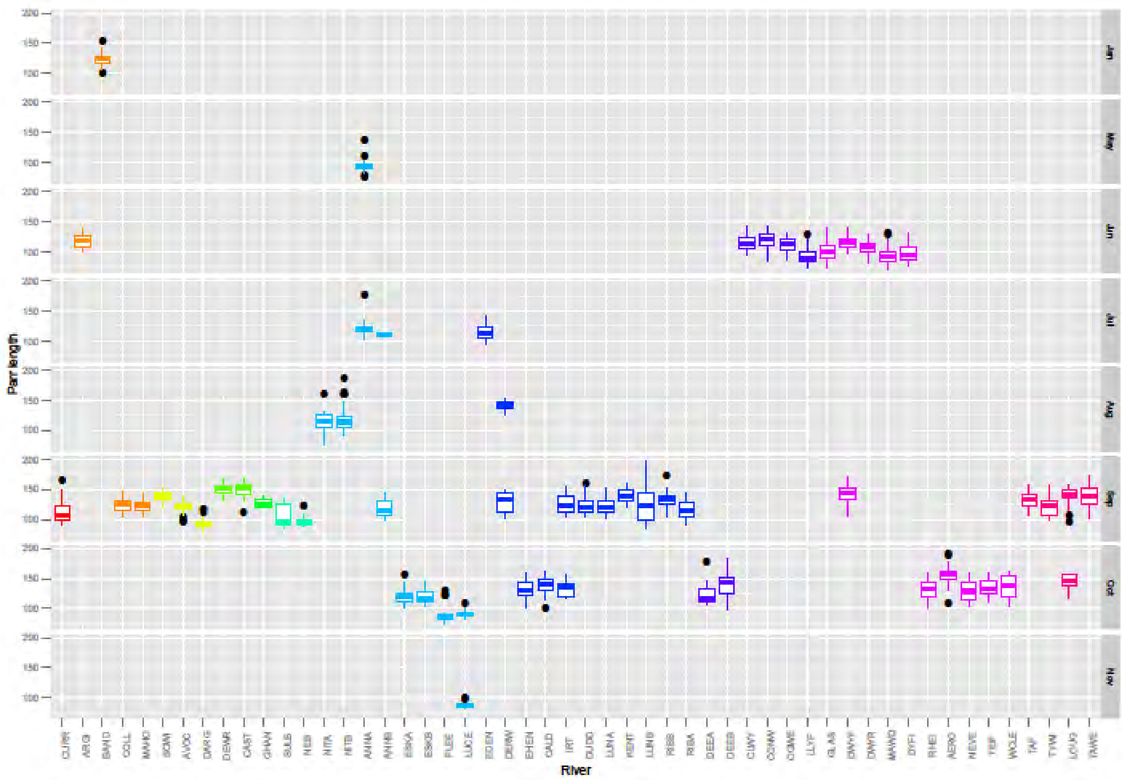


Figure 4.4.1 Parr length distribution among rivers, regions and months

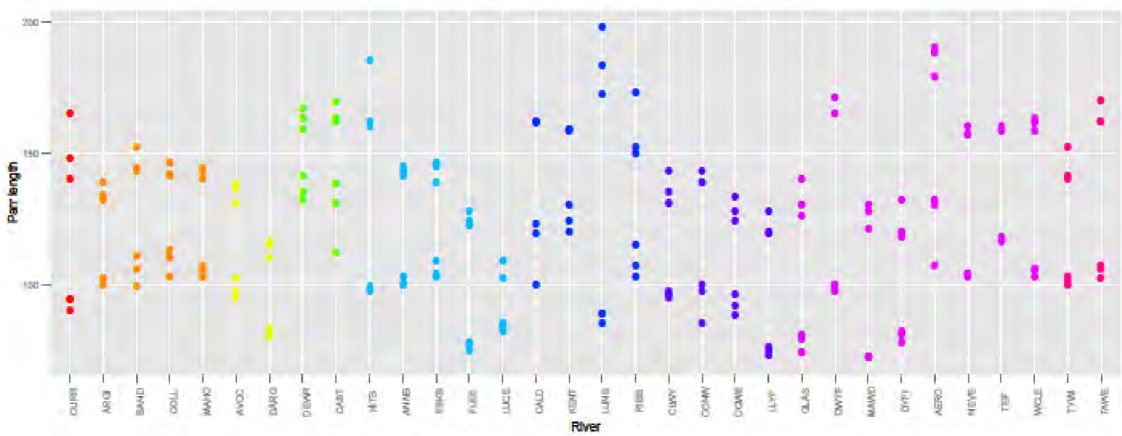


Figure 4.4.2 Length of the three largest and three smallest parr in each river

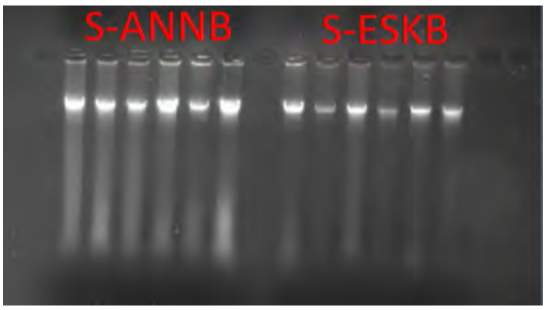


Figure 4.4.3 Agarose gel showing high quality genomic DNA from 12 individuals in two rivers

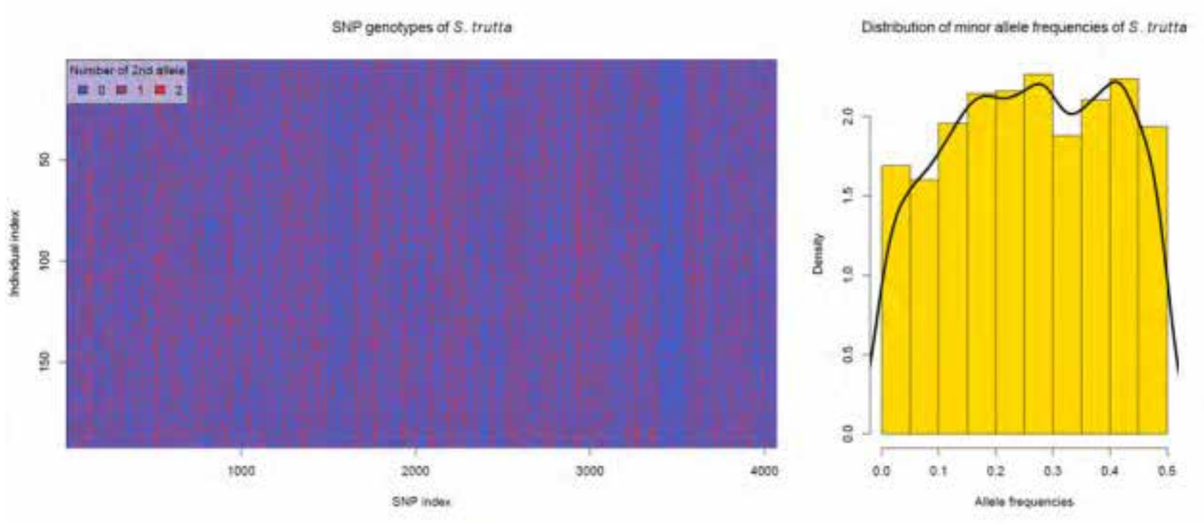


Figure 4.4.4 SNP genotyping description

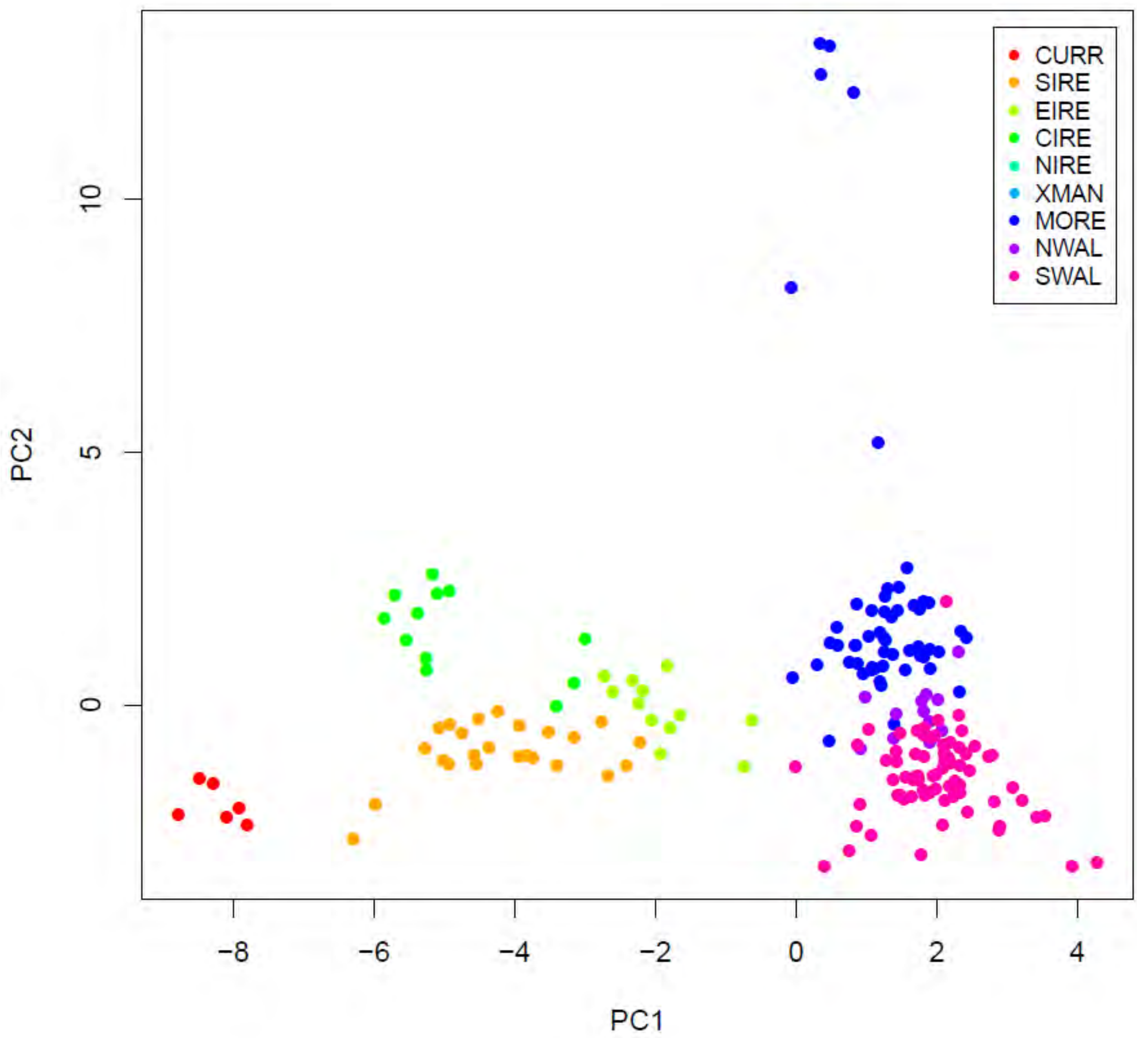


Figure 4.4.5 Individual PCA of SNP data of 196 *S. trutta* from 32 rivers

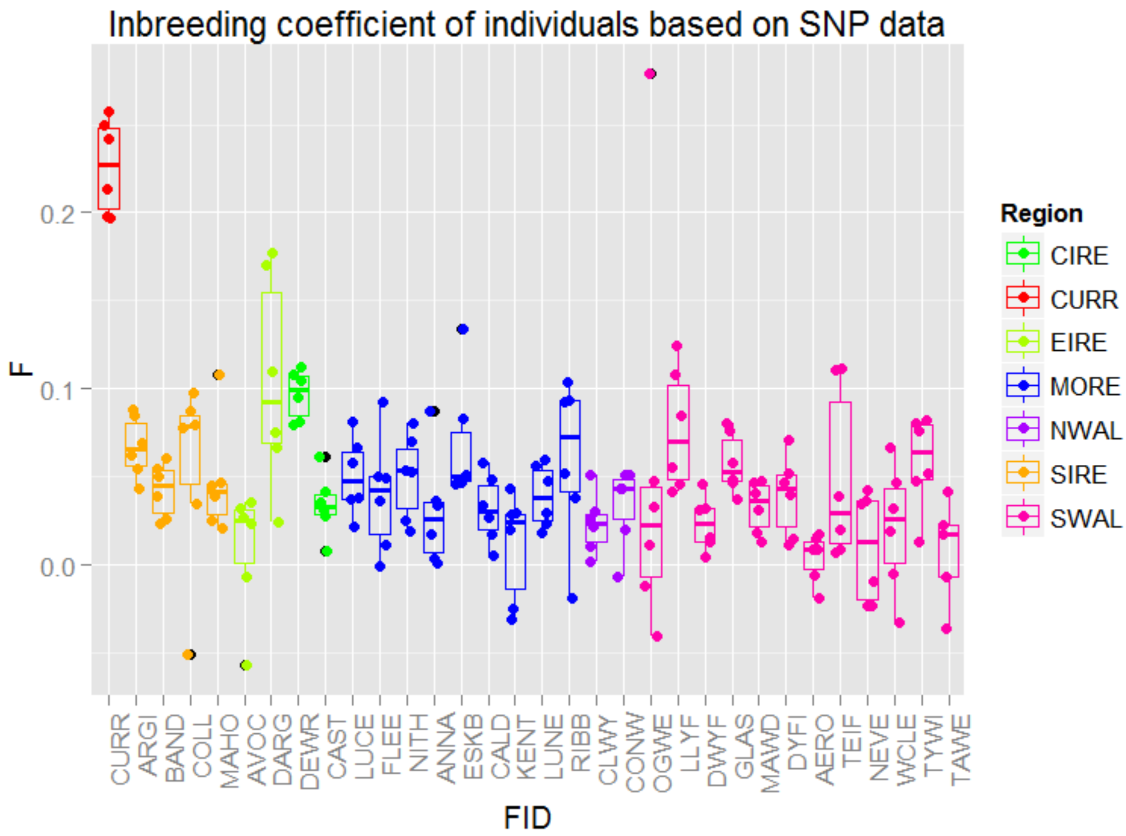


Figure 4.4.6 Inbreeding coefficient of individuals based on SNP data

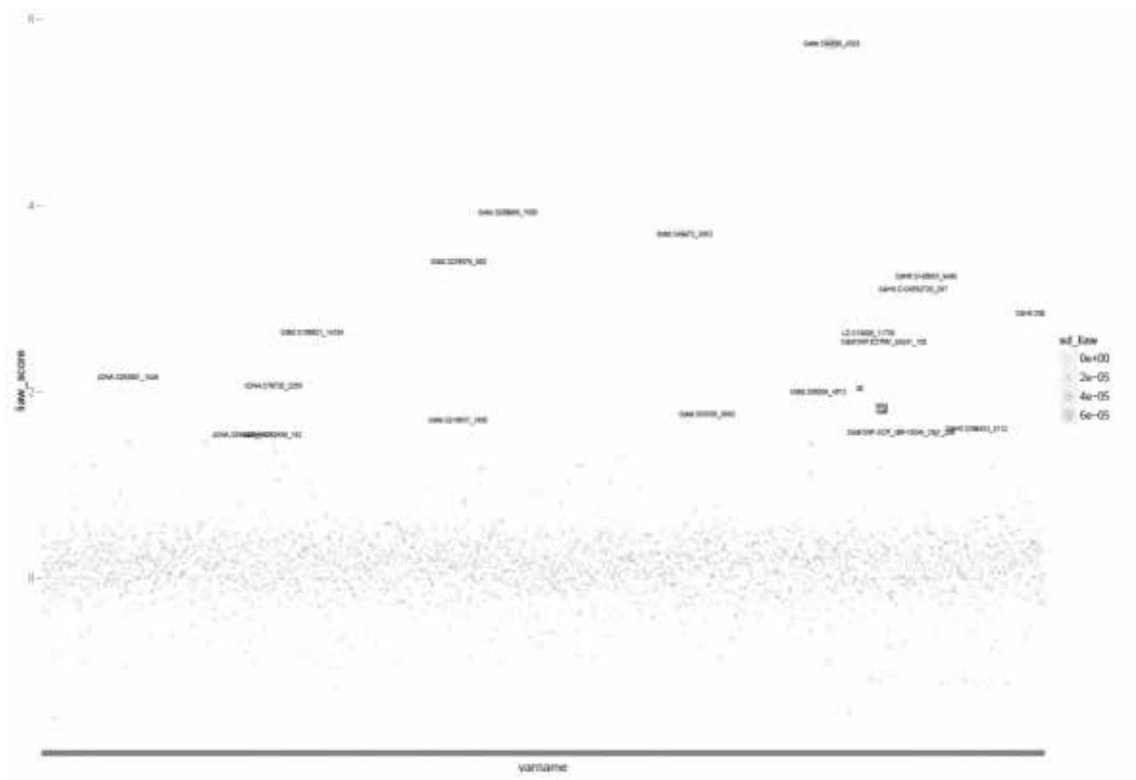


Figure 4.4.7 Liaw scores of SNPs and environmental variables associated to *S. trutta* parr size

4.4.3 Development and Initial Characterisation of Mitochondrial DNA (Mtdna) Single Nucleotide Polymorphisms (Snps) for Brown/Sea Trout (*Salmo Trutta*) Population Genetic Studies

In one the most comprehensive *S. trutta* genetic based investigations carried out to date, McKeown *et al*. (2010) examined the phylogeographic structure of the species in Britain and Ireland using PCR-RFLP of four mtDNA gene segments (16S/ND1, ND5/6, COXIII/ND5 and ND5/12S). Analysis of 3,636 individuals representing 83 geographical locations revealed a total of 25 informative haplotypes (i.e. genetic variants). These proved to be very informative to describe the origin(s) of distinct genetic lineages in the West Atlantic basin.

The main limitation for the methodological approach employed by McKeown *et al*. (2010) i.e. PCR-RFLP of mtDNA gene segments, is associated with logistics. That is, the approach is time consuming and requires the availability of substantial amounts of high quality molecular DNA, which is invariably a problem. To benefit and also to potentially maximise from the valuable information generated in the McKeown *et al*. (2010) study, in the current investigation, an alternative faster methodological approach was devised and implemented as described below.

The full mitochondrial DNA from one to two *S. trutta* specimens representing each of the 25 mtDNA genetic variants (haplotytpes) described by McKeown *et al*. (2010) were sequenced using a panel consisting of 33 PCR primer sets. These primers sets were developed to amplify small overlapping DNA regions (~500 base pairs) encapsulating the complete *S. trutta* mtDNA genome. In addition to those reference specimens, the complete mtDNA from a number of randomly chosen *S. trutta* specimens representing both freshwater and anadromous life histories were also sequenced for comparison.

All sequencing (bi-directional) was carried out on an ABI3730XL DNA analyser at QUB using BigDye terminator v3.1 cycle sequencing kit following robust protocol routinely using within the QUB research group.

Analysis of resulting sequencing data including contig assembly (both for the small individual DNA regions and for the complete mtDNA genome for each *S. trutta* specimen sequenced) was carried out using CLC Genomics Workbench (CLCBio). Assembled full mtDNA genomes were further examined using the Bioedit Sequence Alignment Editor (http://www.mbio.ncsu.edu/bioedit/bioedit.html).

From the complete mtDNA sequence multi-alignment, initial efforts were focused in the identification and mapping of all SNPs explaining the 25 genetic variants (haplotypes) described in McKeown *et al.* (2010), but all SNP variants were considered.

Analysis of sequence multi-alignment identified 152 SNPs (Table 4.4.1). Twenty five SNPs (coloured in orange) are linked to the 25 haplotypes previously identified by McKeown *et al*. (2010). An addition 127 new SNPs were identified from this analysis.

It is anticipated that these SNPs will provide higher resolution from brown / sea trout phylogeographic-studies.

Table 4.4.1 Map SNPs identified from sequencing analysis of mtDNA haplotypes previously identified by McKeown *et al.* (2010). The particular SNPs linking to McKeown *et al.* (2010) are highlighted in orange ("Reference to McKeown *et al.* (2010)"). Excluding 25 SNPs linking to McKeown *et al.* (2010), 127 new and potentially informative SNPs were identified during the analysis. SNPs are identified based on their position ("Map Position Reference genome") against a *S. trutta* completed reference mtDNA genome downloaded from GenBank. Variant positions are provided in Table against reference genome ("Reference Genome"). The "Haplotype" refer to code given to sample representing particular mtDNA haplotypes as previously identified by McKeown *et al.* (2010).

		Haplotype/Individual																															
Map Position Reference genome	Reference Genome	OLD 1	Qub 7.6	Qub 7.6	Qub 7.6	Qub 7.6	Qub 1.1	Qub 1.4	Qub 1.2	Qub 1.3	Qub 1.5	Qub 2.6	Qub 2.6	Qub 3.7	Qub 3.8	Qub 16.8	Qub 22.8	Qub 15.7	Qub 14.3	Qub 6.5	Qub 17.1	Qub 9.3	Qub 9.10	Qub 5.9	Qub 5.9	Qub 8.3	Qub 11.3	Qub 12.3	Qub 20.6	Qub CLT	Qub 21.3	Qub 22.8	Reference to McKeown *et al.* (2010)
350	C						A	A																									New
459	G																			A	A												New
1273	G																					A											New
1813	C																															T	New
1814	A	G	G	G	G	G	G	G	G	G			G	G	G	G	G	G	G	G	G	A		G	G	G		G	G			G	New
1884	C																														A		New
2207	A												G																				New
2214	C		T	T	T																												New
2283	C																						T										New
2300	A															G																	McKeown *et al*. (2010)
2367	G	A																															New
2379+	_																														C Indel		New
2981	C		A	A	A																												New
2984	T													C	C	C	C																McKeown *et al*. (2010)
3041	G																			A	A												McKeown *et al*. (2010)
3042	G																									N							New
3077	C							T																									New
3080	T													C																			New
3119	G													A	A	A	A	A	A	A	A	A	A										New
3149	C													A	A	A	A	A	A	G	G	G	G										McKeown *et al*. (2010)
3164	G																	A										A					New
3314	C																					G											New
3362	A																				G												McKeown *et al*. (2010)
3431	A																	G															New
3434	T																	C															McKeown *et al*. (2010)
3596	G													A					A														New
3630	G																		C														New
3716	C																					T											New
3826	G																					A											New
3850	A																														G		McKeown *et al*. (2010)
4078	G													A	A	A	A	A	A	A	A	A	A										New
4123	G																					A	A										New
4147	C						A	A	A																			A		A			New
4327	A																						G										New
4347	A																						G										New
4501	G													A	A	A		A	A	A	A	A	A										New
4516	G																													A			New
4631																												N					New
4654	C																				A												New
4720	A																			G	G												New
4801	T																															C	New
4864	A						G	G																									New
4961	G																			A	A												New
4970	A																			G	G												New
5023	T																					A	A										New
5353	T																	A															New
6308	G													A	A	A	A	A	A														New
6485	G													A	A	A	A	A	A	A	A	A	A										New
6503	A																					G											New
6536	G																															T	New

		Haplotype/Individual																															
Map Position Reference genome	Reference Genome	OLD 1	Qub 7.6	Qub 7.6	Qub 7.6	Qub 7.6	Qub 1.1	Qub 1.4	Qub 1.2	Qub 1.3	Qub 1.5	Qub 2.6	Qub 2.6	Qub 3.7	Qub 3.8	Qub 16.8	Qub 22.8	Qub 15.7	Qub 14.3	Qub 6.5	Qub 17.1	Qub 9.3	Qub 9.10	Qub 5.9	Qub 5.9	Qub 8.3	Qub 11.3	Qub 12.3	Qub 20.6	Qub CLT	Qub 21.3	Qub 22.8	Reference to McKeown *et al.* (2010)
6605	C																		T														New
6623	A														G	G	G																New
6644	A																			G	G												New
6677	A																						G										New
6683	C																															T	New
6719	G													A	A	A	A																New
7016	A																			G	G												New
7053	T						G	G	G	G				G	G	G	G	G	G	G	G	G	G			G		G				G	New
7389	T						C	C	C	C				C	C	C	C	C	C	C	C	C	C			C		C				C	New
7404	C																					T											New
7830	G																	A														A	New
8355	T																			C	C												New
8413	C														A																		New
8475	G						A	A	A																	A		A					New
8533	G													A																			New
8550	A																			G	G												New
8559	C																							T	T								New
8647	G																									A							New
8736	C																																New
8935	A					G																											New
8948	T																					C	C										New
8963	G																					A											New
9185	G		A	A	A																												New
9299	A																			G	G												New
9577	C						G	G																									New
9595	A						N						C						C														New
9675	A													G	G	G	G	G	G	G	G	G	G										New
9854	G											A						A															New
9863	C																		T														New
9869	G						C	C	C	C	C															C		C					New
9900	A																						G										New
9911	C																						T										New
10288	G		A	A	A																												New
10375	A						G	G	G		G																	G					McKeown *et al*. (2010)
10410	C																					T											New
10435	A									G																							New
10509	G																			A	A												New
10512	C						T	T																									New
10609	C																T																New
10611	T																			C	C												New
10761	C													T		T	T																New
10860	T																			C	C												New
10935	C						G	G																									New
10956	C																	T															New
11043	A																						G										McKeown *et al*. (2010)
11118	C																							T	T								New
11310	G							A																									McKeown *et al*. (2010)
11322	C													T	T	T	T	T	T	T	T	T	T										New
11358	A																			G	G												New
11611	G					A																											New
11677	T																		C														New
11703	A																						G										McKeown *et al*. (2010)
11867	C																													T			McKeown *et al*. (2010)
11978	A	G																															McKeown *et al*. (2010)
12104	G																										A						McKeown *et al*. (2010)
12133	A						G	G	G	G	G			G	G	G	G	G	G	G	G	G	G			G	G	G		G	G		McKeown *et al*. (2010)
12182	A																					G	G										New
12250	G																						A										New
12319	C											T	T																T				McKeown *et al*. (2010)
12580	T																			C	C												New

		Haplotype/Individual																															
Map Position Reference genome	Reference Genome	OLD 1	Qub 7.6	Qub 7.6	Qub 7.6	Qub 7.6	Qub 1.1	Qub 1.4	Qub 1.2	Qub 1.3	Qub 1.5	Qub 2.6	Qub 2.6	Qub 3.7	Qub 3.8	Qub 16.8	Qub 22.8	Qub 15.7	Qub 14.3	Qub 6.5	Qub 17.1	Qub 9.3	Qub 9.10	Qub 5.9	Qub 5.9	Qub 8.3	Qub 11.3	Qub 12.3	Qub 20.6	Qub CLT	Qub 21.3	Qub 22.8	Reference to McKeown *et al.* (2010)
12593	G																												A				McKeown *et al*. (2010)
12664	G		C	C	C																												New
12673	C																											A					McKeown *et al*. (2010)
12793	A						G	G																									New
13048	A																					G	G										New
13054	C																				T												New
13062	A																	G	G														New
13319	G									A																							New
13323	T									C																							New
13327	C			T	T																												New
13375	C																			T	T												New
13387	C														T	T	T																New
13414	C													A	A	A	A																New
13469	A																						G										New
13555	G																							A	A								McKeown *et al*. (2010)
13582	G																A																McKeown *et al*. (2010)
13584	C																			T	T												McKeown *et al*. (2010)
13678	G													A	A	A	A	A	A														McKeown *et al*. (2010)
13717	A						G	G	G		G																G	G					New
13861	C																			A	A												New
13897	A																			G	G												McKeown *et al*. (2010)
13918	A	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G		G	G	G	G	G	G		New
14125	C						T	T	T	T	T			T	T	T	T	T	T	T	T	T	T			T	T	T		T	T		New
14218	T																			C	C												New
14236	G						A	A	A	A	A								A							A	A	A		A			New
14335	A																			G	G												New
14375	A																						G										New
14490	C																		A														New
14526	A								G																								McKeown *et al*. (2010)
14547	C																	T															New
14733	C														A	A	A																McKeown *et al*. (2010)
14796	G													A						A	A												New
15141	G																			A	A												New
15243	G																					A											New
15400	G									A																							New
15501	G																			A	A												New
15809	G																						A										New
16193	T									C																		C					New
16542	T																					C											New
16571	C													A																			New
16582	A																												Indel			Indel	New
16600	C													A	A	A	A	A	A														New

4.4.4 Report on Mixed Stock Analysis and Individual Assignment of Fish Caught at Sea to Their Source Population

Sea trout in the Irish Sea originate from a large number of rivers and would appear from the genetic analysis to be a substantially mixed stock; however it is possible to discern some interesting distribution patterns. A summary of the assignment of individuals captured in the Celtic Sea to the nine identified reporting regions is provided in graphical format in Figure 4.4.8-Figure 4.4.16. Not accounting for any sampling bias, the largest contributing regional group to the sea trout population in the Irish Sea are the rivers constituting the Solway/Morecambe Bay complex with ~31% of the fish captured. The next largest represented group are the rivers in the Southeast coast of Ireland with ~21%. There were no fish assigned to the west coast of Ireland as represented by Lough Currane. Most fish were recovered from Marine Zone 10 (23%), followed by Marine Zones 6 (18%), 12 (11%) and 5 (10%). The largest proportion (58%) of fish captured in MZ10 originates in rivers close by. The rest of the fish come from geographically remote regions, South of Ireland 10%, Southeast Ireland 10% and South Wales 10%. The fish captured in marine zone 6 are the most geographically diverse with for example only 27% of the fish assigning to a river in the area or neighbouring river. It would appear that large numbers of fish from Wales, England and Scotland are occurring on Ireland's east coast. The fish captured found close to the Isle of Man coast derive from rivers located on the Isle of Man.

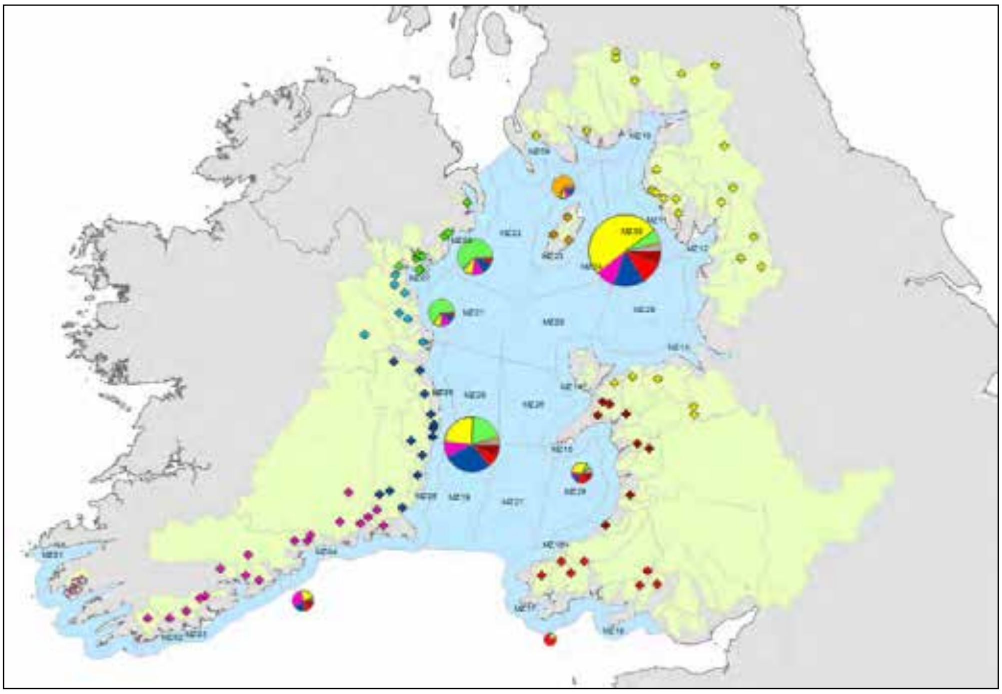


Figure 4.4.8 Proportion of sea trout captured at sea assigning to particular reporting group

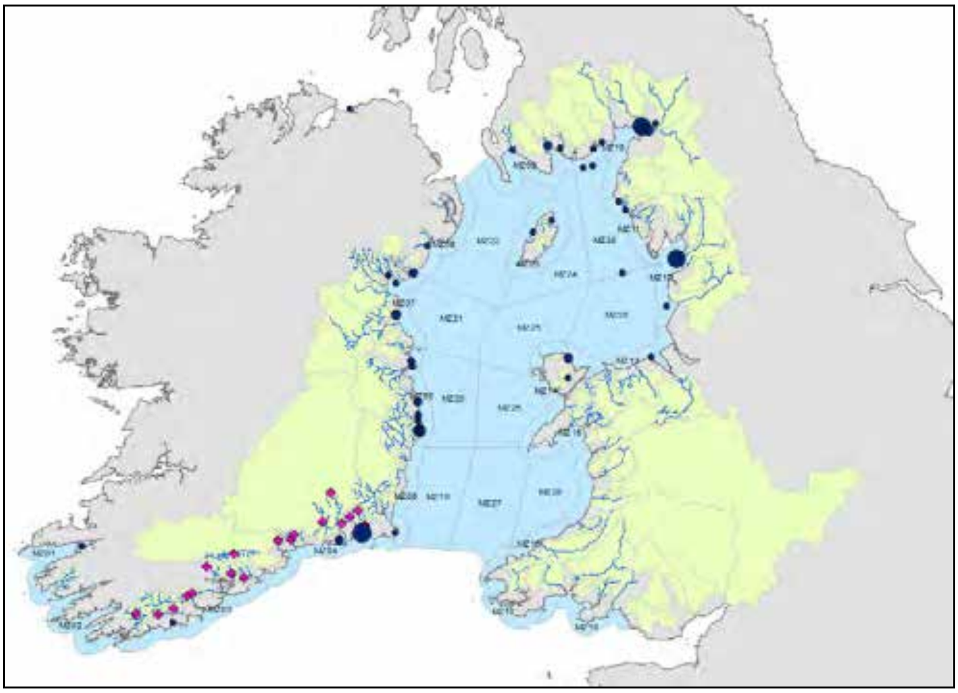


Figure 4.4.9 Sampling location of sea trout captured at sea assigned to the South Ireland reporting group. Pie size reflects the number of fish captured in a given location.

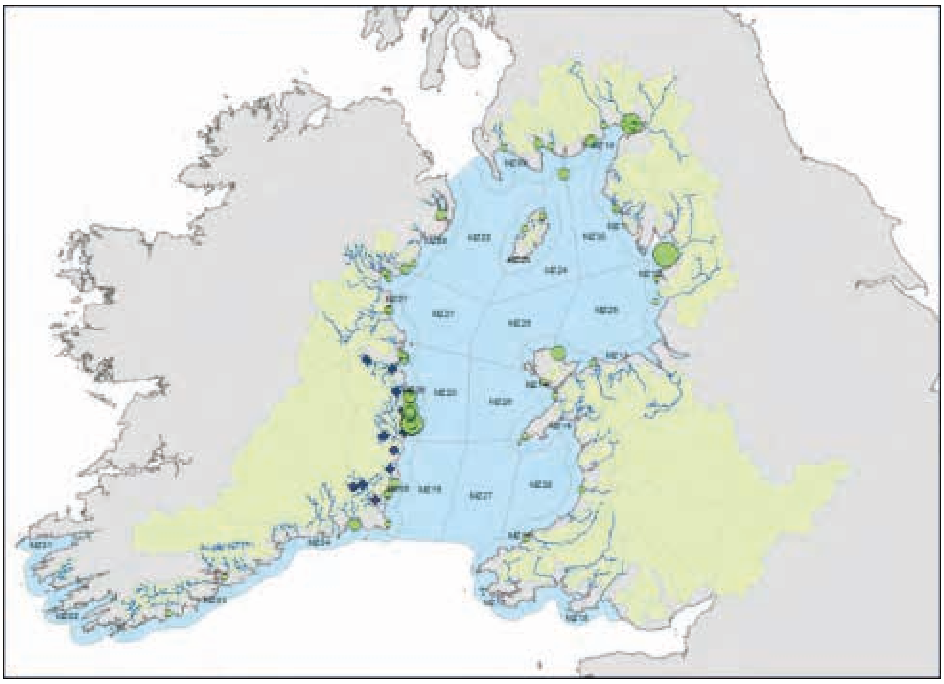


Figure 4.4.10 Sampling location of sea trout captured at sea assigned to the South East Ireland reporting group. Pie size reflects the number of fish captured in a given location.

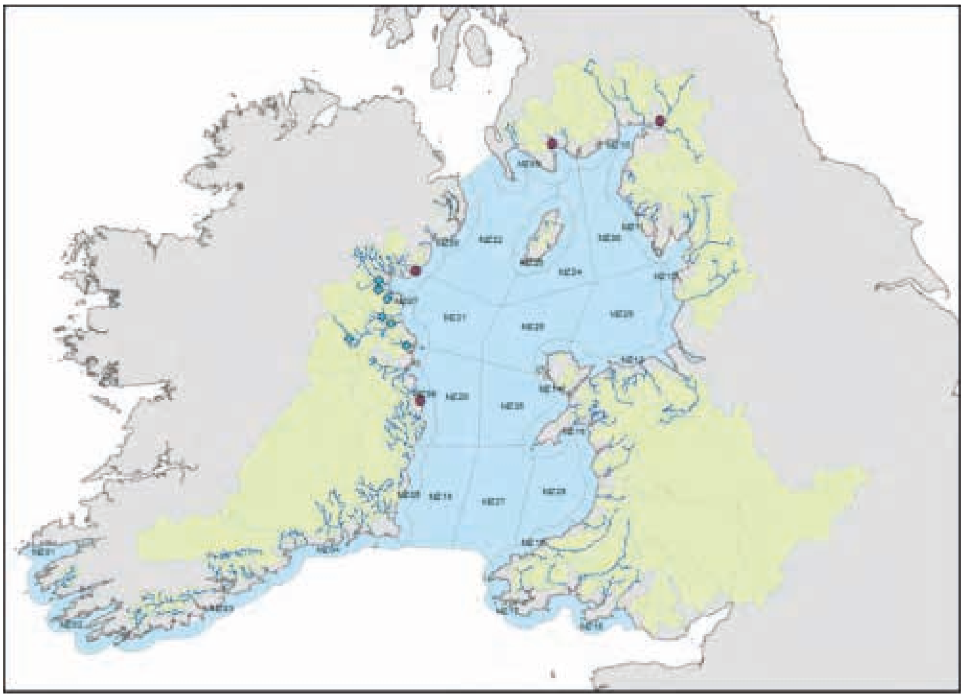


Figure 4.4.11 Sampling location of sea trout captured at sea assigned to the North East Ireland reporting group. Pie size reflects the number of fish captured in a given location.

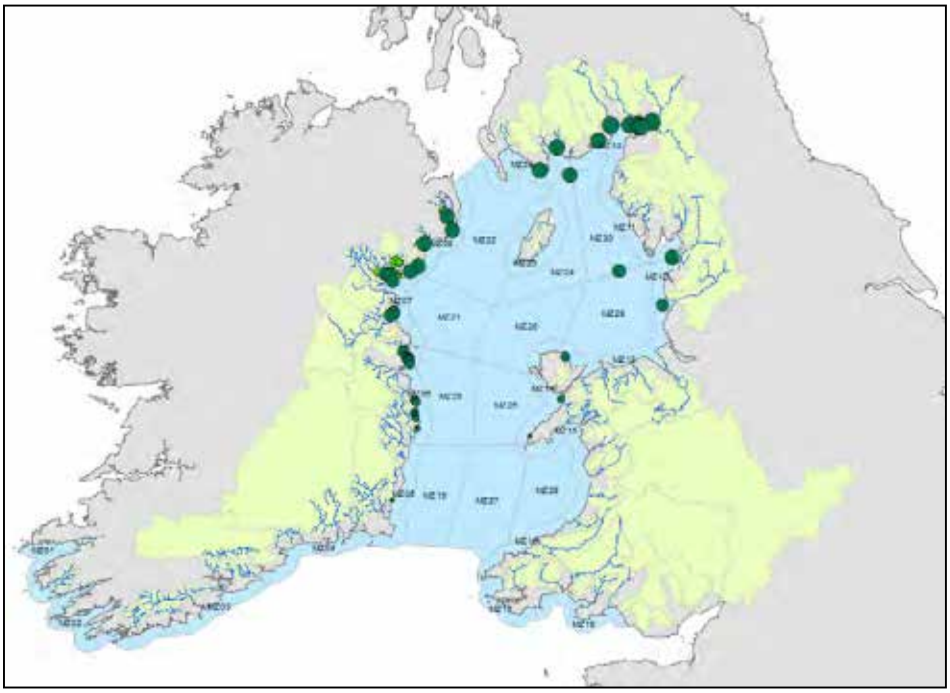


Figure 4.4.12 Sampling location of sea trout captured at sea assigned to the North Ireland reporting group. Pie size reflects the number of fish captured in a given location.

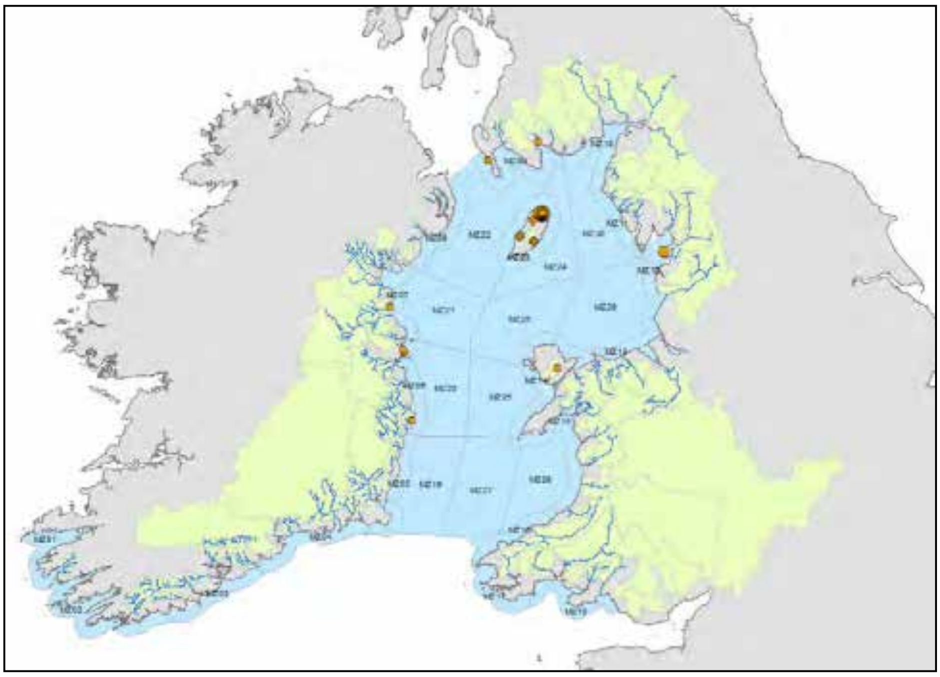


Figure 4.4.13 Sampling location of sea trout captured at sea assigned to the Isle of Man reporting group. Pie size reflects the number of fish captured in a given location.

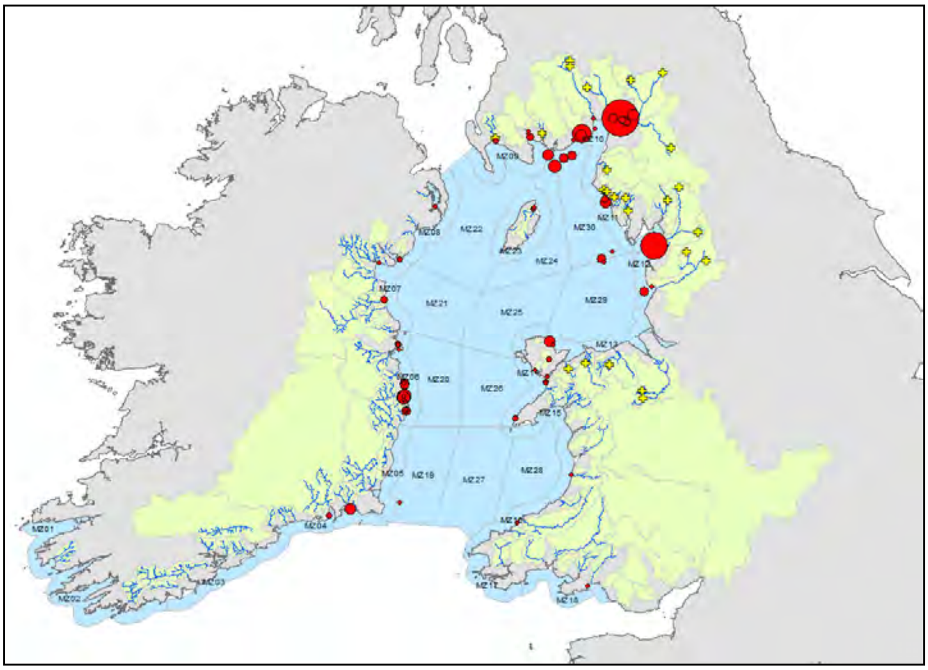


Figure 4.4.14 Sampling location of sea trout captured at sea assigned to the Solway/Morcambe reporting group. Pie size reflects the number of fish captured in a given location.

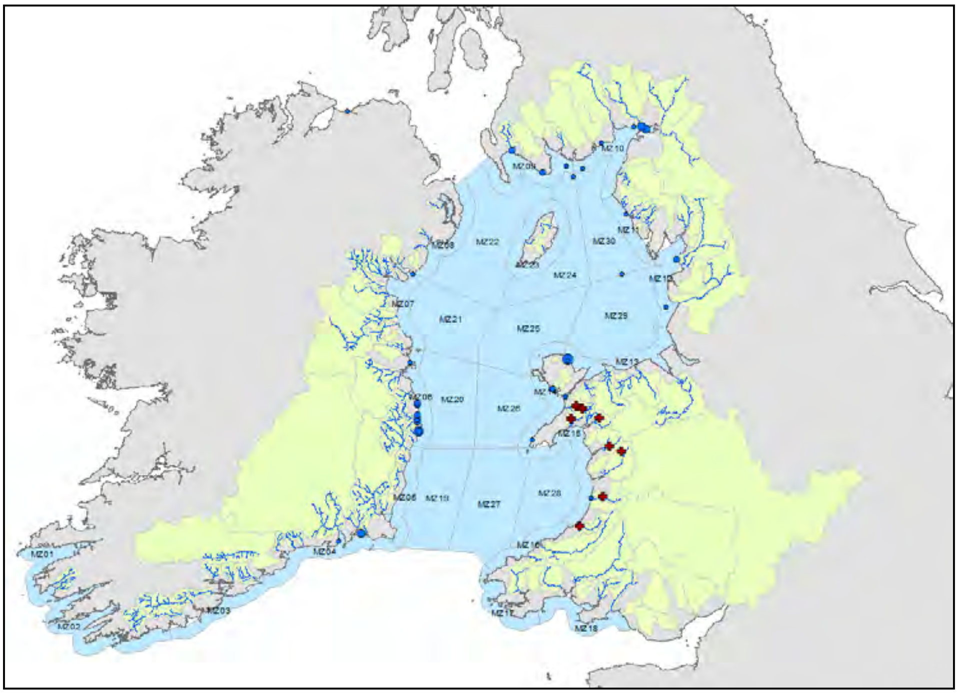


Figure 4.4.15 Sampling location of sea trout captured at sea assigned to the West Wales reporting group. Pie size reflects the number of fish captured in a given location.

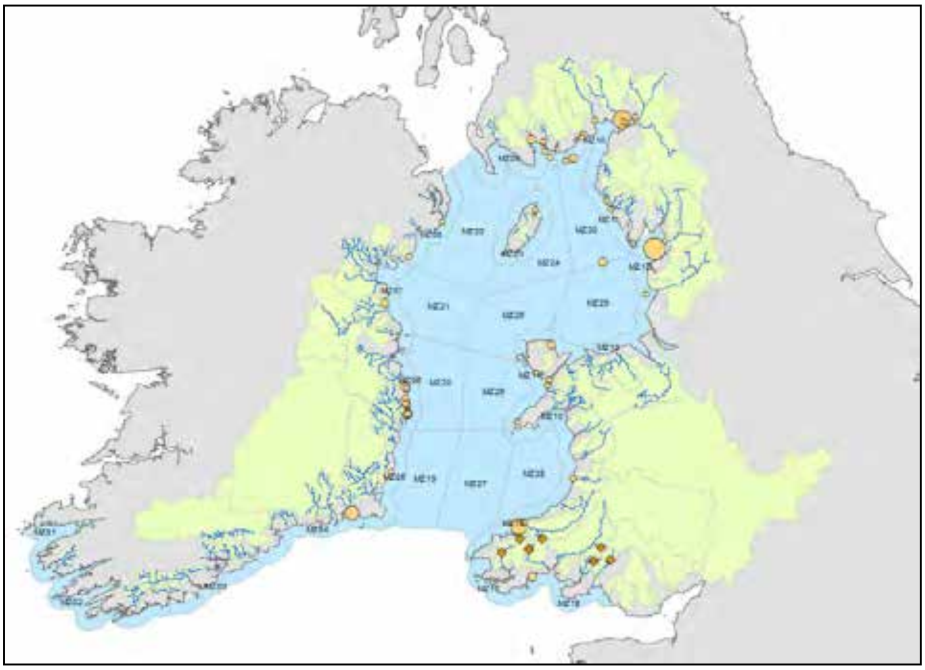


Figure 4.4.16 Sampling location of sea trout captured at sea assigned to the South Wales reporting group. Pie size reflects the number of fish captured in a given location.

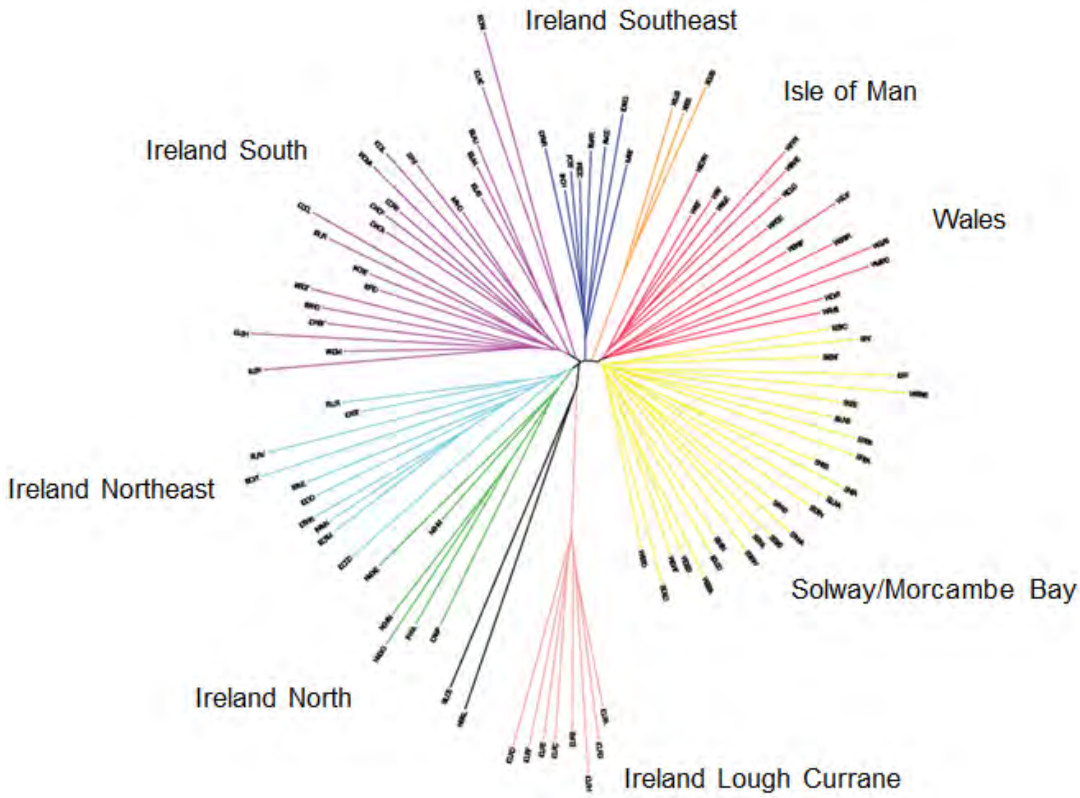


Figure 4.4.17 Neighbour Joining Phenogram showing genetic relationships among sea trout populations sampled in the Celtic Sea trout Project.

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5 Can Chemical Tags be used to Identify Origins and Movements of *Salmo trutta* in the Irish Sea region?

5.1 Summary

Two biogeochemical tags, otolith microchemistry (using Mn, Mg, Sr and Ba) and scale stable isotope chemistry ($\delta^{13}C$, $\delta^{15}N$), were used to try to determine the movement patterns of sea trout *Salmo trutta* L. within the Irish Sea. The current knowledge base for marine movements of sea trout would suggest that sea trout remain in coastal waters close to their river of origin. However, the results of this study suggest that although sea trout may remain in the vicinity of their natal river some fish may undertake more extensive pan-Irish Sea movements than previously thought.

In order to identify the putative origin of marine-caught adult sea trout a freshwater microchemistry baseline was established by sampling juvenile *Salmo trutta* parr from 36 rivers located within 9 subregions of the Irish Sea (southwest Scotland, northwest England, north Wales, mid Wales, south Wales, east coast of Ireland, south coast of Ireland and the Isle of Man). Differences in *Salmo trutta* parr otolith microchemistry, measured using solution based-ICPMS (15 - 20 fish measured per river), were observed between river / region for Mg:Ca, Mn:Ca, Sr:Ca and Ba:Ca concentrations. Individual trout parr were assigned back to river / region of origin using cross-validated quadratic discriminant function analysis (CV-QDFA) and random forest analysis (RF) with 74% (CV-QDFA) / 71% (RF) assignment success to river and 66% (CV-QDFA) / 74% (RF) assignment success to region respectively. In addition, the otolith chemistry of 39 fish, randomly selected from the parr collected from the 36 rivers during the study, was measured and the freshwater baseline used to assign these fish to river of origin. This process was conducted with no prior knowledge of actual river of origin until after the assignment process had been completed. In total, 69% of the fish were correctly assigned back to their river of origin with a mean individual probability of assignment of 0.93 ± 0.11.

The otolith microchemistry of 231 marine-caught sea trout (caught in coastal waters in the Solway Firth, Isle of Man, north Wales and east coast of Ireland) was measured in the sections of the otolith corresponding to the freshwater and marine phases of the life cycle using laser ablation ICPMS. Very few differences were observed in otolith chemistry in the marine section of the otoliths between fish caught in the different coastal locations. Mg:Ca, Mn:Ca, Sr:Ca and Ba:Ca concentrations were measured in the freshwater section of the otolith and the freshwater microchemistry baseline used to assign fish back to putative region of origin. The results indicated that sea trout may undertake more extensive migrations in the Irish Sea than previously thought with, for example, putative classifications of some fish caught in the Solway Firth to south Wales and some fish caught off the east coast of Ireland classifying to regions in the eastern Irish Sea (southwest Scotland, northwest England, North Wales). In addition, the $\delta^{13}C$, $\delta^{15}N$ isotope chemistry in the section of the scale corresponding to the last period of summer growth at sea was measured for in-river adult sea trout from 7 rivers (5 – 19 fish per river) in the eastern Irish Sea (Luce, Nith, Lune, Dee. Conwy), mid Wales (Dyfi) and south Wales (Tywi). No differences in scale $\delta^{13}C$ were observed between rivers but the $\delta^{15}N$ chemistry suggested spatial segregation between fish from the eastern Irish Sea rivers and mid / south Wales. Reference to the Irish Sea $\delta^{15}N$ isoscape of Jennings and Warr (2003) suggested that fish tended to stay in coastal waters close to their river of origin.

The results of this study have provided novel information on the otolith / scale chemistry of *Salmo trutta* parr and adults. Taken together, the results indicate that although some sea trout may stay in coastal waters close to their river / region of origin, other sea trout may undertake pan-Irish Sea

migrations. Clearly any management policies implemented for sea trout in the Irish Sea will need to be transnational in nature in order to account for the pan-Irish Sea movement patterns.

5.2 Introduction

5.2.1 Defining the Problem – Where Do Fish Come From and Where Do They Go?

Some fish species can display complicated and highly varied movement patterns between distinct bodies of water during their life cycles (Cadrin *et al.*, 2013). Such movements can be wholly within the freshwater or marine environments or may involve transitioning between the two in diadromous species. However, defining the movement patterns of fish during their lifetime is key to both understanding their ecology and for conservation management and exploitation management purposes. Within freshwater, fish may undertake short migrations of a few kilometres, for example, the in-stream movement of resident adult brown trout *Salmo trutta* from feeding sites to areas of the stream with suitable substrate for spawning (*e.g.* Vøllestad *et al.*, 2012). In contrast, some species are known to undertake much longer migrations within freshwater. For example, the paddlefish *Polyodon spathula* is known to be highly mobile making extensive movements in excess of 2,000 km within river systems and are frequently capable of covering large distances (*ca.* 40 km) within a 24 hour period (Jennings and Zigler, 2000). The species known to undertake the longest freshwater migrations is the Amazonian catfish *Brachyplatystoma rousseauxii* which migrates over 10,000 km between the juvenile nursery area in the estuary of the Amazon to the breeding zones in the head waters of the western Amazon basin close to the Andes (Garcia Vasquez *et al.*, 2009). In the marine environment, large-scale migrations in the order of 100s of kms between nursery, feeding and spawning grounds are not uncommon with North East Atlantic examples including the Atlantic herring *Clupea harengus* (Ruzzante *et al.*, 2006), European plaice *Pleuronectes platessa* (Dunn and Pawson, 2002) and European sea bass *Dicentrachus labrax* (Pawson *et al.*, 2007). In addition, some fishes can undertake transoceanic migrations in the order of several 1000 kms, for example the feeding migrations of salmonids at sea (Groot and Margolis, 1991; Hansen and Quinn, 1998). The European eel *Anguilla anguilla* undertakes migrations of *ca.* 5,000 km) from its freshwater feeding grounds in European freshwaters to spawning grounds in the Sargasso Sea (Aarestrup *et al.,* 2009). The marine species undertaking the longest transoceanic migration is probably the great white shark *Carcharodon carcharias* with one individual recorded as undertaking a migration from South Africa to Australia and back, a journey in excess of 20,000 km (Bonfil *et al.*, 2005). Clearly, fish can undertake movements of considerable magnitude in both freshwater and marine environments and can make these journeys at different stages of their life cycle: the critical questions facing scientists and managers are where have they come from? (*i.e.* their origins) and where/why do they go? (*i.e.* what are their movement patterns).

5.2.2 Why Do We Want To Know Where Fish Come From And Where They Go?

Defining the movement patterns of fish during their lifetime is key to both understanding their ecology and for conservation management and exploitation management purposes. The key questions to be asked are:

- *What is the geographical range and population structure for the species?* (*i.e.* where is the species found?). Within its range can it be considered to be one large mixed population or can the species be divided up into discrete populations?

- *What are the movement patterns of the species?* (*i.e.* where do they go?). At what stage(s) in their lifecycle do they move from one location to another?

- *Why do they move?* For example, juveniles or adults may move to/between geographically distinct feeding areas at different stages of development or at different times of the year; reproductively mature adults may move to geographically distinct spawning areas; juveniles may reside in discrete nursery rearing areas for a period of time that may span from months to years before joining the adult population to undertake the adult-stage migrations.

- *To what extent do the discrete populations, if present, intermix* with each other during the different lifestage-dependent movement patterns?

The knowledge of population structure and the biological identity, *i.e.* the phenotypic and genotypic diversity, of the discrete populations of a species is important in determining which populations should be conserved to maintain the diversity exhibited by a particular species and for the conservation of biodiversity in general. In addition, knowledge of population structure of exploited species to determine the appropriate management unit for the species. Fisheries are usually managed at the stock level and knowledge of the geographical distribution and movements of each stock (and the populations contained therein) and the degree to which a stock may mix with other stocks at different stages of their lifecycle or at different times of the year is essential for the development of evidence-based management plans for sustainable exploitation (King, 2007). Thus, scientists and resource managers need information on where fish have come from and where they go at different times of the year and at different stages of the life cycle.

5.2.3 How Can We Identify Where Fish Have Come From and Find Out Where They Go?

Understanding the movement patterns of aquatic animals is hampered by the very medium in which they live – water. It is much easier to track terrestrial animals that inhabit the same environment as Man and can be seen and followed more easily. This is further compounded in the marine environment where the Oceans present a vast three dimensional environment in which the fish can move but Man is unable to follow easily. Despite these difficulties, some tracking methodologies, such as the use of external tags attached to the fish, have been used to identify origins of fish and track movement patterns since at least the 1880s (Loerke and Cadrin, 2007). The toolkit for identifying origins and tracking movement patterns can be divided into what are termed "applied" which have been introduced to the animal by the researcher and "natural" markers, a term used to describe some unique natural characteristic of the animal which can be used to identify the origin of the individual and this can also be used to look at movement patterns (see Cadrin *et al.*, 2013 for a detailed review of the subject area).

5.2.3.1 Applied Markers as Tags

The choice of marker, commonly referred to as a "tag", will be dependent on the study animal and the resources (time / money) available. The most commonly-used applied markers, and the ones with the longest history of use, are those known as "external tags" where the external surface of the animal is marked in some way so that it can be visually identified if subsequently recaptured. For aquatic animals these tags include: V-notching (in crustaceans) or fin clipping (in fishes), polyethylene or rubber ribbons / discs (in shellfish), visible implant elastomer (VIE, in fishes), anchor tags (in fishes), laminated disc tags (in flatfishes), passive integrated transponders (PIT tags, in fishes), acoustic tags (in fishes; usually used in radio-tracking), archival data storage tags (DSTs, in fishes) and "pop up" satellite tags (in fishes). The size and cost of the tags can vary from nothing (notching / clipping) or a few pence to thousands of pounds (satellite tags). Similarly, the ease with which tags can be applied, the level of training required, their retention time and the amount of information that can collected from the tag (normally just a unique individual ID and data on size and location of capture) can also vary. [For a detailed review of the range of applied and natural markers and their use in fish biology, please see Cadrin *et al.,* 2013].

Conventional tag-recapture and radio-tracking of individually-tagged fish has helped to reconstruct the movement patterns of fishes (see reviews by Cooke *et al*., 2011 and Cadrin *et al*., 2013). Such research has frequently been carried out by Government fisheries regulatory agencies as part of their stock monitoring and management programmes. For example, the large-scale tagging programmes conducted by Cefas in the UK on European plaice (Dunn and Pawson, 2002) and European sea bass (Pawson *et al*., 2007) that have informed ICES management policies for these species. However, by their very nature, large-scale tagging programmes using applied markers can be extremely labour intensive and logistically difficult to implement regarding sample collection, tagging, release and subsequent recapture and recapture rates can be very low (King, 2007; *e.g.* see Herzka *et al.*, 2009). Furthermore, financial constraints can limit the number of fish that can be tagged with more advanced (and more data-informative) applied markers and the costs associated with associated equipment (*i.e.* radio tags, monitoring equipment) can be high. Therefore, such studies tend to be applied to small numbers of fish and since the number of recaptured or successfully tracked fish is also usually very low, the returns on the investment of both time and financial investment (*e.g.* loss of expensive radio tags) are considered to be poor (see Cadrin *et al.*, 2013). In addition, trying to address the movement patterns of fish at sea in a large three dimensional environment and study the degree of homing observed by anadromous adults to their natal rivers have also proved difficult using many conventional tagging methods with the exception of the more advanced archival and satellite tags (Dingle, 1996; Elsdon *et al*., 2008). However, the knowledge gains from a successful tagging programme can sometimes be considerable and outweigh the input costs of time and materiel (*e.g.* Block *et al.*, 2001; Bonfil *et al.*, 2005; Galuardi and Lutcavage, 2012).

One disadvantage with using applied tags to track the movement patterns of fishes is, due to their size and method of attachment, their application with small fishes can be limited. Advances in technology in the development of miniaturized artificial radio tags combined with more sophisticated radio telemetry have attempted to resolve this problem. For example, recent advances in technology have enabled "tiny" PIT tags to be developed that have been used to document behaviour in ants (Moreau et al., 2011) and bees (Decourtye *et al.*, 2011) and recently a tag of *ca*. 6mm in length has been used on studies of small zebra fish (size range 16-42 mm; Cousin *et al.*, 2012). However, the financial costs of such studies still preclude their widespread application and limit the sample sizes in the studies using these techniques. The use of many conventional external tags has been hindered in smaller fishes by their size and the high mortality observed during the tagging process (reviewed in Cadrin *et al.*, 2013). Therefore, monitoring movement patterns of small fish in freshwater is not feasible until the fish have attained a size at which the impact of attaching / implanting the tag will no longer affect survival or growth (*e.g.* Ombredane *et al*., 1998; Richards *et al*., 2013). Unfortunately this size limitation has hindered our understanding of natal origins and early movement patterns of juvenile fishes, however, such an understanding of early life history variability is fundamental if we are to understand their population structure and movement dynamics (Kennedy *et al*., 2002; Metcalfe *et al*., 2002). In the marine environment, tracking the general movement patterns of adults can also be problematic using traditional tagging techniques as a large investment in tags, time and the number of fish tagged over many years is needed to elucidate stock movement patterns, for example the 30+ years' research to determine the migration patterns of the European sea bass in UK waters (Holden and Williams, 1974; Kelley, 1979; Pawson *et al*., 1987; Pawson *et al.*, 2007; Pawson *et al.*, 2008; Quayle *et al*., 2009).

5.2.3.2 Natural Markers as Tags

There is growing interest in the use of natural markers, to try to understand a species geographical distribution and to answer questions on the dispersal and movement patterns of the juvenile and adult fish (Walther and Thorrold, 2009; ICES, 2012). Natural markers can be defined as some unique natural characteristic of the animal which can be used to identify the origin of the individual and which can also be used to look at movement patterns and include parasites, bacterial communities, distinctive body markings, meristics / morphometrics, genetics and chemical tags such as stable isotopes and trace element microchemistry.

Parasites have been used as biological markers of origin and as a tool for stock discrimination in a range of demersal and pelagic marine fish species as well as anadromous salmonids and some cetacean and invertebrate species (see Mackenzie and Abaunza, 1998; Mackenzie, 2002). Where parasitic infection has been found to be endemic to a specific geographical region, it can be inferred that animals which are subsequently caught outside that region but which are infested with these site-specific parasites will have at some point visited that area during part of their life history (see Mackenzie and Abaunza, 1998; Mackenzie, 2002). Similarly the natural bacterial populations associated with the mucus layer of fish and surrounding seawater have also been used as a biological tag to identify origins in gadids (Wilson *et al.*, 2008; Smith *et al.*, 2009) and on a larger global scale in tracing the origins of marine ornamental fishes (Cohen *et al.*, 2013). In some aquatic species, natural body markings, such as tears, marks, notches and scars in fins and tail flukes, and spot patterns have been used to identify individuals and to track their movement patterns. Although natural spot patterns have been used to identify small juveniles in some species like salmonids (Leaniz *et al.*, 1994; Donaghy *et al.*, 2005; Merz *et al.*, 2012) this approach has mainly been adopted with marine megafauna such as large elasmobranchs (*e.g.* Castro and Rosa, 2005; Van tienhoven *et al.,* 2007) and cetaceans (*e.g.* Dufault and Whitehead, 1995) where individuals can be easily recognised from a distance and with minimal handling / interference and is usually applied in studies where samples sizes are small.

The use of genetic markers has been used extensively and effectively in studies of population differentiation (Hamilton, 2009; Nielsen and Slatkin, 2013), to identify species / populations of high conservation value due to their genetic pedigree (Avise, 1989; Hedrick, 2001) and in fisheries it has been used as a tool for stock discrimination for management purposes (Carvalho and Hauser, 1994; Shaklee *et al.,* 1999) and as a forensic tool in food traceability to identify the provenance (species and location of capture) of fisheries products (Martinsohn *et al.*, 2011; Nielsen *et al.*, 2012). Initially protein polymorphisms were used for population differentiation but now molecular analysis of DNA polymorphisms using microsatellites and mitochondrial DNA has become the standard (Begg and Waldman, 1999; Okumuş and Ciftci, 2003) with an increasing use of single nucleotide polymorphisms (SNPs) (Syvänen, 2001; Helyar *et al.*, 2011). Nuclear DNA analysis has now become the standard tool in assessing population differentiation in fishes for both conservation and exploitation purposes (*e.g.* Sato *et al.*, 2004). Salmonids are one group of fishes whose genetic diversity and population structure have been extensively researched (*e.g.* Sato et al., 2004; Verspoor et al., 2007). Given their strong homing fidelity to their natal spawning sites (Dittman and Quinn, 1996; Davidsen *et al.*, 2013), salmonids show very strong genetic structuring over a range of spatial scales and the geographical scale of research has ranged from macro-scale studies covering large geographical ranges inhabited by a species (*e.g*. Utter *et al.*, 1989; Bernatchez *et al.*, 1992; King *et al.,* 2001; Sato *et al.,* 2004; CSTP Genetics (see Chapter 4)) to the micro-scale examining fine-scale population structuring within a single freshwater catchment (*e.g.* Carlsson and Nilsson, 2000; Kitanishi *et al.,* 2009; Stelkens *et al.,* 2012).

Geographic variation in morphometric (*i.e.* the analysis of body shape) and meristic (*i.e.* the counting quantitative features of fish) characters have been used to discriminate between stocks of fish for over 100 years (Cadrin, 2000). Distinct phenotypic traits such as body shape, head / mouth shape, or otolith / scale shape formation or the analysis of discrete countable serially repeated meristic structures which are fixed within the larvae or embryos (*e.g.* number of gill rakers, fin rays or vertebrae) have also been used as tools in identifying stock structure (*e.g.* Cadrin, 2000; Turan, 2004; ICES, 2012; Cadrin *et al.*, 2013). These observed differences will have a genetic basis but can be subject to environmental modification. For example, meristic trait expression in fishes can be modified during the early larval stages by environmental factors such as temperature, salinity, oxygen, pH, or food availability (Barlow, 1961; Lindsey 1988). Similarly, morphometry in fishes is genetically determined but under environmental modification with differential patterns of growth, driven by temperature and food availability, resulting in differences in body shape (Marcil *et al.,* 2006), scale shape (de Pontual and Prouzet, 1987; Richards and Esteves, 1997;) and otolith shape (Campana and Casselman, 1993; Cardinale *et al.*, 2004). Differences in body shape were initially measured using univariate comparisons, often corrected for differences in body size using residual analysis (Reist, 1986). However, the field of multivariate morphometrics has developed whereby several morphometric measures can be combined into a single statistical analysis using a suite of multivariate methods (Cadrin, 2000). The most commonly-used approach now is the use of geometric morphometrics whereby landmarks are used together with procrustes superimposition to provide measures of body shape that are independent of size, translation or rotation (Zelditch *et al.*, 2004). Thus, thin-plate spline analysis of body shape is fast becoming the standard approach to analyse differences in body shape in fishes (*e.g.* serranids, Cavalcanti *et al.,* 1999; hammerhead sharks, Cavalcanti, 2004; flatfish, Cadrin and Silva, 2005; cichlids, Clabout *et al.,* 2007) including juvenile and adult salmonids (Sheehan *et al.*, 2005; Monet *et al.,* 2006; Morinville and Rasmussen, 2008; Vehanen and Huusko, 2011). Another developing area of research over the last 30 years is the use of otolith shape analysis as a tool for stock discrimination (Campana and Casselman, 1993). As with body shape analysis, recent developments have moved from using simple univariate analysis of linear measurements to more powerful analyses of outline and shape using techniques such as elliptical and Fourier analysis and such approaches are developing into a powerful technique for stock discrimination (*e.g.* Galley *et al.*, 2006; Burke *et al.*, 2008; Javoor *et al.*, 2011).

5.2.3.3 Biogeochemical Markers

Otolith Microchemistry

Over the last 30 years there has been a dramatic rise in the use of the microchemistry of calcareous structures such as scales, fin rays, vertebrae and otoliths (Wells *et al.*, 2003 Clarke *et al.*, 2007; Elsdon *et al.*, 2008; Ramsay *et al.*, 2011; Tillett *et al.*, 2012) to assess fish origins and to try to understand movement patterns. This work is based on the fact that more than 90% of the trace and ultra-trace elements which make up the otolith (Campana and Neilson, 1985) are derived to some degree from the chemistry of the surrounding ambient water (Farrell and Campana, 1996; Bath *et al*., 2000; Walther and Thorrold, 2006) making them an ideal biogeochemical marker (Campana, 1999; Elsdon *et al.*, 2008). Therefore, otoliths can be viewed as “black box recorders” providing a record of the chemically distinct waters in which a fish has resided during its lifetime (Thorrold *et al*., 1997; Thorrold *et al*., 1998b; Walther *et al*., 2008; Veinott *et al*., 2012).

Natural biogeochemical markers have shown great potential during recent years to identify the origins of fishes and to study connectivity between fish populations in, and movements between, chemically distinctive water bodies by fishes during their lifetime. The use of microchemistry to study origins and movement patterns of fishes has tended to focus more on estuarine and marine fish species (for reviews of the marine literature see Gillanders, 2005; Elsdon *et al.,* 2008; Sturrock *et al.,* 2012). However, the use of these natural biogeochemical markers is also gaining momentum as an alternative approach to the use of conventional mark and re-capture methods to look at origins and movement patterns of fish within freshwater (*e.g.* Wells *et al.,* 2003; Muhlfield *et al.,* 2005; Veinott and Porter, 2005; Zeigler and Whitledge, 2010; Ramsay *et al.*, 2011; Zeigler and Whitledge, 2011; Martin *et al.*, 2013a and 2013b) and also to track the movements of diadromous species during transitions between freshwater and marine environments (*e.g.* Walther *et al.*, 2008; Martin *et al.*, 2010; Walther and Limburg, 2012). The advantage of biogeochemical markers, in addition to being a natural internal tag, is that it allows the origins and movement patterns of fishes that have been too small to tag using conventional external tags to be studied. In addition, it circumvents the need to apply external tags to large numbers of fish in the hope of recapturing sufficient number to derive reliable information on movement patterns since every fish is already 'tagged' and carries a record of its own lifetime movements in its otoliths.

Stable Isotopes

In addition to the use of trace elements there is growing interest in the use of stable isotopes as natural biogeochemical tags to study origins and movement patterns of animals (Rubenstein and Hobson, 2004: Graham *et al.*, 2010; Hobson *et al.*, 2010; Trueman *et al.*, 2012a; McMahon *et al.*, 2013). In the same way that water chemistry exhibits spatial variation and different bodies of water can have a distinctive chemistry, the isotopic composition of water can also vary (West *et al.*, 2010). Isotopes exhibiting spatial variation in the marine (M), estuarine (E) and freshwater (F) environments that have been used to study origins and movement patterns include nitrogen ($\delta^{15}N$; M-E-F), carbon ($\delta^{13}C$; M-E-F) oxygen ($\delta^{18}O$; M-F), sulphur ($\delta^{34}S$; M-E) and strontium ($\delta^{87}Sr$; F). For a review of marine studies see Trueman *et al.* (2012) and McMahon *et al.*, (2013); freshwater examples include Kennedy *et al.* (2005), Barnett-Johnson *et al.* (2008), Zeigler and Whitledge (2011) and Martin *et al.* (2013a and 2013b). Ramsay *et al.*, (2012) have shown that measurement of scale $\delta^{13}C$ and $\delta^{15}N$ signatures provided a better biogeochemical tag than a multi-elemental tag (Mg, Mn, Sr and Ba) in the scale or otolith at classifying brown trout *S. trutta* to site of origin in the River Dee in North Wales. The use of isotopic elemental tags to identify origin may provide an easier and quicker technique than those used to measure element microchemistry.

Most stable isotope studies have used isotopic tags to examine large-scale movement patterns in the marine environment, for example for marine mammals (Newsome *et al.*, 2010; Gimenez *et al.*, 2013), turtles (Ceriani *et al.*, 2012) and large marine fishes such as bluefin tuna *Thunnus thynnus*, yellowfin tuna *Thunnus albacares* and swordfish *Xiphias gladius* (Ménard *et al.,* 2007; Rooker *et al.,* 2008; Graham *et al.*, 2010). However, the application of carbon, nitrogen, oxygen and sulphur isotopes is also developing into a useful tool to look at fish movements in freshwater (*e.g.* Kennedy *et al.*, 2005; Barnett-Johnson *et al.*, 2008; Zeigler and Whitledge, 2011; Martin *et al.*, 2013a and 2013b). As our understanding of the spatial variation of element isotope ratios has developed, it has been possible to draw up isotopic landscape maps, or 'isoscapes' that map geographic changes in terrestrial or aquatic isotopic signatures (see Graham *et al.*, 2010; West *et al.*, 2010). These isoscape maps can then provide information on the movement patterns and foraging behaviour of freshwater or aquatic study species (see Graham *et al.*, 2010; Hobson *et al.*, 2010). To date, isoscape maps have been drawn up for deuterium ($\delta^{2}H$), carbon ($\delta^{13}C$), oxygen ($\delta^{18}O$), nitrogen ($\delta^{15}N$) and strontium ($\delta^{87}Sr$) (West *et al.*, 2010). Whilst isoscape maps for all 5 isotopes have been developed for the terrestrial environment (West *et al.*, 2010), to date, deuterium and nitrogen have not proved suitable for isoscape mapping in freshwater but $\delta^{13}C$ (M-F), $\delta^{18}O$ (M-F) and strontium $\delta^{87}Sr$ (F) have been used to map freshwater movement patterns (*e.g.* Barnett-Johnson *et al.*, 2008; Zeigler and Whitledge, 2011). In the marine environment, attention has focussed on the use of carbon ($\delta^{13}C$), oxygen ($\delta^{18}O$) and nitrogen ($\delta^{15}N$) isoscapes to look at movement patterns (reviewed in Graham *et al.*, 2010). Recent studies of scale $\delta^{13}C$ and otolith $\delta^{13}C$ and $\delta^{18}O$ chemistry has provided valuable insights into the large-scale marine migrations of Atlantic salmon and identification of their feeding areas at sea (Mackenzie *et al.*, 2011; Mackenzie *et al.*, 2012; Hanson *et al.,* 2013). However, the use of this technique to assess smaller scale migrations, for example by sea trout with coastal waters, has not been attempted. Although $\delta^{15}N$ and $\delta^{13}C$ isoscape maps have been drawn up for the coastal shelf seas around the UK (Jennings and Warr, 2003; Barnes *et al.*, 2009), including the Irish Sea, however, their potential for use as a tool to track movement patterns of fishes within coastal waters has been limited. (Jennings and Warr, 2003; Barnes *et al.*, 2009).

5.3 Aims

The aims of this study were:

1) To describe using solution-based inductively-coupled plasma mass spectrometry the trace element composition (*i.e.* microchemistry) in the otoliths of juvenile *Salmo trutta* parr sampled from rivers draining into the Irish Sea and to determine whether specific differences exist between sub-regions (*i.e.* southwest Scotland, northwest England, north / mid / south Wales, east coast of Ireland, south coast of Ireland, Isle of Man) that could be used to establish a freshwater microchemistry baseline for *Salmo trutta* in the Irish Sea region.

2) To test the efficacy of the freshwater baseline by measuring the otolith chemistry of *Salmo trutta* parr, randomly selected from fish collected during the study (but not used to establish the baseline) and using the freshwater baseline to assign these fish to putative source with no prior knowledge of actual river of origin until after the assignment process had been completed.

3) To describe using laser ablation inductively-coupled plasma mass spectrometry the trace element composition (*i.e.* microchemistry) in the sections of the otoliths of *Salmo trutta* caught in coastal waters in the Irish Sea corresponding to the freshwater and marine phases of the lifecycle.

4) To determine whether specific differences in the marine phase otolith microchemistry exist between *Salmo trutta* caught in different areas of the Irish Sea.

5) To assign marine-caught *Salmo trutta* back to putative freshwater region of origin based on the otolith microchemistry of the freshwater phase of their otolith using the freshwater microchemistry baseline.

6) To describe using isotope ratio mass spectrometry the $\delta^{13}C$ and $\delta^{15}N$ signatures in the section of the scales corresponding to the last period of summer growth at sea for in-river caught adult *Salmo trutta* and to determine whether the isotopic signatures suggest spatial segregation in feeding area at sea between fish from different sub-regions of the Irish Sea.

7) To assess the putative movement patterns of *Salmo trutta* in the Irish Sea based on the otolith microchemistry and scale isotope chemistry data.

5.4 Methods

5.4.1 Collection of Fish

5.4.1.1 Collection of Juvenile Trout Parr in Freshwater

Juvenile brown trout parr were collected for use in this study from 36 rivers located in SW Scotland, NW England, Wales, Isle of Man and Ireland (see Figure 5.4.1 and Table 5.4.1 for site locations). Most samples (n=33) were collected in summer 2010 although 3 rivers were sampled in 2011 (Cree, Argideen, Bandon). Where possible, rivers were selected to provide fish from some of the main sea trout producing rivers in 10 sub-regions:

- SW Scotland: 6 rivers = Luce, Cree, Fleet, Nith, Annan, Border Esk
- NW England: 6 rivers = Ehen, Derwent, Kent, Lune, Ribble,
- N Wales: 4 rivers = Dee, Clwyd, Conwy, Llyfni
- Mid Wales: 4 rivers = Mawddach, Dyfi, Rheidol, Teifi
- S Wales: 4 rivers = W. Cleddau, Tywi, Loughor, Tawe
- E coast of Ireland (N of the Skerries): 2 rivers = Dee (White River), Castletown,
- E coast of Ireland (S of the Skerries): 3 rivers = Dargle, Avoca, Sow
- S coast of Ireland Isle of Man: 4 rivers = Mahon, Colligan, Bandon, Argideen
- SW coast of Ireland: 1 river = Currane
- Isle of Man: 3 rivers = Sulby, Glass, Neb

Full details on the sample collection and sample storage protocols are provided in the CSTP Task 3 chapter in this report. In summary, trout parr were collected using electrofishing and euthanized using approved techniques for use in the UK or the Republic of Ireland. After death, total length (TL, ± 0.1 mm), fork length (FL, ± 0.1 mm), and body mass (BM, ± 0.1 g) were measured. Fish were returned to the laboratory, frozen at -20°C until transported to the School of Ocean Sciences in Menai Bridge on ice and stored at -30ºC until processed. In Ireland fish were returned to IFI's laboratory and frozen at -18ºC. Although not aged, the size range of fish sampled (Table 5.4.1) suggests that one and two year old trout parr were sampled. For most rivers 25 fish were collected for otolith microchemistry analysis, although 29 fish were collected from the Cree and 15 fish were collected from the Dee (White River) and Sow (Table 5.4.1). In order to establish the freshwater microchemistry baseline between 14 and 20 fish were selected at random for extraction, cleaning (see Section 5.4.3.3) and measurement (see Section 5.4.4). In order to test the freshwater microchemistry baseline a further 39 fish were selected at random from the remaining 219 fish and their otolith chemistry was measured and the established baseline used to assign these fish to river of origin. This process was conducted "blind", i.e. with no prior knowledge of the actual river of origin of each fish until after the assignment process had been completed.

Table 5.4.1 Details of river site locations (River, site name and GPS coordinates for middle of stream reach sampled) where juvenile *Salmo trutta* parr were collected for the Irish Sea microchemistry baseline. Twenty five fish were sampled at each site (unless otherwise indicated) and the number of fish analysed using sb-ICPMS is indicated. Size data are presented as mean Total Length ± SD plus the minimum-maximum size range.

Region and River number	River	Site Name	GPS Location	Year sampled	TL range (mm)	Mean TL (mm)	Number analysed by sb-ICPMS
S-W Scotland							
1	Luce	Lady Burn	54.878, -4.810	2010	84 - 109	91.5 ± 5.4	19
2	Cree*	Penkiln Burn	55.019, -4.425	2011	85 - 170	126.1 ± 19.7	19
3	Fleet	Barley Burn	54.895, -4.216	2010	80 - 109	89.1 ± 6.8	20
4	Nith	Wanlock Water	55.414, -3.817	2010	90 - 128	114.2 ± 10.9	19
5	Annan	Windyhill Burn	55.212, -3.617	2010	75 -135	95.6 ± 11.5	19
6	Border Esk	Meggat Water	55.228, -3.083	2010	100 - 156	119.8 ± 13.2	18
NW England							
7	Ehen	Kirk Beck	54.465, -3.498	2010	94 - 130	109.8 ± 9.2	20
8	Derwent	Marron	54.573, -3.448	2010	102 - 148	124.7 ±15.9	19
9	Kent	Lambrigg Beck	54.361, -2.668	2010	103 - 153	130.4 ± 14.2	19
10	Lune	Ellergill Beck	54.442, -2.556	2010	75 - 135	125.6 ± 16.6	15
11	Ribble	Twiston Beck	53.897, -2.299	2010	100 - 156	118.4 ± 13.2	19
Wales							
12	Dee	Eglwyseg	52.985, -3.185	2010	104 - 176	122.7 ± 16.6	19
13	Clwyd	Deunant	53.192. -3.562	2010	95 - 143	116.1 ± 12.4	19
14	Conwy	Roe	53.214, -3.848	2010	100 - 143	122.3 ± 11.2	18
15	Llyfni	Nant Tal-y-Mignedd	53.055, -4.201	2010	73 - 128	91.2 ± 15.0	17
16	Mawddach	Nant Pwll y Gele	52.762, -3.841	2010	76 - 116	90.6 ± 11.1	20
17	Dyfi	Cerist	52.726, -3.705	2010	81 - 120	99.6 ± 11.1	19

Region and River number	River	Site Name	GPS Location	Year	TL range (mm)	Mean TL (mm)	Number analysed by sb-ICPMS
Wales							
18	Rheidol Melindwr		52.402, -3.974	2010	102 - 161	137.7 ± 14.7	20
19	Teifi	Nant Bargod	52.026, -4.399	2010	111 - 157	129.8 ± 11.8	18
20	W. Cleddau	Anghof	51.917, -4.935	2010	111 - 159	138.7 ± 13.8	19
21	Tywi	Sawdde	51.898, -3.805	2010	100 - 158	121.5 ± 15.9	20
22	Loughor	Aman	51.804, -3.898	2010	117 - 159	144.7 ± 11.0	16
23	Tawe	Main river	51.801, -3.707	2010	104 - 170	129.3 ± 16.3	19
Ireland							
24	Dee (White River)**	Main river	53.843, -6.395	2010	132 - 167	149.9 ± 9.7	15
25	Castletown	Main river	54.031, -6.445	2010	112 - 169	149.5 ± 12.0	19
26	Dargle	Main river	53.155, -6.196	2010	80 - 116	93.9 ± 9.3	19
27	Avoca	Derry	n/a	2010	103 - 144	122.1 ± 11.5	19
28	Sow**	Main river	52.396, -6.472	2010	121 - 153	138.5 ± 8.7	15
29	Mahon	Main river	52.212, -7.485	2010	103 - 144	122.1 ± 11.5	20
30	Colligan	Main river	52.171, -7.663	2010	n/a	n/a	18
31	Argideen	Main river	51.647, -9.022	2011	100 - 139	117.5 ± 11.6	19
32	Bandon	Brinney	51.783, -8.702	2010	99 - 152	123.9 ± 12.5	19
33	Currane	Finglas	51.804, -10.141	2010	90 - 165	114.2 ± 19.1	20
Isle of Man							
34	Sulby	Main river	54.316, -4.486	2010	84 - 137	103.6 ± 20.0	15
35	Glass	Main river	54.204, -4.659	2010	88 - 122	96.9 ± 9.1	19
36	Neb	Main river	54.154, -4.502	2010	78 - 120	88.5 ± 9.1	18

* n = 29, ** n = 15, n/a = data not available

Figure 5.4.1 Map of the Irish Sea/Celtic Sea region showing the location of the 36 rivers sampled to construct the juvenile microchemistry baseline. Boundary markers indicate the subdivision of the Irish Sea/Celtic Sea into 10 regions.

5.4.1.2 Collection of Adult Sea Trout at Sea

Full details for the marine sampling programme are provided in CSTP Report (Chapter 3) and only a summary will be presented here. Briefly, adult sea trout were collected in coastal waters in the Irish Sea region (Figure 5.6.2) in 2010, 2011 and 2012 using a variety of sampling techniques including angler-caught (rod and line), gill netting, seine netting, stake netting, haaf netting and surface water pelagic trawling. For the purposes of this study, 231 fish collected from the following Marine Zones (MZ, Figure 5.6.2) were selected for otolith microchemistry analysis:

- MZ6 (East coast of Ireland) n = 67
- MZ10 (Solway Firth) n = 72
- MZ13 (North Wales) n = 24
- MZ14 (North Wales) n = 32
- MZ23 (Isle of Man) n = 36

Fish caught by CSTP personnel were killed using approved techniques for use in the UK or Republic of Ireland whilst commercially-caught animals were supplied to the project as dead animals. In some cases, total length (TL, ± 0.1 mm) and body mass (BM, ± 0.1 g) were measured after capture and size measurements were made of the remaining fish at the processing stage. All fish were frozen at -20ºC as soon as possible after death until transported on ice to Menai Bridge where they were stored at -30ºC until processed. In Ireland fish were stored at IFI facilities at -18 ºC, or at other regional laboratories, until processed.

Table 5.4.2 Data summary for the marine-caught *Salmo trutta* for the 5 marine zones used in the adult microchemistry analysis. Data are provided on the number of fish collected in each marine zone between 2010 and 2012 and size data presented as mean Total Length ± SD plus the minimum-maximum size range. For locations of each marine zone, see Figure 5.4.2.

Marine Zone	Location	Number of fish	Years Collected
6	East coast of Ireland	67	2010 = 2 2011 = 39 2012 = 27
10	Solway Firth	72	2010 = 45 2011 = 27
13	North Wales	24	2010 = 4 2011 = 20
14	North Wales	32	2011 = 20 2012 = 12
23	Isle of Man	36	2010 = 13 2011 = 23

5.4.1.3 Collection of Scales from Adult Sea Trout Caught In-River

Scales collected from adult sea trout that were caught in-river from the following 7 rivers during 2010 and 2011 were used in this study:

- River Luce, SW Scotland
- River Nith, SW Scotland
- River Lune, NW England
- River Dee, N Wales
- River Conwy, N Wales
- River Dyfi, Mid Wales

- River Tywi, S Wales

In addition, scales samples were also obtained from three Irish rivers (Slaney, Dargle, Castletown) but it was not possible to clean and prepare these samples in the time available.

The geographical location of each river is presented in Figure 5.4.3 and further details on the year of capture, samples sizes and the size range of fish caught are presented in Table 5.4.3. Full details on the sample collection and sample storage protocols are provided in this report (Chapter 3). In summary, scales were collected from the lateral flank below the dorsal fin of fish that were collected by CSTP personnel, anglers, commercial net fishermen or by the Environment Agency / Natural Resources Wales. All fish were dead prior to scale collection. The scales from each fish were retained in customised CSTP scale envelopes with the relevant sample data recorded on the envelope: unique fish code, river, location/date of capture, total length (± 5 mm), body mass (if possible) and sex (if possible). Scale envelopes were returned to the School of Ocean Sciences or Inland Fisheries Ireland and stored in the laboratory until processed. The fish used in this study comprised of fish collected as part of the sampling programme (Task 3) of the Celtic Sea Trout Programme for which sufficient scales were retained to allow their use in both Task 7 (Marine Ecology and life history variation) and Task 5 (Stock movement).

5.4.2 Otolith Extraction for Microchemistry Analysis

Salmo trutta carcasses were removed from the freezer and allowed to thaw prior to otolith extraction. Juvenile trout parr were removed from the freezer in batches of 10 and allowed to thaw for approximately 10 minutes (to allow the cranial cavity and membranous labyrinth housing the sagittal otoliths to thaw). A similar process was followed for adult sea trout except that fish were removed from the freezer in batches of 5 and allowed to thaw for approximately 30 minutes. Sample preparation protocols followed those outlined in Ramsay *et al.* (2011) and were the same for juvenile and adult fish. In summary, access to the cranial cavity was obtained through a transverse cut along the head of the fish to allow the membranous labyrinth and both otoliths to be exposed. Both right and left sagittal otoliths were extracted from the cranial cavity using acid-washed fine-tipped plastic forceps and placed into acid-washed petri dishes containing ultra-pure Milli Q water (Millipore™ hereafter referred to as Milli Q). Sagittal otoliths were cleaned of any adhering vestigial tissue using an acid-washed fine-bristled nylon brush and triple-rinsed in Milli Q. Right and left otoliths from each fish were then placed into labelled acid-washed 1.5 ml polypropylene micro-centrifuge tubes, sealed and transported to a laminar positive flow cabinet where they were dried for a period of 24 hours. To ensure the removal of any remaining adhering vestigial tissue or detritus which may be trapped within the interstitial lamellar spaces (see Brophy *et al*., 2003 on the contamination residue within microscopic calcified structures) both right and left otoliths were subjected to 5 minutes sonication in 3% H_2O_2 (see Ramsay *et al.,* 2011 for details), triple-rinsed in Milli Q and dried for a further 24 hours in a laminar positive flow cabinet. The left sagittal otoliths were used in all ICPMS analyses (solution-based or laser ablation) unless for reasons otherwise stated, for example if the left otolith was found to be crystalline or lost during sample extraction/preparation.

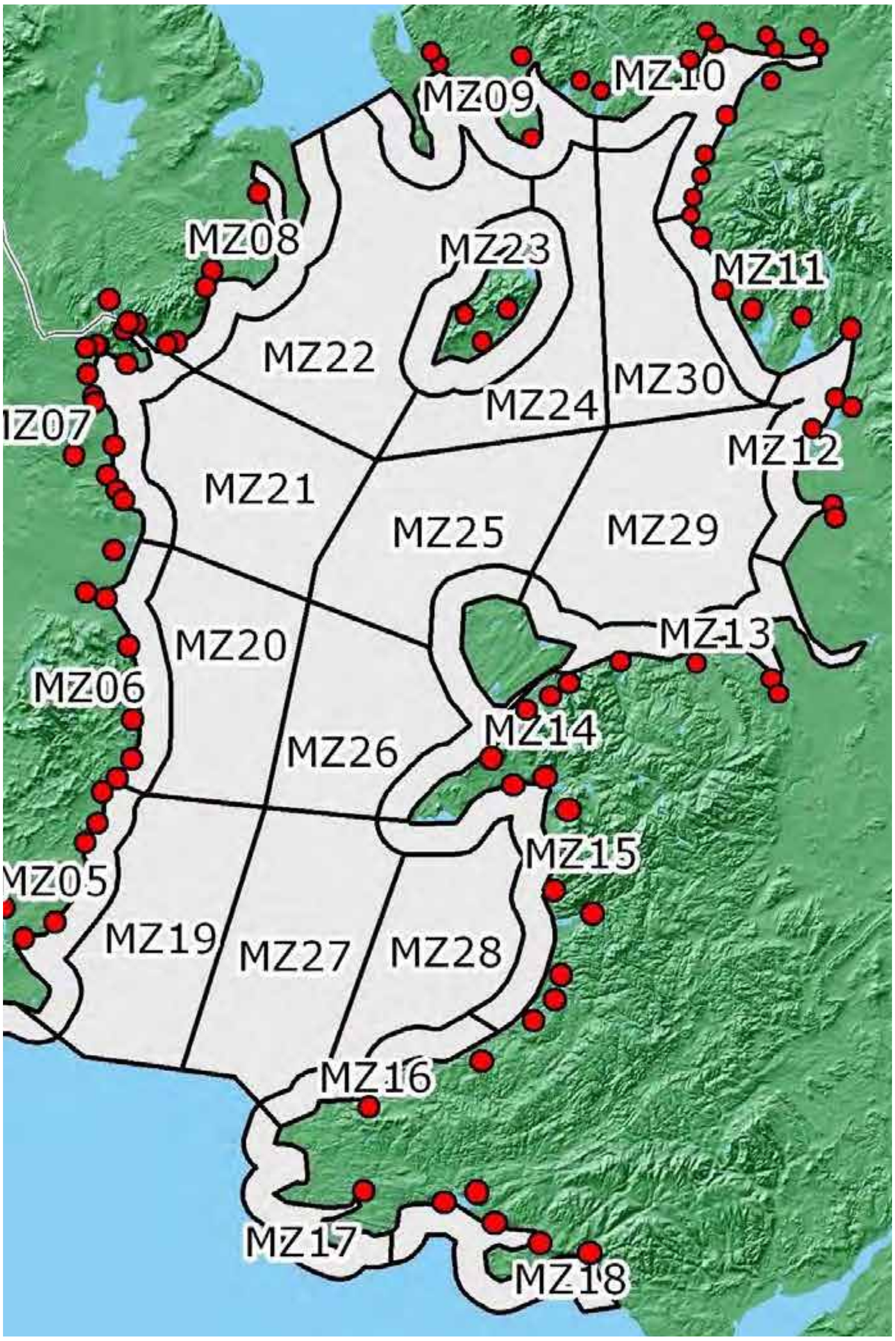


Figure 5.4.2 Map of the Irish Sea region showing the 30 Marine Zones designated for sampling for sea trout at the outset of the Celtic Sea Trout Project. Fish collected in Marine Zones 6, 10, 13, 14 and 23 were used in the adult otolith microchemistry study.

Table 5.4.3 Details on in-river *Salmo trutta* used in the scale stable isotope study. Size data are presented as mean Total Length ± SD plus the minimum-maximum size range. Scale stable isotope analyses were conducted as single samples or in duplicate as indicated.

River	Year sampled	Sample size	Sample analysis	TL range (mm)	Mean TL (mm)
Luce	2010	5	2 single 3 duplicate	430 – 675*	501 ± 97
Nith	2010	8	4 single 4 duplicate	420 – 675	515 ± 83
Lune	2011	10	2 single 8 duplicate	490 – 699	588 ± 69
Dee	2010	5	5 single	372 – 517**	---
Conwy	2011	5	1 single 4 duplicate	390 – 590	450 ± 81
Dyfi	2011	6	6 single	275 – 559	455 ± 101
Tywi	2010 2011	5 14	4 single 15 duplicate	537 – 665 240 - 790	602 ± 50 588 ± 142

Note: size data only available for *4/5 and **2/5 fish; --- = not calculated

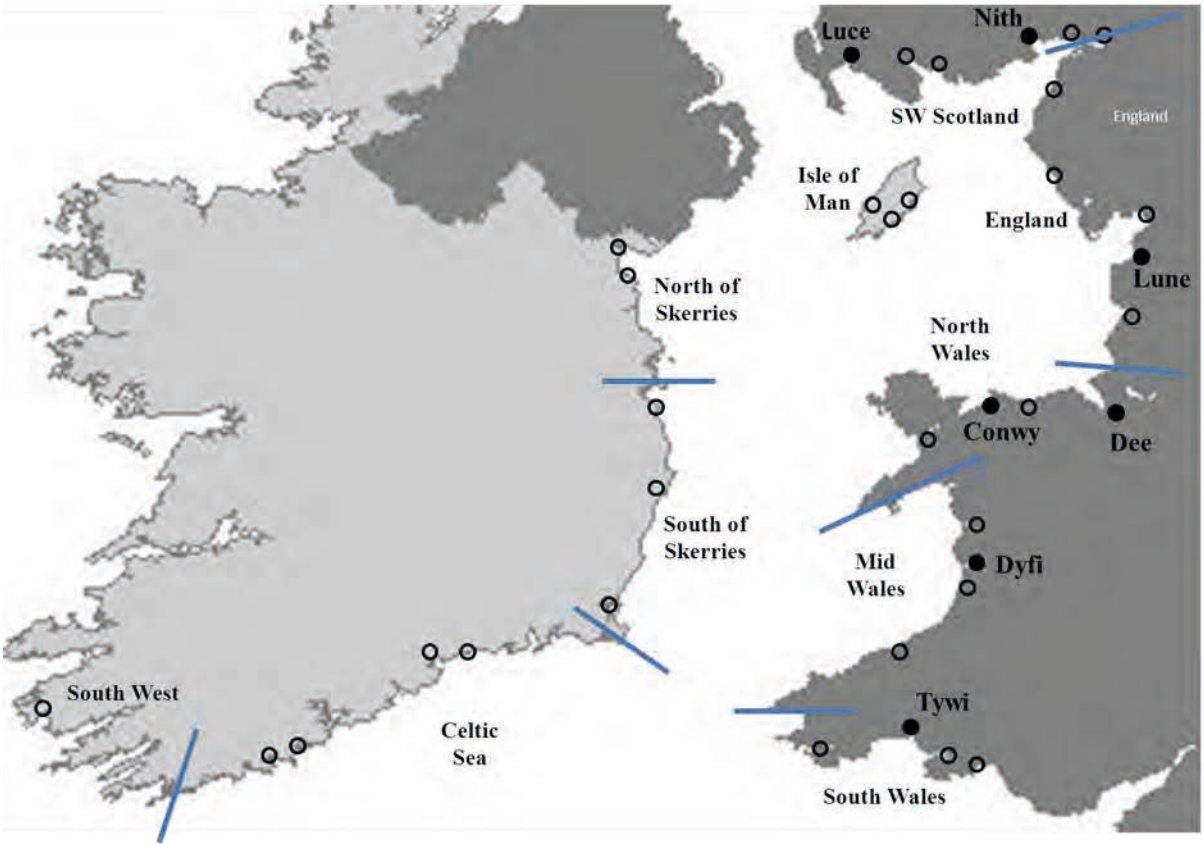


Figure 5.4.3 Map showing the location of the 7 rivers (solid circles) used in the scale stable isotope analysis. For comparative purposes the locations of the other 29 rivers sampled for the juvenile otolith microchemistry analysis are also shown (open circles). The Irish Sea region is divided up into 10 regions as indicated by the blue boundary markers.

5.4.3 Sample Preparation

5.4.3.1 Digestion and Dilution of Juvenile Trout Otoliths for Sb-ICPMS

All equipment used in sample preparation was acid-washed, triple-rinsed in Milli-Q and dried for 24 hours in a positive flow cabinet before use. Otolith digestion was a 2-stage process. Initially, 0.5 ml 3M HNO_3 was pipetted into the micro-centrifuge tubes and left for 24 h to allow digestion to occur. To assist in the calibration of the machine and the samples, the digestion acid was spiked with a known concentration of 3 elements (10 ppb Indium (In), 10 ppb Rhenium (Re), 20 ppb Barium (Ba). After 24 hours, the otolith-acid solution was then pipetted into a scintillation vial. The micro-centrifuge tube was rinsed with a further 1 ml 2% HNO_3 (spiked with 10 ppb In, 10 ppb Re, 20 ppb Ba) which was also transferred to the scintillation vial. 0.25 ml of this solution was pipetted into an ICPMS tube and 4.75 ml of a 1 % HNO_3 / 0.5% HCl solution was added.

5.4.3.2 Preparation of Adult Trout Otoliths for LA-ICPMS

Left adult otoliths were embedded in Kleer-Set™ polyester resin (MetPrep) using a polyethylene mould (10mm depth 8mm Ø). Otoliths were individually mounted on glass slides that had been acid-washed and triple-rinsed in Milli-Q glass using Crystalbond™ and ground on the sulcal side using 1200 and 2500 silicon carbide abrasive paper until the primordia was exposed. Otoliths were removed from the glass slides and the exposed surface triple-rinsed in Milli Q. Samples were then dried in the laminar positive flow cabinet and stored in individually labelled plastic envelopes prior to LA-ICPMS.

5.4.3.3 Preparation of Adult Scale Samples for Stable Isotope Analysis

Scales from the sea trout scale archive that were available for use in this study were examined to assess their quality and to select which fish scale samples would be cleaned and prepared for isotopic analysis. In turn, the scales from each envelope were immersed in de-ionised water in a petri dish and examined using a binocular dissecting microscope. Preferentially fish with original scales, *i.e.* not regrown following scale loss, were selected for use in this study (n = 41). However, in order to increase the number of fish used in this study, some fish with regrowth scales (n = 16), or fish where the scale sample consisted of a mixture of original and regrowth scales (n = 1) were also used included.

In total, the scales from 58 adult sea trout were cleaned and prepared for isotopic analysis in this study using the methods outlined in Hutchinson and Trueman (2006) and Mackenzie et al. (2011). Scales were briefly (*ca.* 2-5 minutes) soaked in de-ionised water, manually cleaned using forceps and fine-bristled nylon brush to remove surface adherents such as lipids and guanine, and dissected under a binocular light microscope. The last summer of growth at sea (as indicated by widely spaced circuli) was identified and excised using a scalpel blade to obtain a temporally-distinct sample. This sampling approach is discussed in detail in MacKenzie et al. (2011): in fish caught during summer sampling, the summer section from the edge of the scale was sampled, while in fish caught during the winter, the last summer growth section was sampled. The measured values were taken to represent the isotopic composition of the scale averaged over the last season of marine growth. The cut sections for each fish were stored in labelled eppendorf tubes until a sufficient mass of material had been collected for each fish. For each fish, ~0.60 mg of excised scale sample was weighed into a 4 x 6 mm tin cap crushed to form a small cube. The average sample mass of scale samples was 0.64 ± 0.08 mg (range 0.41 – 0.83 mg). Depending on availability scales, fish were measured in duplicate (n = 34) or by single measurement (n = 24). These 58 fish consisted of 41 fish where only original scales were analysed, 6 fish where only regrowth scales were analysed and 11 fish where both original and regrowth scales were analysed. In the latter group, 10 fish were measured in duplicate where one sample consisted of original scales and one sample consisted of regrowth scales and one fish was measured in duplicate where one sample consisted of original scales and the second consisted of a mixture of original and regrowth scales. Prior to analysing the isotopic composition of the 92 sea trout scale samples, some preliminary calibration work was conducted to determine whether it was possible to analyse < 0.60 mg of excised scale sample in order to reduce the time spent preparing scale material for isotopic analysis and to allow fish for which fewer scales were available to be used in future studies. Scales from a single marine-caught sea trout (caught in MZ13 and killed according to UK Schedule 1 requirements) were removed and original growth scales were cleaned and excised in the same way as described above. Replicate excised scale samples ranging in mass from 0.20 to 0.70 mg and approximating samples sizes of 0.2 mg (n = 5), 0.3 mg (n = 5), 0.4 mg (n = 5) and 0.6 mg (n = 14) were cleaned, cut and prepared for isotopic analysis as explained above. Since 10 fish were measure in duplicate where one replicate consisted of original scales and the other replicate consisted of regrowth scales, it was possible to compare the $\delta^{15}N$ and $\delta^{13}C$ values obtained for the two scale types to determine whether they provided similar isotopic values for the last period of marine growth.

5.4.4 Sample Measurement Protocols

5.4.4.1 sb-ICPMS Analysis of Juvenile Trout Otoliths

In total 17 elements (Table 5.4.4) were targeted for analysis using solution-based inductively-coupled plasma mass spectrometry of the juvenile trout otoliths. The selected elements were chosen because of the ease with which they could be assayed and the sensitivity of the mass spectrometer to determine their strength (concentration) and quality (limits of detection).

Table 5.4.4 Elements assayed (in descending order of their relative atomic mass down columns) in the juvenile *Salmo trutta* otoliths using sb-ICPMS.

Lithium, Li	Nickel, Ni^{60}	Barium, Ba
Magnesium, Mg	Copper, Cu	Cerium, Ce^{140}
Calcium, Ca^{43}	Zinc, Zn	Gadolinium, Gd^{157}
Chromium, Cr^{52}	Rubidium, Rb	Lead, Pb^{208}
Manganese, Mn	Strontium, Sr	Uranium, U^{238}
Cobalt, Co^{59}	Cadmium, Cd^{111}	

All otolith samples, internal standards, quality control standards and system blanks were run at the National Oceanography Centre Southampton on a Thermo Scientific X-Series II inductively-coupled plasma mass spectrometer (ICPMS) equipped with an auto sampler. All samples were injected into the ICPMS and were aerosolized in a gas plasma produced in a quarts torch at 5000° Kelvin, with the sample ions drawn from the plasma into an off-axis high-performance quadrupole mass analyser. The effects of possible polyatomic ionization interference were assessed for certain elements (due to their physical nature and their ion molecular reactions when introduced into the ICPMS; Gray, 1989; Evans and Ebdon, 1990) before the data were analysed. To reduce this occurring, the Thermo X-Series II machine has a 3rd generation collision-reaction cell incorporating kinetic energy discrimination into the spectrometer. The raw data produced from the sb-ICPMS analysis were examined using the Thermo Scientific X-Series II integrated software to assess and identify any of the interfering polyatomic elements and to calibrate the samples against the internal standards (ISTD). This method of calibration can be used to correct for any elemental drift observed on the machine.

The limits of detection (LOD), the detection limit (DL) and the quantification limit (QL) were calculated using the data from the calibration blanks. LOD values are a measure of instrument performance and the precision to which the elements contained within the sample otoliths can be measured. DL values were calculated using the solution concentrations equivalent to three times the standard deviation of the blanks (3 x σ) analysed. QL values were calculated using the equivalent of ten times the standard deviation of the blanks response (10 x σ). Any elements falling below the DL would not be suitable for further analysis. The QL allows the assessment of elemental concentrations which are between the DL and the QL which may be a result of either signal enhancement or suppression and as a result would not be suitable for further analysis. Six elements were found to be below the LOD – Li, Co, Cd, Ce, Gd and U – and were omitted from subsequent analysis. In addition, Ni was removed from subsequent analyses due to possible background ion effects as the sample interface cones are made of nickel. In total ten elements were identified to be above the LOD – Mg, Ca, Cr, Mn, Cu, Zn, Rb, Sr, Ba and Pb. However, Cr, Cu, Zn and Pb were found to vary in their concentrations when compared to the internal standards and those standards used to calibrate possible effects of machine drift and were subsequently removed from the final analysis.

The data sets for each element were screened for potential outliers (Barnett and Lewis, 1994) using the Grubbs test (Grubbs, 1950; Grubbs, 1969) and identified outliers adjusted using Winsorisation (see Hawkins, 1980; Sokol and Rohlf, 1995). After data screening and outlier correction, the remaining elements – Mg, Ca, Mn, Rb, Sr, and Ba – were then standardized to calcium to produce element:Ca ratios (see Campana, 1999; Thresher, 1999; Elsdon and Gillanders, 2004). The concentration of calcium within otoliths was assumed to be 400,000 µg g^{-1} from the stoichiometry of calcium carbonate (see Dove *et al*., 1996; Milton and Chenery, 1998; Zdanowicz, 2001; Ludsin *et al*., 2006; Swan *et al*., 2006; Lowe *et al*., 2011).

5.4.4.2 LA-ICPMS Analysis of Adult Sea Trout Otoliths

Left adult sea trout sagittal otoliths were laser-ablated (LA) to determine their trace elemental concentrations using a Class 4 Nd:YAG solid state 193 nm excimer lamp-pumped laser ablation system (New Wave Research, U.S.A) attached to an *in situ* Agilent 7500c inductively-coupled plasma mass spectrometer (ICPMS) at the British Geological Survey, Keyworth. Prior to analysis, sectioned otoliths were mounted (using Crystalbond™) with the sulcus facing upwards onto acid-washed / triple-rinsed glass slides which fit the dimensions of the laser ablation cell. Each slide held between 24-32 otoliths which were analyzed in batches of 8, with each slide containing approximately equal numbers of adult otoliths from each of the marine zones to be analysed and arranged on the slide in a random order (Ramsay *et al.*, 2011). This method of analysis removed the possibility of systematic error which could arise as a result of a variation between runs (see Brophy *et al*., 2003, Ramsay *et al.*, 2011). Mounted otoliths were housed in an airtight ablation cell clamped to an adjustable motorized stage of a binocular microscope and CCD video camera coupled to a computer monitor. Otolith images were illuminated using a 3-way light source (either transmitted, ring or coaxial) to allow the precise focus and identification of the sample area to be ablated with the observations of the analysis then viewed on the monitor.

Adult sea trout otoliths were ablated across the surface of the sulcus side of the otolith from the primordium (*i.e.* area surrounded by the nucleus, as defined by Campana and Nielson, 1985) to the dorsal edge at a rate of 4 µm s^{-1} using a 50 µm Ø laser spot size firing at a repeat rate of 10Hz with an irradiance of 0.87 GW cm^{-2} and a fluorescence of 3.53 J cm^{-2} with a 30 second wash out between samples. Otolith-ablated material was carried to the ICPMS in a flow of helium (0.80 l min^{-1}) where it was combined with a stream of argon carrier gas (0.85 l min^{-1}) before reaching the ICPMS.

To correct for changes in ablation efficiency between scans and along whole traverses and to assess instrument sensitivity (possible machine drift *e.g.* non-spectral interferences resulting in signal suppression/enhancement), element:Ca ratios were compared to a standard reference material. Calibration was conducted using the international standard NIST 612 (National Institute of Standards and Technology, USA) with NIST 610 used as a secondary reference material. Raw counts (cps) of a suite of elements from each of the ablated otoliths were transferred using the Agilent Proprietary ICP-MS software (Agilent Technologies, U.S.A.) and processed off line using the Iolite software package extension in Igor Pro (Igor Pro 6.2: WaveMetrics). In total 16 elements were targeted for analysis in the adult sea trout otoliths using LA-ICPMS (Table 5.4.5).

Ablated otolith material was measured for their limits of detection (LOD) and to assess instrument performance and precision. LOD was used to assess which elements were at / below their limits of detection within the otoliths, with those elements falling below the LOD removed for this study. In total, 8 elements - Na, Mg, K, Mn, Zn, Sr, Ba and Ca – indicated concentrations above the LOD.

Table 5.4.5 Elements assayed (in descending order of their relative atomic mass down columns) in the adult *Salmo trutta* otoliths using LA-ICPMS.

Lithium, Li	Chromium, Cr	Strontium, Sr
Boron, B	Manganese, Mn	Tin, Sn
Sodium, Na	Iron, Fe	Barium, Ba
Magnesium, Mg	Copper, Cu	Lead, Pb^{208}
Aluminium, Al	Zinc, Zn	
Calcium, Ca^{43}	Rubidium, Rb	

The data sets for each element were screened for potential outliers (Barnett and Lewis, 1994) using the Grubbs test (Grubbs, 1950; Grubbs, 1969) and identified outliers adjusted using Winsorisation (see Hawkins, 1980; Sokol and Rohlf, 1995). After data screening and outlier correction, the data for Na, Mg, K, Mn, Zn, Sr, and Ba were then standardized to calcium to produce element:Ca ratios (see Campana, 1999; Thresher, 1999; Elsdon and Gillanders, 2004). The concentration of calcium within otoliths was assumed to be 400,000 $\mu g\ g^{-1}$ from the stoichiometry of calcium carbonate.

5.4.4.3 EA-IRMS Analysis of Adult Sea Trout Scale Samples

Fish that were available for use in this study were extracted from the sea trout scale archive and their scales were examined under a binocular dissecting microscope to assess whether a sufficient mass / number of scales had been selected for isotopic analysis. In addition, where possible, fish were selected that possessed sufficient number / mass of scales that were "original" (*i.e.* not regrowth scales). The stable isotopic composition of the scales from 58 adult sea trout were examined in this study. In total, 70/92 (76%) of the samples run in this study were derived from "original" scales (*i.e.* not including any regrowth scales), 20/92 (22%) of the samples were derived from fish for which only regrowth scales were used. The remaining 2 samples (2%) were for fish where a mixture of original and regrowth scales were cleaned and cut. The average sample mass of scale samples was 0.64 ± 0.08 mg (range 0.41 – 0.83 mg).

Although it has been suggested that need to acid clean to decalcify and remove effect of DIC on scale carbon chemistry (Perga and Gerdeaux, 2003), a number of studies have shown that this is not necessary (*e.g.* Sinnatamby *et al.*, 2007; Ventura and Jeppesen, 2010; MacKenzie *et al.*, 2011; Roussel *et al.*, 2014) and it was not done in the present study.

Carbon-13 and Nitrogen-15 isotope ratios were measured at the National Oceanography Centre Southampton by continuous flow elemental analysis isotope ratio mass spectrometry (CF-EA-IRMS) using a EuroVector (model EA 3000) elemental analyser (EA) combined with a GV Instruments Isoprime mass spectrometer and using L-glutamic acid as an in-house calibration standard. Measurement precision assessed as 2 x standard deviation of 16 replicate analyses of USGS40 glutamic acid for $\delta^{15}N$ and $\delta^{13}C$ are, respectively, 0.7‰ and 0.1‰. Isotope ratios are expressed conventionally as values in parts per thousand (‰) according to the following equation:

$$X = [(R_{sample} - R_{standard})/R_{standard}] \times 1000$$

where X is $\delta^{13}C$ or $\delta^{15}N$, R_{sample} is the corresponding ratio $^{13}C/^{12}C$ or $^{15}N/^{14}N$ in the scale sample and $R_{standard}$ is the corresponding ratio $^{13}C/^{12}C$ or $^{15}N/^{14}N$ in the international isotope standard: PeeDee Belemnite for $\delta^{13}C$ and atmospheric nitrogen for $\delta^{15}N$ respectively.

5.4.5 Data Analyses

5.4.5.1 Microchemistry Data

Element:Ca ratio data were Log_{10} transformed (Muhlfeld, *et al*., 2005; Ramsay *et al.,* 2011; Ramsay *et al.*, 2012) prior to statistical analysis to meet the assumptions of normality and equal variance. Due to the large sample sizes (n = 665 for juvenile trout and 231 for adult sea trout respectively), some Log_{10} transformed data failed tests for normality (Anderson-Darling test AD) and / or equal variance (Levene's test). However, the AD test is sensitive to sample size and any slight deviation within a large data set may increase the chances of a rejection of a normal distribution (see McGuinness, 2002). Therefore, graphical plots were used to assess normal distributions (see Gillanders and Kingsford, 2003; De Vries *et al.*, 2005; Ramsay *et al.*, 2011), with only minor deviations from normality often indicated by the plots. In addition, where data remained heterogeneous after transformation, analyses were still performed using a probability of $\alpha = 0.05$ (based on McGuinness, 2002) since ANOVA has been found to be robust to departures of normality and heterogeneity where data are balanced and sample numbers are shown to be relatively large (see Underwood, 1997; Gillanders and Kingsford, 2003). In addition, assignment analyses (see below) were conducted using two comparable techniques which either assume normality or do not which allow the robustness of the parametric statistics to be assessed. Statistical analyses were performed on the elements:Ca ratios for elements most commonly used in studies of this nature – Mg, Mn, Sr and Ba (see Wells *et al*., 2000; Wells *et al*., 2003; Ramsay *et al.*, 2011; Ramsay *et al*., 2012; Martin *et al.*, 2013a and 2013b). Rubidium (Rb) was excluded from the statistical analyses as although it is found within animal tissue and can in some instances mimic potassium in its distribution and excretory patterns (Hays and Swenson, 1985; Soetan *et al*., 2010), it is biologically mediated and has little or no biological relevance in microchemistry studies due to its highly labile nature (Rooker *et al.*, 2001). For the adult sea trout, although 7 element:Ca ratios were detectable and available for analysis, in the freshwater section of the otolith (see Section 2.5.2) only elements:Ca for Mg, Mn, Sr and Ba were analysed (*i.e.* excluding Na:Ca, K:Ca and Zn:Ca) to provide comparability with the juvenile otolith microchemistry data set and to allow the juvenile data set to be used for assignment analysis of adult fish.

5.4.5.2 Assessing Freshwater Growth in Adult Sea Trout Otoliths

To determine which region (see Table 5.4.1) adult sea trout would be assigned to based on the elemental signal laid down in the otolith during their period of freshwater residency, it was first necessary to determine the growth zone within the otolith corresponding to the period of freshwater residency (*i.e.* pre-smolt phase) within the river (see Veinott *et al*., 2012). Since transects were conducted across the otolith from the primordium to the dorsal edge, it was possible from the Sr measurements to determine which laser ablations in the transect corresponded to the pre-smolt phase of the lifecycle (see Figure 5.4.4). The transect in Figure 5.4.4 shows the influence of maternally-derived (*i.e.* marine-derived) Sr laid down in the otolith during the early (*i.e.* embryo, alevin and early first-feeding) stages of the lifecycle in freshwater. This is followed by the fry/parr phase of the lifecycle where Sr concentrations are lowest on the otolith transect; the length of this part of the transect will correspond to the number of years spent in freshwater. Following on from the freshwater-residency section of the transect is a transition zone where otolith Sr concentrations rise as the fish undertakes smolt migration and makes the transition from freshwater (*i.e* low Sr) to sea water (*i.e.* high Sr). The final zone in the ablation transect corresponds to the period of adult growth with the peaks and troughs in this part of the transect possibly corresponding to periods of time spent in different areas at sea or movements into estuaries (Figure 5.4.4). The section of the otolith transect corresponding to the pre-first feeding (i.e. once maternally-derived Sr was no longer influencing the Sr signal) fry / parr phase of freshwater residency was identified for each adult sea trout and the element:Ca ratios for Mg, Mn, Sr and Ba measurements obtained in that section were used to calculate the freshwater signal for each fish and used in subsequent statistical analyses.

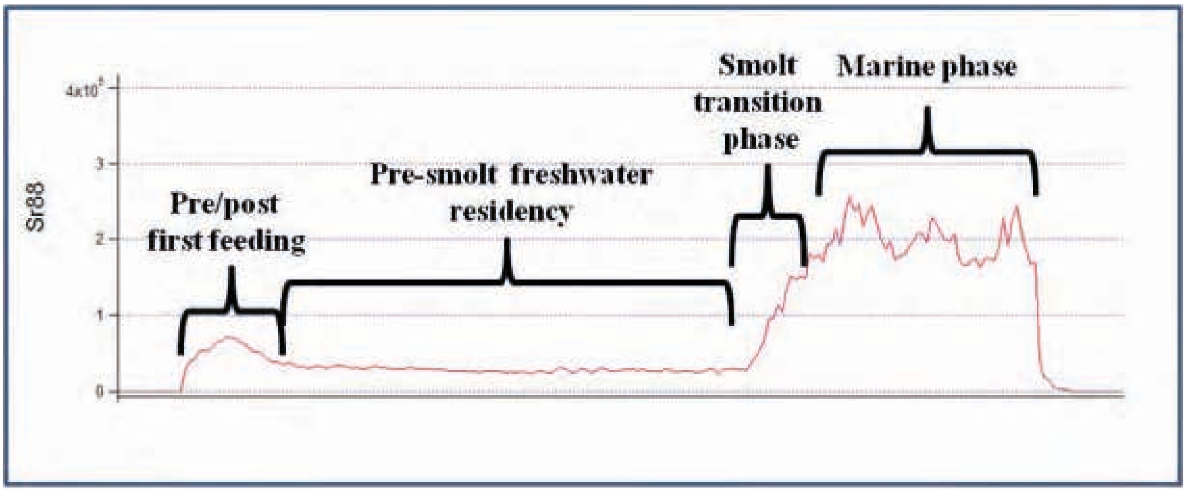


Figure 5.4.4 Strontium^{88} (counts s^{-1}) transect through the otolith of a marine-caught adult sea trout showing how it is possible to identify the different phases of the life cycle based on measured strontium values.

5.4.6 Statistical Analyses

Both univariate and multivariate parametric and non-parametric analyses were used to explore the otolith microchemistry and scale isotope chemistry data. Statistical analyses were conducted using SPSS v20 and Minitab v14. For all statistical tests, differences present at the 5% level were considered significant (unless Bonferroni-corrected for multiple pairwise comparisons as indicated in the Results text). For the otolith microchemistry data, differences in otolith trace elemental concentrations and multi-elemental fingerprints between rivers and between regions were assessed using multivariate and univariate analyses of variance (MANOVA and ANOVA) or using the non-parametric Kruskal-Wallis test. A MANOVA was conducted to determine whether overall the multi-element otolith fingerprint differed between rivers or between regions and then one way ANOVAs were conducted separately on each of the four element:Ca ratio data sets to determine which elements may be significantly different between rivers/regions. Where an ANOVA was significant, Scheffe's *post-hoc* or Tamhane's T2 multiple comparison tests (Bonferroni-corrected by the statistical software package used) were used to identify any significant differences in element:Ca ratios between rivers or between regions depending on whether variances were equal or unequal respectively between treatment groups. Where the Kruskal-Wallis test was significant, pairwise *post-hoc* comparisons were made using a Mann-Whitney U test.

Two assignment tests – Quadratic discriminant function analysis (QDFA) and Random Forest analysis (RF) – were used on the juvenile parr dataset to determine whether distinctive otolith microchemistry signals exist within the Irish Sea region at the river or region level. Quadratic discriminant function analysis (QDFA) was conducted to assess the accuracy with which juvenile brown trout parr were classified back to their natal rivers and regional zone based on their otolith chemical signatures (Wells *et al*., 2000; Clarke *et al*., 2007; Ramsay *et al.*, 2011). QDFA was used since data were normally distributed but did not possess equal variances even after various transformations (Log_{10}, Log_e, square root, 1/x). The QDFA involved an 'original' classification (which used the discriminant functions to classify the same samples that were used to develop the functions) and a 'cross-validation' (CV) classification (which involves leaving one sample out of the dataset before establishing the discriminant functions and then classifying the sample that was removed) (Sharma, 1996). To complement the classifications achieved with the QDFA, a non-parametric Random Forest analysis (RF: Breiman, 2001) was also run. Random Forest is a classifier consisting of a collection of tree-structured classifiers where independent identically distributed random vectors and each tree casts a unit vote for the most popular class at input (Breiman, 2001). Furthermore, it has been shown to perform extremely well with large unbalanced data sets without preprocessing (*e.g.* rescaled, transformed or modified) when compared to other classifiers such as discriminate analysis (see Liaw and Wiener, 2002), subsequently there is no need for cross-validation or separate tests set to get unbiased estimates of the generalized error (test error) (Liaw and Wiener, 2002). Only elements that showed significant differences in concentration among sites were included in the classification analyses. Principal Component Analysis (PCA) plots were used to provide a visual representation of the classification of individual fish to their river or region of origin. Cohen's kappa statistic was used to compute the chance-corrected agreement between actual and predicted group (river or region) memberships of fish (Titus *et al.*, 1984; Barnett-Johnson *et al*., 2008; Ramsay *et al.*, 2011; Ramsay *et al.*, 2012) using QFDA or RF. The kappa statistic ranges between 0 (indicating that the classification to site was no improvement over that achieved by chance) and 1 (indicating that there was perfect agreement in the classification to site when taking into account classification by chance). The relationship between the classification accuracies obtained using CV-QDFA and RF was assessed using least-squares linear regression analysis. Using the mean element:Ca ratios of Mg, Mn, Sr and Ba in the juvenile parr phase of the otoliths of the adult sea trout and the juvenile freshwater microchemistry baseline, each adult sea trout was assigned to a putative freshwater region using QDFA.

Statistical analysis of the scale calibration data was conducted using Pearson's Product-Moment correlation analyses and paired *t* tests to assess similarities between duplicate measures from the same fish and between original and regrowth scales from the same fish. The effect of sample mass on scale $\delta^{15}N$ and $\delta^{13}C$ was examined using one way ANOVA. Where the ANOVA was significant, Scheffe's *post-hoc* or Tamhane's T2 multiple comparison tests (bonferroni-corrected) were used to identify which pairwise comparisons were significantly different depending on whether variances were equal or unequal respectively between treatment groups. A similar statistical approach was used to analyse the scale $\delta^{15}N$ and $\delta^{13}C$ values in the last period of marine growth for the in-river caught adult sea trout – *i.e.* ANOVA followed by Scheffe's *post-hoc* or Tamhane's T2 test as appropriate. Quadratic discriminant function analysis (QDFA) was used on the adult sea trout scale isotope chemistry dataset to determine whether distinctive isotopic signals existed between 4 distinct regions (Solway Firth, Liverpool Bay, Cardigan Bay and South Wales) which would suggest that adults sea trout were feeding in different areas in UK coastal waters. QDFA was conducted to assess the accuracy with which in-river caught adult sea trout would classified to these 4 putative coastal feeding zones. QDFA was used since data were normally distributed but did not possess equal variances even after various transformations (Log_{10}, Log_e, square root, 1/x). The QDFA involved an 'original' classification (which used the discriminant functions to classify the same samples that were used to develop the functions) and a 'cross-validation' (CV) classification (which involves leaving one sample out of the dataset before establishing the discriminant functions and then classifying the sample that was removed) (Sharma, 1996). Cohen's kappa statistic was used to compute the chance-corrected agreement between actual and predicted group memberships of fish as outlined previously.

5.5 Results

5.5.1 Microchemical Analyses of Juvenile *Salmo Trutta* Parr

5.5.1.1 Otolith Microchemistry of Juvenile Trout Parr from 36 Rivers in the Irish Sea Region

The Mg, Mn, Sr and Ba otolith concentrations (expressed as element:Ca ratios, ug g^{-1}) in the otoliths of juvenile sea trout from the 36 rivers in the Irish Sea region are presented in Table 5.5.1 and Figure 5.5.1. Differences in otolith chemistry between rivers can be seen with a 2 fold difference in Mg:Ca (0.0402 – 0.0892 ug g^{-1}; Figure 5.5.1a), a 5.8 fold difference in Sr:Ca (0.5378 – 3.1257 ug g^{-1}; Figure 5.5.1c) and order of magnitude differences in Mn:Ca (10.4 fold; 0.0045 – 0.0468 ug g^{-1}; Figure 5.5.1b) and Ba:Ca (14.1 fold; 0.0035 – 0.0497 ug g^{-1}; Figure 5.5.1d) respectively. The River Currane in south west Ireland (River 33 in Figure 5.5.1) was notable for exhibiting high Mn:Ca, Sr:Ca and Ba:Ca ratios compared to the other rivers. MANOVA indicated significant differences in the Log_{10} element:Ca ratios of Mg, Mn, Sr and Ba in the sagittal otoliths of trout parr from each of the 36 rivers (MANOVA using Wilks' criterion, $F_{(140,2495)} = 72.003$, $P < 0.001$). When analysed individually, ANOVA indicated highly significant differences between the 36 rivers for each of the 4 elements (Mg:Ca, $F_{(35,664)} = 27.15$, $P < 0.001$; Mn:Ca, $F_{(35,664)} = 55.59$, $P < 0.001$; Sr:Ca, $F_{(35,664)} = 194.11$, $P < 0.001$; Ba:Ca, $F_{(35,664)} = 117.12$, $P < 0.001$). Given the large number of rivers and the subsequent multivariate analyses of the data (see Section 5.5.1.2), multiple pairwise *post-hoc* comparisons of the data were not conducted.

The differences in otolith chemistry observed between the rivers appeared to be related to latitude and region. A positive correlation between latitude and element:Ca ratio was observed for Strontium and Barium with Sr:Ca and Ba:Ca ratios tending to increase with latitude (Sr [excl. Currane as outlier] $r_{33} = 0.376$, $P = 0.03$; Ba, $r_{34} = 0.357$, $P = 0.04$ [excl. Tywi and Currane as outliers, $r_{32} = 0.659$, P < 0.001]) (see Figure 5.5.2). No correlations with latitude were observed for Magnesium ($r_{34} = -0.073$, $P = 0.68$) and Manganese ($r_{34} = -0.274$, $P = 0.11$) (Figure 5.5.2).

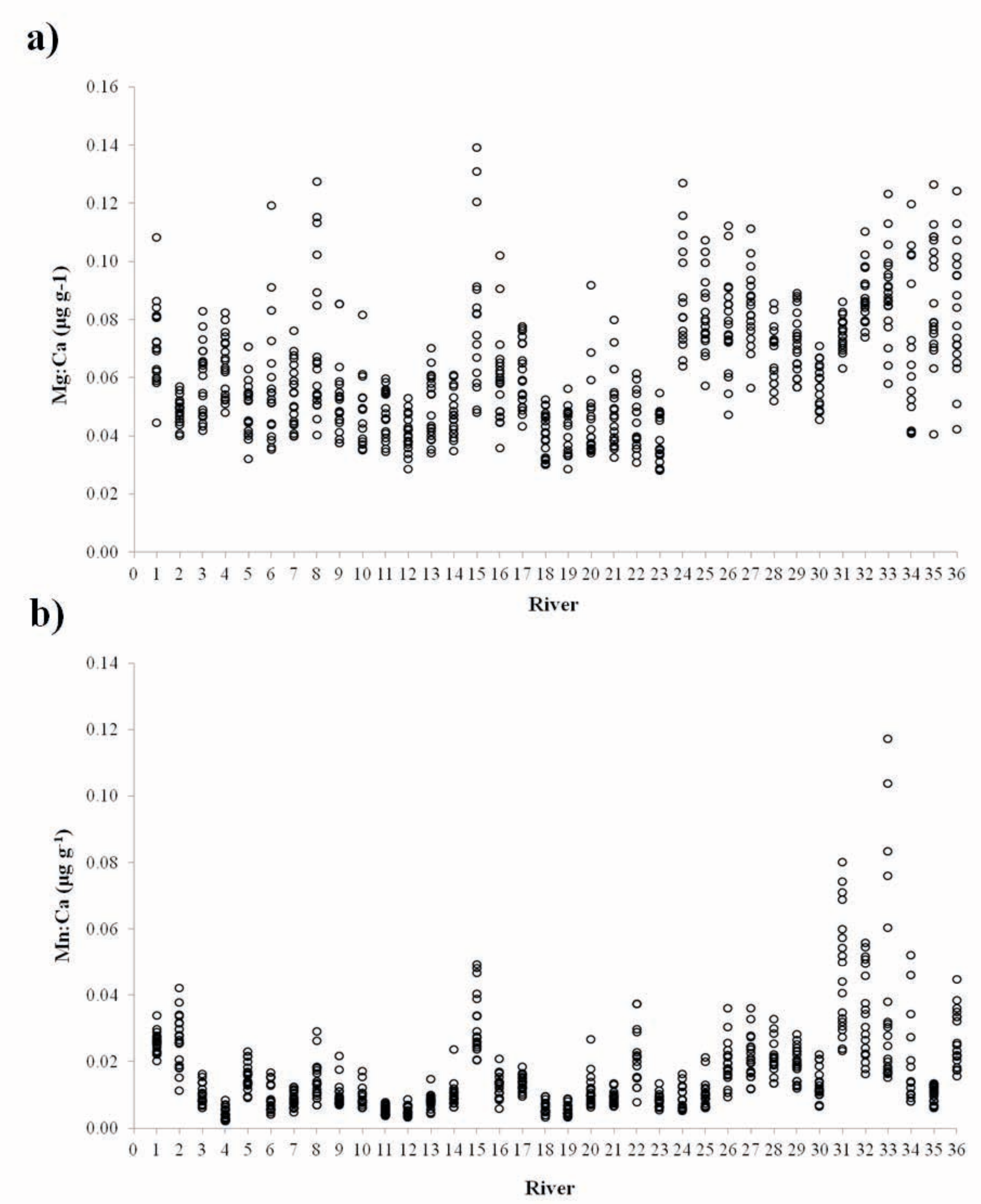
The location, i.e. region, of river appeared to influence otolith microchemistry with rivers in SW Scotland, NW England and Wales having lower Mg:Ca and Mn:Ca than rivers in Ireland or the Isle of Man (Figure 5.5.3). The data were grouped according to region and the mean element:Ca ratios for the juvenile *Salmo trutta* parr are presented in Table 5.5.2 and Figure 5.5.4.

ANOVA indicated significant differences in the Log_{10} element:Ca ratios of Mg, Mn, Sr and Ba in the sagittal otoliths of trout parr from each of the 10 regions (Mg:Ca, $F_{(9,664)} = 54.87$, $P < 0.001$; Mn:Ca, $F_{(9,664)} = 35.54$, $P < 0.001$; Sr:Ca, $F_{(9,664)} = 81.08$, $P < 0.001$; Ba:Ca, $F_{(9,664)} = 71.58$, $P < 0.001$). *Post-hoc* comparisons (using Tamhane's T2 test; Bonferron-corrected, $P = 0.05/45 = 0.0011$) indicated that for Mg and Mn there was a trans-Irish Sea difference in otolith chemistry (Table 5.8). For Mg, all pairwise comparisons between the Irish regions and the Isle of Man being significantly different to the UK regions (Table 5.5.3) and in total 27/45 pairwise comparisons between regions (i.e. 60%) were significantly different. For Mn, all pairwise comparisons between the UK regions and the North Skerries region were significantly different from the remaining Irish regions and the Isle of Man (Table 5.5.3) and in total 23/45 pairwise comparisons between regions (*i.e.* 51%) were significantly different. Differences in Strontium and Barium otolith chemistry between regions was more variable (Table 5.5.3) with 32/45 pairwise comparisons between regions (*i.e.* 71%) being significantly different for Sr and 24/45 pairwise comparisons (*i.e.* 53%) being significantly different for Ba respectively.

Table 5.5.1 Differences in element:Ca ratios (ug g^{-1}) in the otoliths from juvenile *Salmo trutta* parr sampled from 36 rivers in the Irish Sea region.

Region and River	Mg:Ca	Mn:Ca	Sr:Ca	Ba:Ca
S-W Scotland				
Luce	0.07087 ± 0.01411	0.02597 ± 0.00309	1.74023 ± 0.08929	0.00812 ± 0.00081
Cree	0.04868 ± 0.00463	0.02654 ± 0.00797	2.62468 ± 0.19554	0.02086 ± 0.00251
Fleet	0.05930 ± 0.01219	0.01033 ± 0.00297	1.19087 ± 0.07128	0.01682 ± 0.00320
Nith	0.06393 ± 0.01045	0.00449 ± 0.00189	1.36930 ± 0.16843	0.04278 ± 0.00726
Annan	0.05033 ± 0.00945	0.01580 ± 0.00392	2.30653 ± 0.27315	0.04971 ± 0.00829
Border Esk	0.05846 ± 0.02166	0.00938 ± 0.00427	0.75100 ± 0.05908	0.02919 ± 0.00664
NW England				
Ehen	0.05464 ± 0.01080	0.00875 ± 0.00232	0.82533 ± 0.06499	0.02395 ± 0.00349
Derwent	0.07132 ± 0.02621	0.01457 ± 0.00594	0.68646 ± 0.07135	0.02788 ± 0.00464
Kent	0.05277 ± 0.01361	0.01001 ± 0.00379	0.69453 ± 0.05006	0.01202 ± 0.00247
Lune	0.04869 ± 0.01244	0.00963 ± 0.00321	1.22401 ± 0.08613	0.01682 ± 0.00213
Ribble	0.04742 ± 0.00774	0.00570 ± 0.00140	0.89759 ± 0.12373	0.01999 ± 0.00274
Wales				
Dee	0.04089 ± 0.00628	0.00566 ± 0.00149	0.93794 ± 0.12844	0.00991 ± 0.00241
Clwyd	0.04976 ± 0.01095	0.00834 ± 0.00222	1.09368 ± 0.12044	0.00673 ± 0.00189
Conwy	0.04750 ± 0.00783	0.01021 ± 0.00389	0.92323 ± 0.05235	0.01743 ± 0.00255
Llyfni	0.08181 ± 0.02688	0.03190 ± 0.00957	1.83959 ± 0.17103	0.01080 ± 0.00198
Mawddach	0.05952 ± 0.01563	0.01257 ± 0.00348	0.82098 ± 0.07143	0.00712 ± 0.00203
Dyfi	0.06116 ± 0.01126	0.01381 ± 0.00231	1.14382 ± 0.15104	0.01444 ± 0.0 0458
Rheidol	0.04064 ± 0.00762	0.00632 ± 0.00198	1.17686 ± 0.09801	0.00354 ± 0.00048
Teifi	0.04123 ± 0.00798	0.00568 ± 0.00174	0.88527 ± 0.07877	0.00462 ± 0.00045
W. Cleddau	0.04594 ± 0.01451	0.01142 ± 0.00476	0.93175 ± 0.10482	0.00739 ± 0.00120
Tywi	0.04759 ± 0.01260	0.00907 ± 0.00194	0.64098 ± 0.05326	0.04452 ± 0.00620
Loughor	0.04432 ± 0.00969	0.02120 ± 0.00861	1.45153 ± 0.36689	0.01388 ± 0.00355
Tawe	0.04017 ± 0.00876	0.00929 ± 0.00355	0.59922 ± 0.32916	0.02384 ± 0.00515
Ireland				
Dee (White River)	0.08774 ± 0.01903	0.00943 ± 0.00358	0.53782 ± 0.05437	0.01752 ± 0.00184
Castletown	0.08117 ± 0.01279	0.01040 ± 0.00420	0.96441 ± 0.20157	0.01774 ± 0.00329
Dargle	0.07873 ± 0.01645	0.01956 ± 0.00650	1.31608 ± 0.14575	0.02221 ± 0.00641
Avoca	0.08421 ± 0.01280	0.02145 ± 0.00653	1.48612 ± 0.20396	0.01191 ± 0.00372
Sow	0.06813 ± 0.01044	0.02151 ± 0.00574	1.35381 ± 0.08528	0.00682 ± 0.00093
Mahon	0.07231 ± 0.01063	0.01971 ± 0.00471	0.97006 ± 0.15722	0.00792 ± 0.00171

Colligan	0.05760 ± 0.00751	0.01349 ± 0.00461	0.74395 ± 0.10893	0.00411 ± 0.00053
Argideen	0.07548 ± 0.00563	0.04678 ± 0.01817	1.25459 ± 0.10283	0.00358 ± 0.00076
Bandon	0.08797 ± 0.00941	0.03408 ± 0.01350	0.76559 ± 0.14691	0.00640 ± 0.00154
Currane	0.08916 ± 0.01543	0.03933 ± 0.03141	3.12573 ± 0.86176	0.04388 ± 0.05368
Isle of Man				
Sulby	0.07158 ± 0.02645	0.01974 ± 0.01414	1.81680 ± 0.20536	0.01707 ± 0.00553
Glass	0.08713 ± 0.02129	0.01044 ± 0.00253	1.49612 ± 0.11852	0.00954 ± 0.00180
Neb	0.08295 ± 0.02183	0.02690 ± 0.00853	1.22774 ± 0.07550	0.01513 ± 0.00412



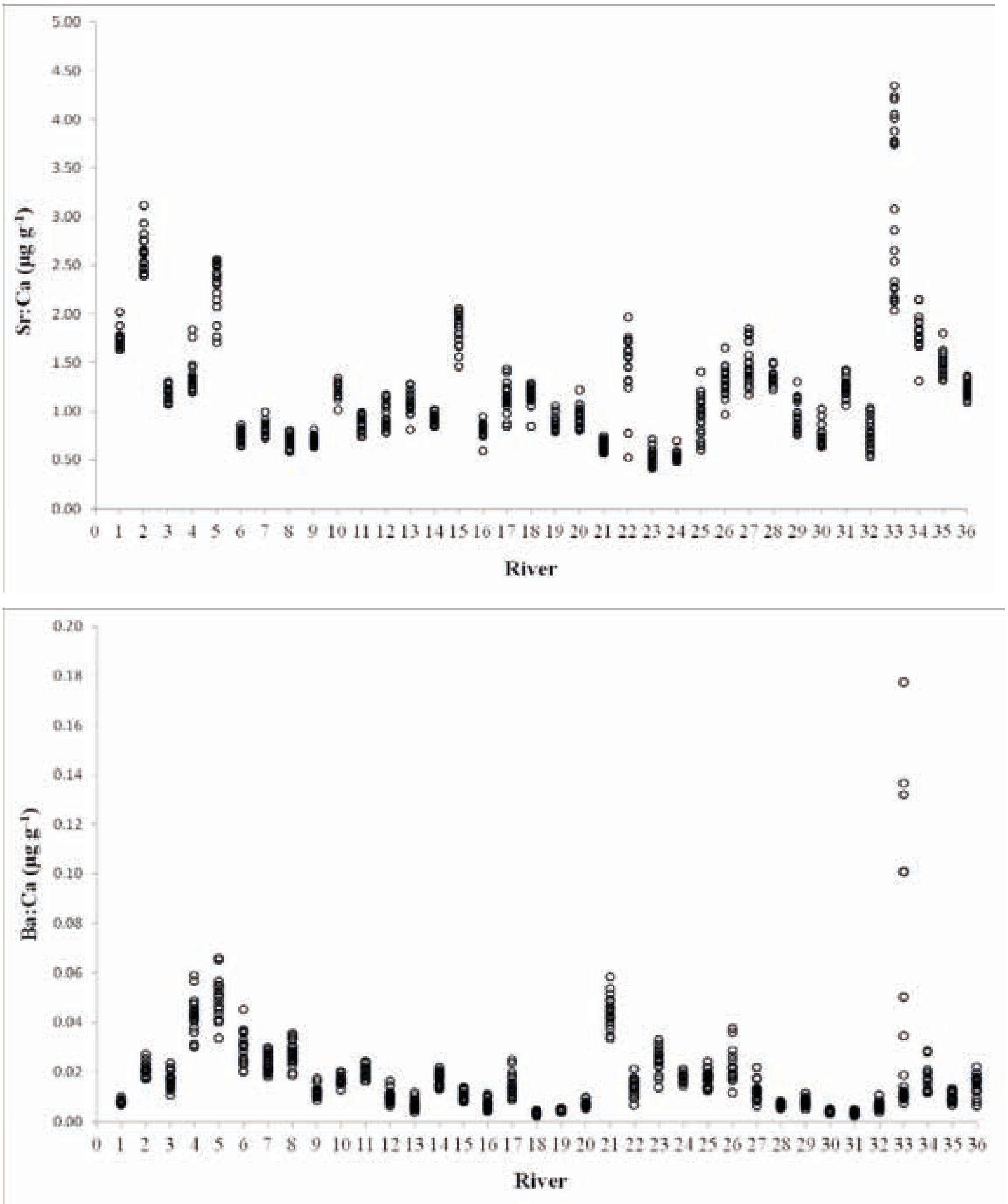


Figure 5.5.1 Scatter plots showing the concentrations of (a) Magnesium (Mg) and (b) Manganese (Mn) expressed as element:Ca ratios (ug g^{-1}) for the juvenile (c) Strontium (Sr) and (d) Barium (Ba) expressed as element:Ca ratios (ug g^{-1}) for the juvenile *Salmo trutta* parr sampled from 36 rivers in the Irish Sea region. For river codes see Table 5.4.1.

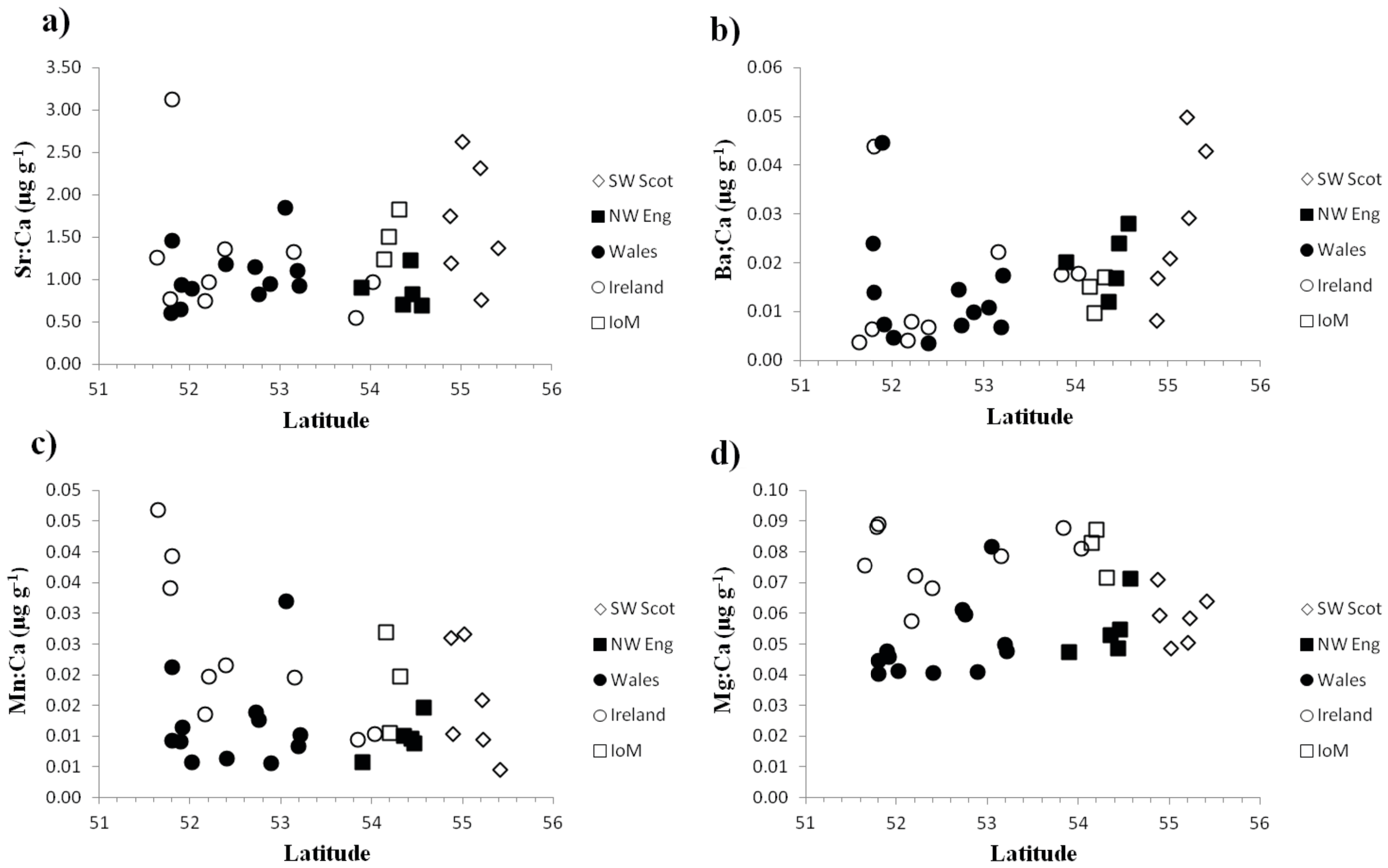
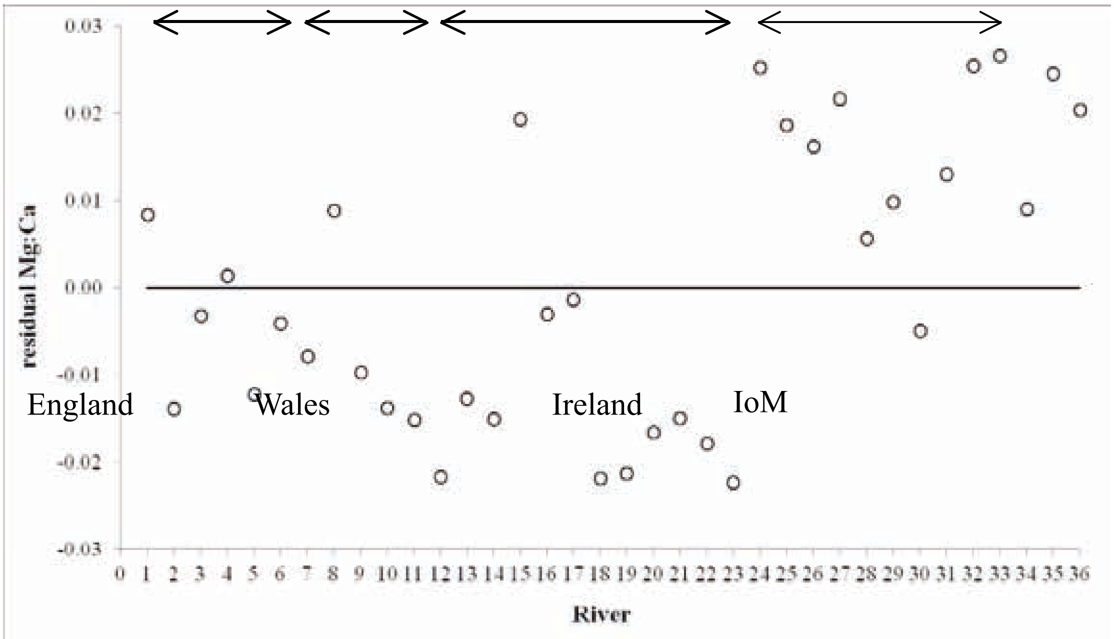
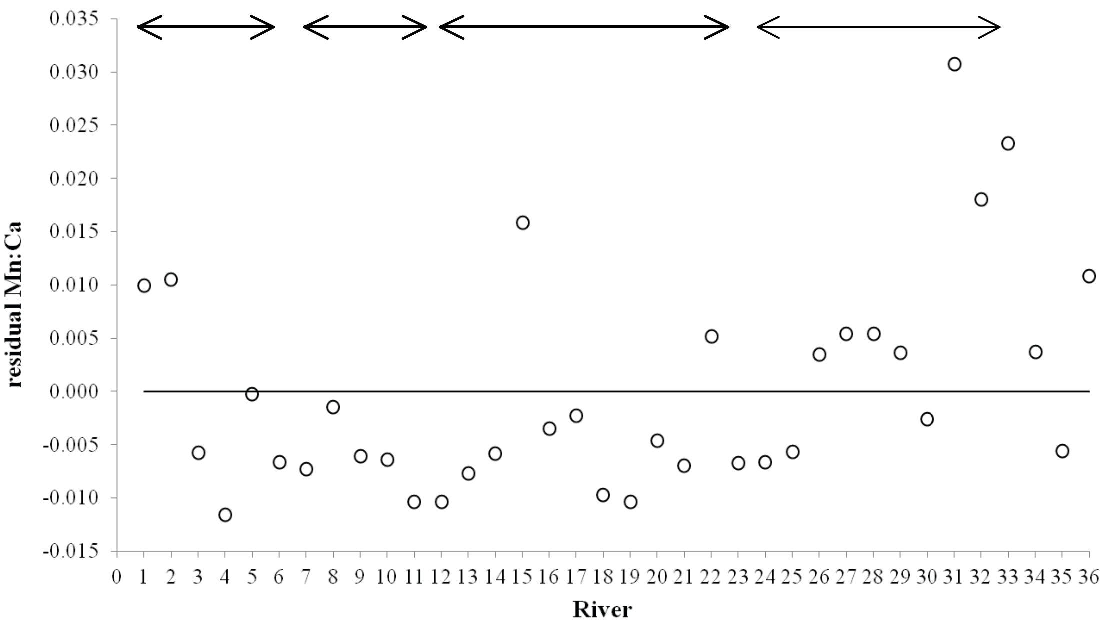


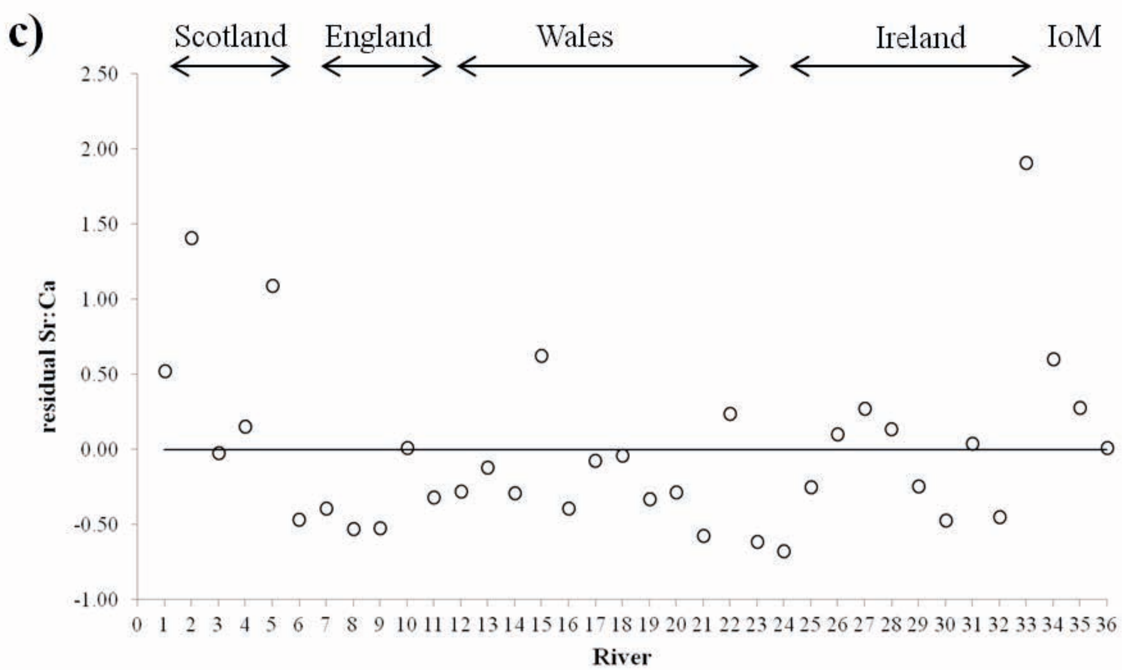
Figure 5.5.2 Scatter plots showing the relations between Latitude and (a) Strontium (Sr), (b) Barium (Ba), (c) Manganese and (d) Magnesium (expressed as element:Ca ratios, ug g^{-1}) in the sagittal otoliths of juvenile *Salmo trutta* parr sampled from 36 rivers in the Irish Sea region. For river codes see Table 5.4.1.

a) Scotland England Wales Ireland IoM



b) Scotland England Wales Ireland IoM





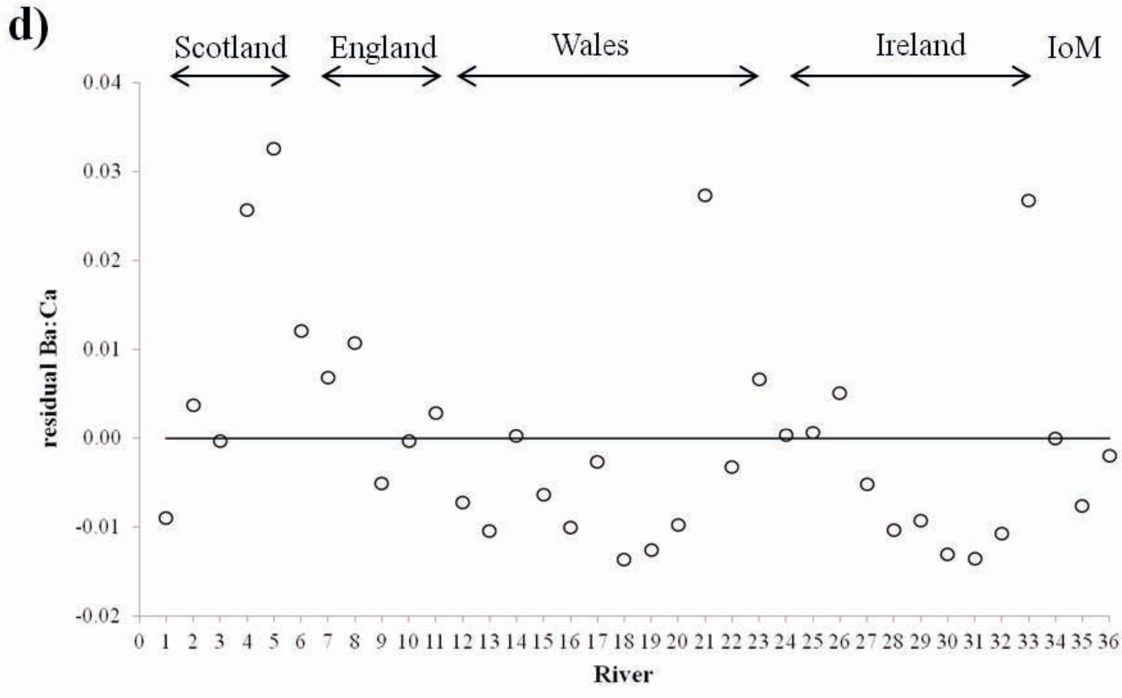


Figure 5.5.3 Scatter plots showing the residual concentrations of (a) Magnesium (Mg) and (b) Manganese (Mn) for the juvenile *Salmo trutta* parr sampled from 36 rivers in the Irish Sea region (c) Strontium (Sr) and (d) Barium (Ba) for the juvenile *Salmo trutta* parr sampled from 36 rivers in the Irish Sea region. Data for each river are expressed as a residual from the overall average element:Ca ratio (ug g^{-1}) for all 36 rivers combined. Rivers lying above the horizontal solid line have a higher average element:Ca ratio and those lying below the line have a lower average element:Ca ratio than the average for all 36 rivers combined. For river codes see Table 5.4.1. (IoM = Isle of Man)

Table 5.5.2 Differences in element:Ca ratios (ug g^{-1}) in the otoliths from juvenile *Salmo trutta* parr sampled from 9 regions around the Irish Sea. See Figure 5.4.1 for a map to identify regions [note: North and South of the Skerries are combined into one region as E. Ireland in this table]. Samples sizes refer to the number of rivers in each region.

Region	Mg:Ca	Mn:Ca	Sr:Ca	Ba:Ca
SW Scotland (n = 6)	0.05859 ± 0.00832	0.01542 ± 0.00913	1.66377 ± 0.70510	0.02791 ± 0.01589
NW England (n = 5)	0.05497 ± 0.00960	0.00973 ± 0.00319	0.86558 ± 0.21935	0.02013 ± 0.00615
Isle of Man (n = 3)	0.08055 ± 0.00804	0.01903 ± 0.00825	1.51355 ± 0.29492	0.01391 ± 0.00391
North Wales (n = 4)	0.05499 ± 0.01827	0.01403 ± 0.01206	1.19861 ± 0.43422	0.01122 ± 0.00449
Mid Wales (n = 4)	0.05064 ± 0.01123	0.00960 ± 0.00419	1.00674 ± 0.17981	0.00743 ± 0.00491
South Wales (n = 4)	0.04458 ± 0.00318	0.01274 ± 0.00573	0.90587 ± 0.39269	0.02241 ± 0.01622
E. Ireland* (n = 5)	0.08000 ± 0.00744	0.01647 ± 0.00605	1.13165 ± 0.38393	0.01524 ± 0.00596
South Ireland (n= 4)	0.07334± 0.01248	0.02852 ± 0.01492	0.93355 ± 0.23704	0.00550 ± 0.00202
SW Ireland (n = 1)	0.08916	0.03933	3.12573	0.01191

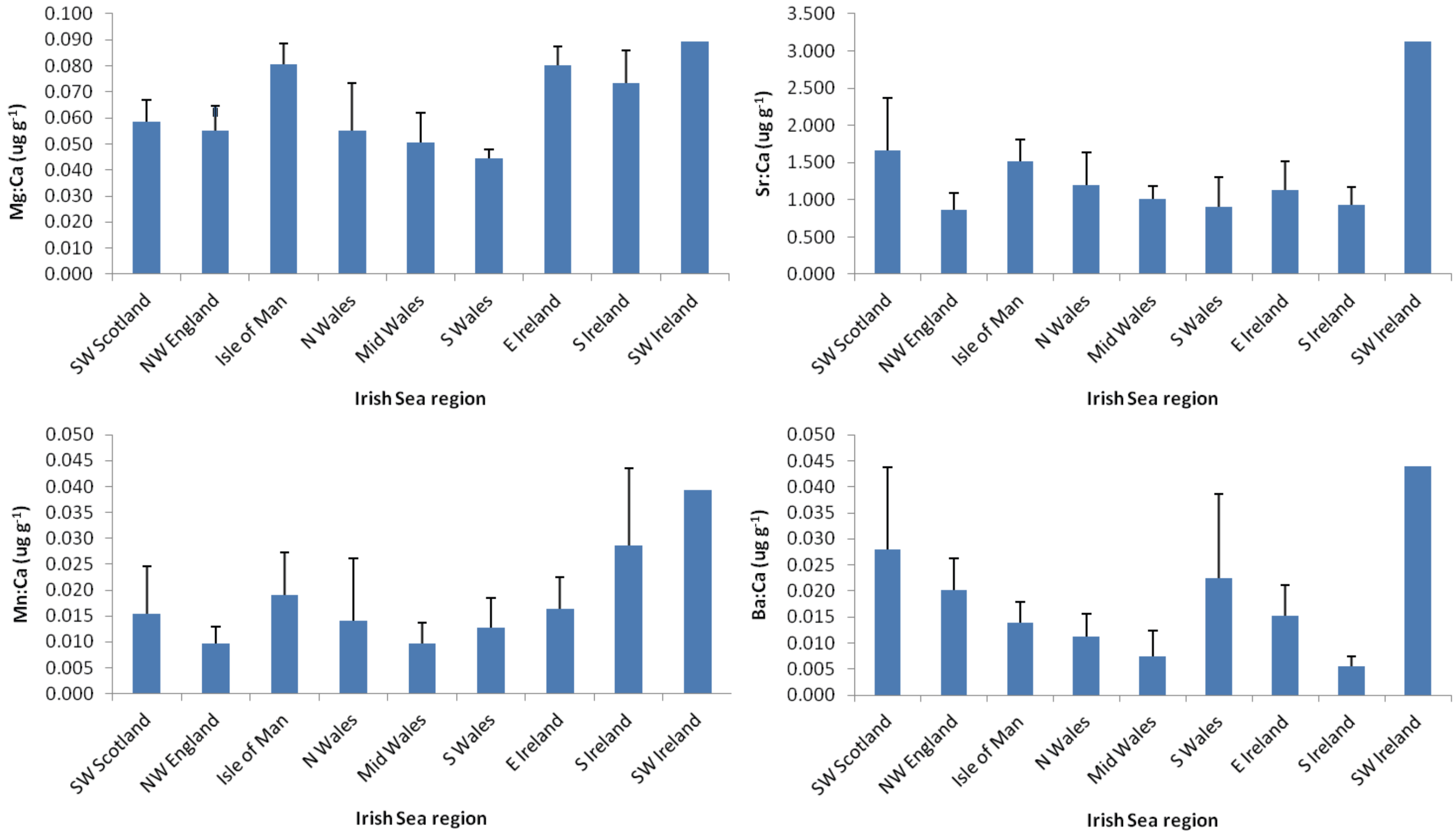


Figure 5.5.4 Differences in element:Ca ratios (ug g^{-1}) for Magnesium, Manganese, Strontium and Barium in the otoliths of juvenile *Salmo trutta* parr sampled from 9 regions around the Irish Sea. [See Figure 5.4.1 for a map to identify regions. Note: North and South of the Skerries are combined into one region as E. Ireland].

Table 5.5.3 Results of *post-hoc* comparisons between regions to determine where significant differences in otolith chemistry (element:Ca ratios, ug g^{-1}) are reported following a significant ANOVA. Comparisons were made using Tamhane's T2 test (Bonferroni-corrected; $P = 0.05/45 = 0.0011$). Significant differences are indicated in red and non-significant differences are indicated in yellow.

a) Mg:Ca

Region	1	2	3	4	5	6	7	8	9	10
1 SW Scot										
2 NW Eng										
3 N. Wales										
4 Mid Wales										
5 S Wales										
6 N. Skerries										
7 S Skerries										
8 S Ireland										
9 SW Ireland										
10 Isle of Man										

b) Mn:Ca

Region	1	2	3	4	5	6	7	8	9	10
1 SW Scot										
2 NW Eng										
3 N. Wales										
4 Mid Wales										
5 S Wales										
6 N. Skerries										
7 S Skerries										
8 S Ireland										
9 SW Ireland										
10 Isle of Man										

c) Sr:Ca

Region	1	2	3	4	5	6	7	8	9	10
1 SW Scot										
2 NW Eng										
3 N. Wales										
4 Mid Wales										
5 S Wales										
6 N. Skerries										
7 S Skerries										
8 S Ireland										
9 SW Ireland										
10 Isle of Man										

d) Ba:Ca

Region	1	2	3	4	5	6	7	8	9	10
1 SW Scot										
2 NW Eng										
3 N. Wales										
4 Mid Wales										
5 S Wales										
6 N. Skerries										
7 S Skerries										
8 S Ireland										
9 SW Ireland										
10 Isle of Man										

5.5.1.2 Classification of Trout Parr to Their River of Origin Using Otolith Microchemistry

The original classification of juvenile brown trout parr back to their river of origin using QDFA (river as variable, Log10 element:Ca ratios as predictors) was high with 560/665 brown trout parr correctly classified back to their river of origin (84.2%,Table 5.5.4). Similarly, CV-QDFA correct classification was also high with 490/665 brown trout parr correctly classified back to their river of origin (74 ± 18%,Table 5.5.5). The most important elements in explaining the high proportion of variance and discrimination between the 36 rivers were Mn and Ba with principal component scores of 0.569 and -0.055 respectively (Figure 5.5.5). PCA 1 indicated a variance (eigenvalue) of 1.787 and accounted for 44.7 % of the total variance, with PCA 2 eigenvalue of 1.046 accounting for 26.2 % of the variability. Both the first two principal components (PCA 1 and PCA 2) represented 70.8 % of the combined total variability observed for the 36 rivers using the four elements Mg, Mn, Sr and Ba. Cohen's kappa statistic indicated that the chance-corrected classification accuracy of trout parr to river using QDFA was 0.84 (C.I 0.81 - 0.87) and 0.73 (C.I 0.69 - 0.76) using CV-QDFA. Finally, the classification rate using Random Forest was 71% (± 21) with 471/665 trout parr correctly classified back to river of origin (Table 5.5.6). The chance-corrected Random Forest classification accuracy of trout parr to river of origin using Cohen's kappa statistic was 0.70 (C.I 0.66 - 0.74).

Classification accuracy varied between rivers with assignments using CV-QDFA below 50% for 4 rivers – Dyfi (42%), Fleet, Mahon (both 45%) and Avoca (47%) – whilst assignment success was 100% for 5 rivers – Nith, Annan, Tywi, Argideen and Currane – and in excess of 85% for a further 5 rivers – Dee (White River) (87%), Teifi (89%), Bandon (90%), Cree and Rheidiol (both 95%) (Table 5.5.5; Figure 5.5.6). Using Random Forest, fewer rivers exhibited 100% classification accuracy compared to CV-QDFA –(only Cree and Argideen) whilst more rivers exhibited assignment successes of less than 50%, and lower values than those observed using CV-QDFA – Avoca (26%), Fleet (33%), Dyfi (37%), Border Esk (39%) and Dargle (47%) (Table 5.5.6). However, a larger number of rivers exhibited classification accuracies between 85-99% - Currane (85%), Colligan, Teifi (both 89%), Luce, Rheidiol, Tywi (all 90%), Dee (White River) (93%), Nith, Annan and Glass (all 95%).

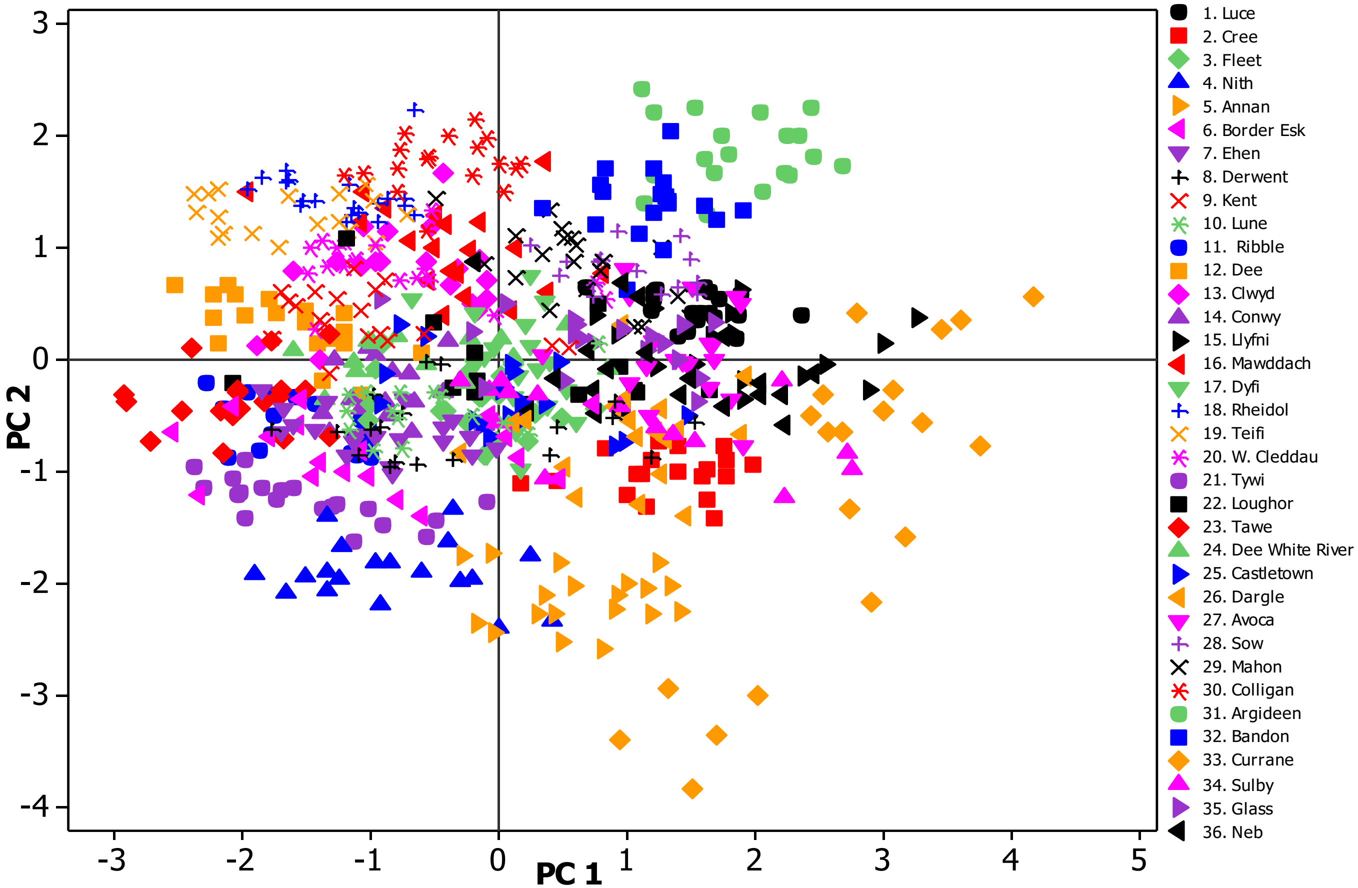


Figure 5.5.5 PCA plot showing the clustering of juvenile *Salmo trutta* based on their otolith microchemistry (Mg, Mn, Sr and Ba) for 36 rivers sampled within the Irish Sea region.

Table 5.5.4 Classification of juvenile *Salmo trutta* to river using Quadratic Discriminant Function Analysis based on the Log_{10} element:Ca ratios Mg, Mn, Sr and Ba in the saggital otoliths. Fish were sampled from 36 rivers and QDFA of their otolith microchemistry was used to determine whether fish could be assigned back to known river of origin.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1.Luce	**17**														4																					
2.Cree		**19**																																		
3.Fleet			**12**							1		2					3									2										
4.Nith				**19**																																
5.Annan					**19**																															
6.Border E						**13**	1	2																												
7.Ehen						2	**17**				2																									
8.Derwent						3		**16**															1													
9.Kent									**19**																											
10.Lune			3							**11**																1										
11.Ribble							1				**15**	1		2																						
12.Dee			2									**16**	2							1																
13.Clwyd													**14**						1																	
14.Conwy							1				2			**16**											1											
15.Llyfni	2														**12**																					
16.Mawddach																**16**	2			1									3	1		1				
17.Dyfi			1							1							**11**			1		1														
18.Rheidol																		**20**																		
19.Teifi																2			**17**	1										2						
20.W.Cleddau													1				1			**13**		1							1							
21.Tywi																					**20**															
22.Loughor										1			1									**11**	1				1									1
23.Tawe								1														1	**17**													
24.Dee (W.R)																								**15**												
25.Castletown																									**16**		1									
26.Dargle			2							1							2								2	**15**	0									5
27.Avoca																											**14**	0	1							
28.Sow															1					1							1	**15**								2
29.Mahon																				1							1		**12**			1				1
30.Colligan													1			1														**15**						
31.Argideen																															**19**					
32.Bandon																1																**17**				
33.Currane																																	**20**			
34.Sulby																						1					**1**							**14**		
35.Glass																																			**19**	
36.Neb																						1				1			3					1		**9**
Total N^{o}	19	19	20	19	19	18	20	19	19	15	19	19	19	18	17	20	19	20	18	19	20	16	19	15	19	19	19	15	20	18	19	19	20	15	19	18
N^{o} correct	17	19	12	19	19	13	17	16	19	11	15	16	14	16	12	16	11	20	17	13	20	11	17	15	16	15	14	15	12	15	19	17	20	14	19	9
Proportion	90	100	60	100	100	72	85	84	100	73	79	84	74	89	71	80	58	100	94	68	100	69	90	100	84	79	74	100	60	83	100	90	100	93	100	50

Table 5.5.5 Classification of juvenile *Salmo trutta* to river using Cross-Validation Quadratic Discriminant Function Analysis based on the Log_{10} element:Ca ratios Mg, Mn, Sr and Ba in the saggital otoliths. Fish were sampled from 36 rivers and CV-QDFA of their otolith microchemistry was used to determine whether fish could be assigned back to known river of origin using the "leave one out" approach.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
1.Luce	**15**														4																					
2.Cree		**18**																																		
3.Fleet			**9**							2		2					3								2	2										
4.Nith				**19**																																
5.Annan					**19**																															
6.Border Esk						**10**	2	4																												
7.Ehen						2	**14**				4																									
8.Derwent						6		**13**	1														2	1												
9.Kent									**15**																											
10.Lune			3							**10**							1									1										
11.Ribble							2		1		**13**	1		2																						
12. Dee			2						1			**15**	2						1	1																
13.Clwyd			1									1	**12**					1	1									1		1					2	
14.Conwy							1				2			**13**											1											
15.Llyfni	2														**11**																					
16.Mawddach																**12**	2			1						1			5	1		1				
17.Dyfi			3							1						1	**8**			1		1				1										
18.Rheidol																		**19**																		
19.Teifi																2			**16**	1										2						
20.W. Cleddau													2			1	1			**12**		1							1							
21.Tywi																					**20**		1													
22.Loughor	1	1					1			1			1	3						1		**9**	1				1							1		1
23.Tawe								2														1	**15**													
24.Dee (W.R)																								**13**												
25.Castletown									1															1	**14**		1									
26.Dargle			2							1							3								2	**11**										5
27.Avoca	1														1												**9**	1	1					1	2	
28. Sow															1					1							2	**12**								2
29.Mahon																2				1							2		**9**			1				1
30.Colligan													1			1														**14**						
31.Argideen																															**19**					
32.Bandon																1													1			**17**				
33.Currane																										1							**20**	1		
34.Sulby																						3					2							**11**		
35.Glass													1														1								**15**	
36 Neb																	1					1				2	1	1	3					1		**9**
Total N°	19	19	20	19	19	18	20	19	19	15	19	19	19	18	17	20	19	20	18	19	20	16	19	15	19	19	19	15	20	18	19	19	20	15	19	18
N° correct	15	18	9	19	19	10	14	13	15	10	13	15	12	13	11	12	8	19	16	12	20	9	15	13	14	11	9	12	9	14	19	17	20	11	15	9
Proportion	79	95	45	100	100	56	70	68	79	67	68	79	63	72	65	60	42	95	89	63	100	56	79	87	74	58	47	80	45	78	100	90	100	73	79	50

Table 5.5.6 Classification of juvenile *Salmo trutta* to river using Random Forest Analysis based on the Log_{10} element:Ca ratios Mg, Mn, Sr and Ba in the saggital otoliths. Fish were sampled from 36 rivers and RFAof their otolith microchemistry was used to determine whether fish could be assigned back to known river of origin.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
1.Luce	**17**														2																					
2.Cree		**19**																																1		
3.Fleet			**6**	1						3		1					6					1			2	1										
4.Nith				**18**																																
5.Annan					**18**																					1							2			
6.Border Esk						**7**		4															2										0			
7.Ehen						4	**12**		1		2																									
8.Derwent						5	1	**12**	2															1												
9.Kent									**14**														1		2											
10.Lune			5							**9**		1														1										
11.Ribble							5				**14**	1		3																						
12. Dee									1			**15**	3						1	1																
13.Clwyd			1									1	**10**							1								1								
14.Conwy							1				3			**15**											2											
15.Llyfni	2														**12**							2					3						1	3		
16.Mawddach									1							**11**				1									4							
17.Dyfi			5							1			1			1	**7**			1		1				3	1									
18.Rheidol													1					**18**	1																	
19.Teifi																2		1	**16**	1										2						
20.W. Cleddau													3			3	1			**11**		1														
21.Tywi						2		1													**18**															
22.Loughor										1							1					**9**														1
23.Tawe								1													2	1	**16**													
24.Dee (W.R)								1																**14**												
25.Castletown			2				1			1							1								**11**											
26.Dargle			1														1								2	**9**	2									3
27.Avoca															1												**5**	1	1							1
28. Sow															1					1							2	**12**								2
29.Mahon																2	2			2						1	2		**11**			2				1
30.Colligan													1			1		1											1	**16**		1				
31.Argideen																															**19**					
32.Bandon																						1							2			**16**				
33.Currane					1										1																		**17**	1		
34.Sulby																											1							**9**	1	
35.Glass																											1	1							**18**	
36 Neb																										3	2		1					1		**10**
Total N°	19	19	20	19	19	18	20	19	19	15	19	19	19	18	17	20	19	20	18	19	20	16	19	15	19	19	19	15	20	18	19	19	20	15	19	18
N° correct	17	19	6	18	18	7	12	12	14	9	14	15	10	15	12	11	7	18	16	11	18	9	16	14	11	9	5	12	11	16	19	16	17	9	18	10
Proportion	90	100	33	95	95	39	60	63	74	60	74	79	53	83	71	55	37	90	89	58	90	56	84	93	58	47	26	80	55	89	100	84	85	60	95	56

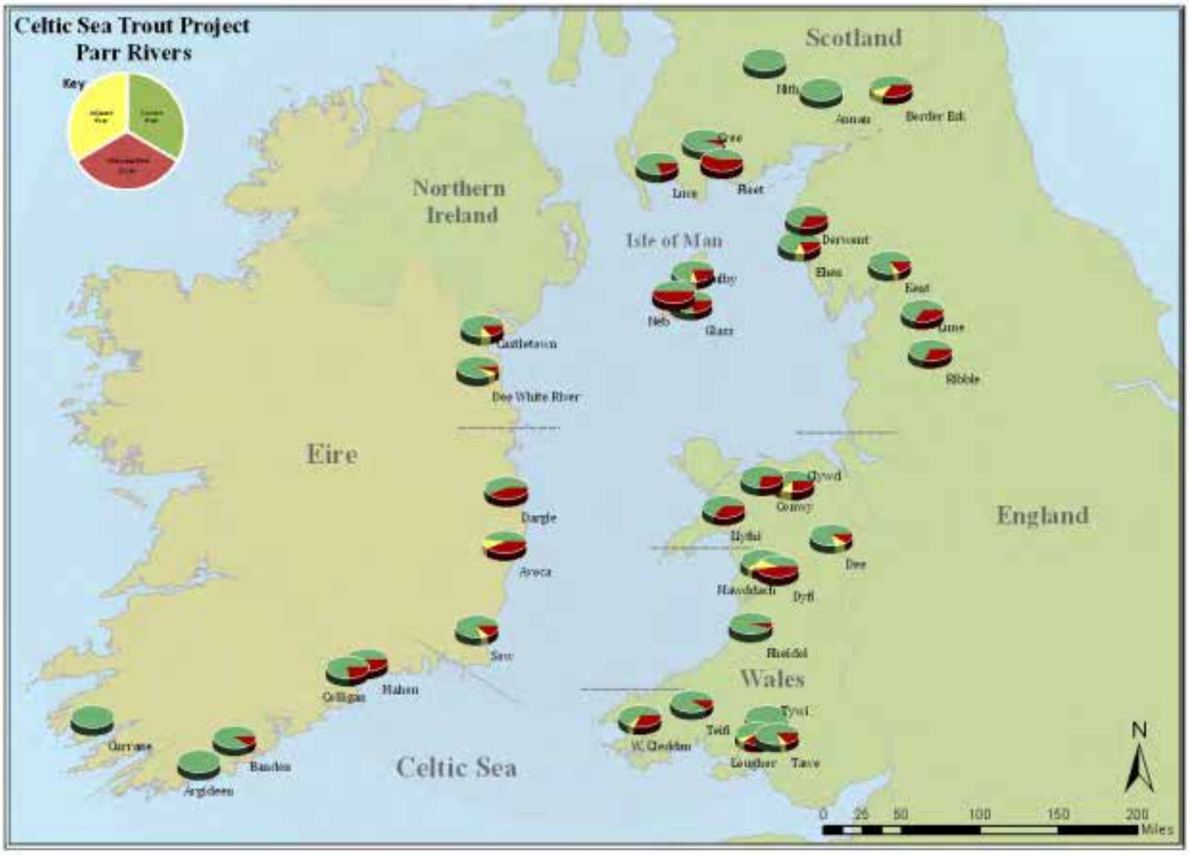


Figure 5.5.6 Map of the Irish Sea region showing the 36 rivers sampled and the proportion of the juvenile *Salmo trutta* from that river that were correctly classified back to that river (green sector in pie chart), back to an adjacent river (yellow sector in pie chart) or misclassified to another river (red sector in pie chart) using cross-validated Quadratic Discriminant Function Analysis.

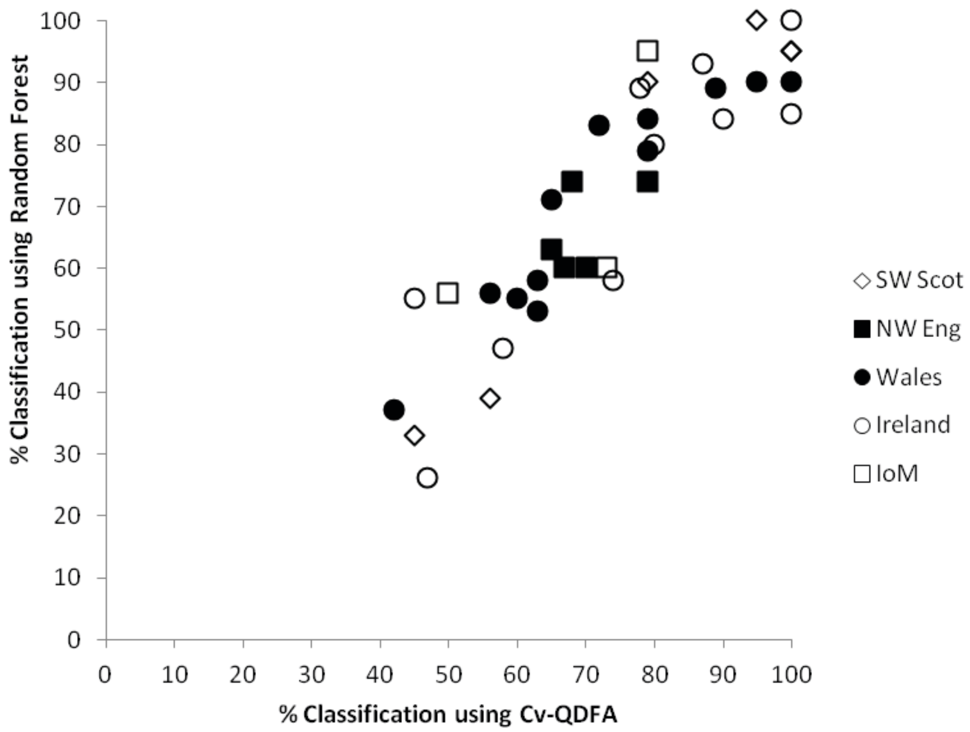


Figure 5.5.7 Scatterplot showing the relationship between the classification accuracies of assigning juvenile *Salmo trutta* back to river of origin using cross-validated Quadratic Discriminant Function analysis (CV-QDFA) and Random Forest analysis**.**

Classification accuracies using the two techniques were significantly correlated (r_{36} = 0.898, P < 0.001; Figure 5.5.7) and were described by the following linear regression:

$$Y = 1.05X – 6.51 \ (r^2 = 0.806, P < 0.001)$$

where Y is the % classification success using Random Forest and X is the % classification success using CV-QDFA. The intercept for the regression line (-6.51 ± 6.69 se) was not significantly different from zero (t = -0.97, P = 0.34) and the forced regression line had a slope of 0.97 (± 0.02 se).

5.5.1.3 Classification of Trout Parr to Their Region of Origin

When fish were grouped according to the 10 regional groupings (see Figure 5.4.1), the classification success using QDFA was lower with only 457/665 trout parr (69%) correctly classified back to their region of origin (Table 5.5.7). CV-QDFA classification accuracy was similar with 440/665 parr (66%) correctly classified back to their region of origin (Table 5.5.8). The most important elements in explaining the high proportion of variance and discrimination between the regions were Sr and Ba with standardized canonical discriminate function coefficients of 0.883 and 0.653 respectively. Cohen's kappa statistic indicated that the chance-corrected classification accuracy of trout parr to region using QDFA was 0.65 (C.I 0.61 - 0.69) and 0.62 (C.I 0.58 - 0.66) using CV-QDFA. A PCA plot is presented in Figure 5.5.8 to indicate the degree of separation between trout parr in the different regional groupings using the element:Ca ratios of Mg, Mn, Sr and Ba. The most notable groupings were the three Welsh regions and North-West England which clustered together and the three regions, SW Scotland, Celtic Sea and SW Ireland which each tended to cluster as a discrete group on the PCA plot (Figure 5.5.8).

Classification accuracy to region of origin using Random Forest was higher compared to the QFDA analyses with 495/665 trout parr correctly assigned to their region of origin (74%,Table 5.5.9). The chance-corrected Random Forest classification accuracy of trout parr to region of origin using Cohen's kappa statistic was 0.71 (C.I 0.67 - 0.76). Classification accuracy varied between regions but CV-QDFA provided much poorer classification success for SW Scotland and North Wales compared to Random Forest analysis (SW Scotland, 50% *cf.* 73%; North Wales, 41% *cf.* 70%). In contrast, Random Forest provided poorer classification accuracy for South Skerries compared to CV-QDFA (59% *cf.* 70%). No region exhibited 100% assignment success using either classification technique – although assignment success tended to be higher for the Irish regions (Table 5.5.8 and Table 5.5.9). Classification accuracies using the two techniques were not correlated ($r_{10} = 0.473$, $P <$ 0.17; Figure 5.5.9).

5.5.1.4 Assigning Unknown Juvenile Salmo Trutta Parr to River of Origin

In addition to establishing the microchemistry baseline for juvenile *Salmo trutta* from the 36 rivers in the Irish Sea region (see Section 5.5.6), the otolith chemistry of a further 39 fish was measured and the established baseline used to assign these fish to river of origin. This process was conducted "blind", *i.e.* with no prior knowledge of the actual river of origin of each fish until after the assignment process had been completed. The results of this assignment process are presented in Table 5.5.10. The probability of assignment to the first choice river of origin ranging from 0.266 to 1.000 (Table 5.5.10). For most of the fish, the probability of assignment to their most likely river of origin based on their otolith microchemistry was high (> 0.900). However, where assignment probability to the first choice river of origin was lower than P= 0.900, assignment probabilities to the second river of origin ranged from 0.109 to 0.460. Third choice river assignment probabilities, where present, ranged from 0.001 to 0.460 (Table 5.5.10).

For 7 fish, the assignment technique did not extend beyond a single choice of river whilst for some fish, the probability of assignment to the first river of choice was very low and the likelihood of assignment to the second river of choice was almost as high (*e.g*. Fish 4, 27 and 32) and for some fish even the probability of the third choice river was high (*e.g.* Fish 26, 32)

In total 27/39 fish (*i.e.* 69%) were correctly assigned back to their river of origin. Where the assignment was successful, the probability of assignment was usually high with a mean assignment success of 0.926 ± 0.106, however, probability was low (arbitrarily set at < 90%) for some rivers (*e.g.* Fish IDs 4, 22, 33 and 39). For 6 fish, their assignment was to their river of origin with a mean assignment success of 0.297 ± 0.065 (Table 5.5.10). Fish that were not assigned to their river of origin tended to misclassify to a geographically distant river rather than an adjacent river (with the exception of fish 3).

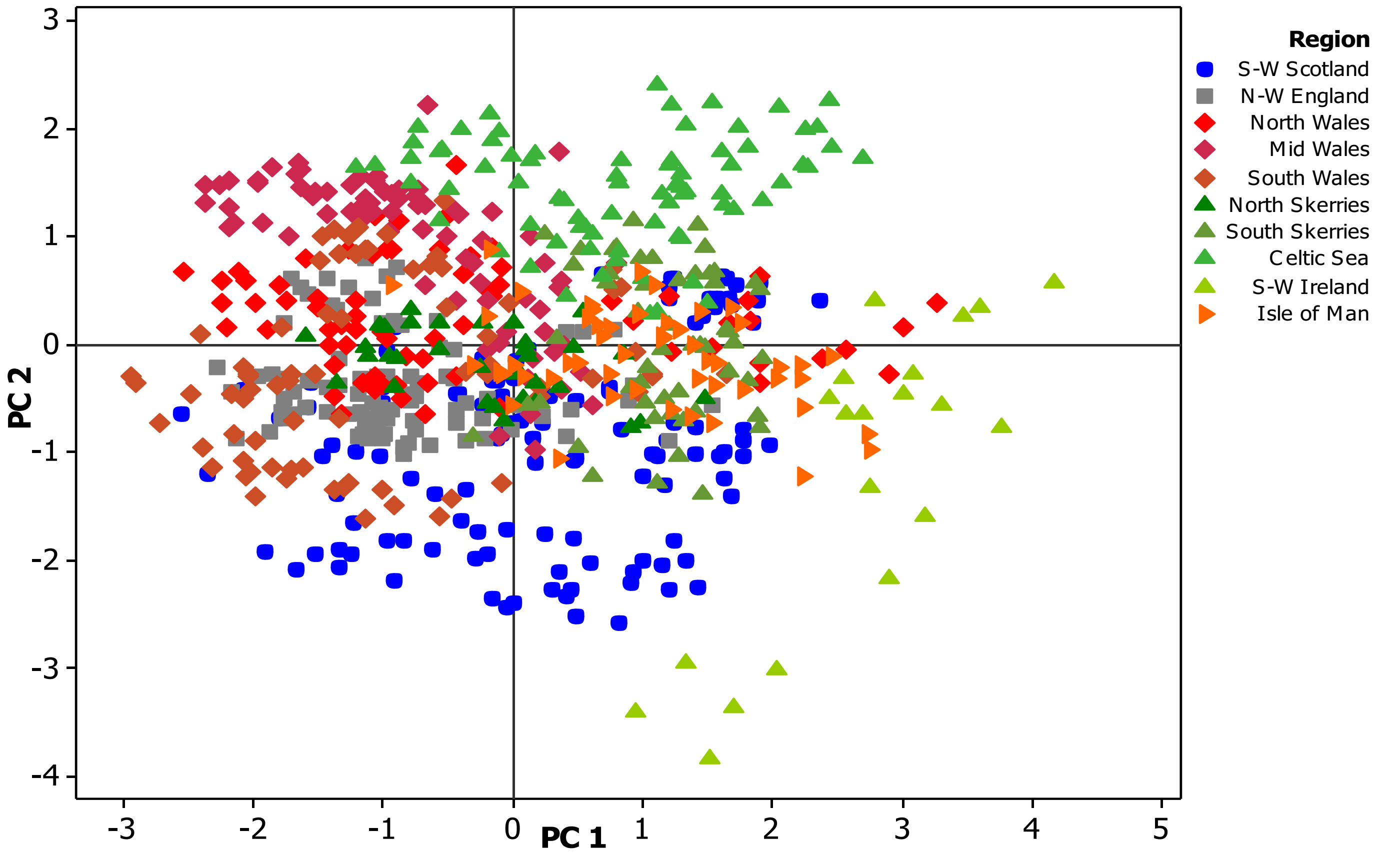


Figure 5.5.8 PCA plot indicating regional groupings of juvenile *Salmo trutta* parr based on their otolith microchemistry (Mg, Mn, Sr and Ba). Fish were sampled from 36 rivers in 10 regions around the Irish Sea (see Table 5.4.1 for details).

Table 5.5.7 Classification of juvenile *Salmo trutta* to region using Quadratic Discriminant Function Analysis based on the Log_{10} element:Ca ratios Mg, Mn, Sr and Ba in the saggital otoliths. Fish were sampled from 36 rivers in 10 regions and QDFA of their otolith microchemistry was used to determine whether fish could be assigned back to known region of origin.

	S-W Scotland	**N-W England**	**North Wales**	**Mid Wales**	**South Wales**	**North Skerries**	**South Skerries**	**Celtic Sea**	**S-W Ireland**	**Isle of Man**
S-W Scotland	**57**	2	3	3	4		2			3
N-W England	17	**67**	15		2	1				
North Wales	22	2	**31**	4	4		3			
Mid Wales		1	14	**58**	10		1	5		1
South Wales	4	13	5	1	**51**					1
North Skerries	9	5	1	5		**31**	1			
South Skerries	4	1	2	1	2	2	**39**	7		8
Celtic Sea		1	1	5			1	**64**		
S-W Ireland	1								**20**	
Isle of Man			1	0	1		6			**39**
N^o	114	92	73	77	74	34	53	76	20	52
N^o correct	57	67	31	58	51	31	39	64	20	39
Percentage	50	73	43	75	69	91	74	84	100	75

Table 5.5.8 Classification of juvenile *Salmo trutta* to region using Cross-Validation Quadratic Discriminant Function Analysis based on the Log_{10} element:Ca ratios Mg, Mn, Sr and Ba in the saggital otoliths. Fish were sampled from 36 rivers in 10 regions and CV-QDFA of their otolith microchemistry was used to determine whether fish could be assigned back to known region of origin using the "leave one out" approach.

	S-W Scotland	**N-W England**	**North Wales**	**Mid Wales**	**South Wales**	**North Skerries**	**South Skerries**	**Celtic Sea**	**S-W Ireland**	**Isle of Man**
S-W Scotland	**57**	2	3	3	4		3		2	4
N-W England	17	**64**	15		2	1				
North Wales	22	2	**30**	4	4		3		1	2
Mid Wales		1	14	**58**	11		1	6		1
South Wales	4	15	5	1	**48**					1
North Skerries	9	6	1	5		**31**	1			
South Skerries	4	1	2	1	2	2	**37**	8		8
Celtic Sea		1	1	5			1	**62**		
S-W Ireland	1		1						**17**	
Isle of Man			1		3		7			**36**
N^o	114	92	73	77	74	34	53	76	20	52
N^o correct	57	64	30	58	48	31	37	62	17	36
Proportion	50	70	41	75	65	91	70	82	85	69

Table 5.5.9 Classification of juvenile *Salmo trutta* to region using Random Forest Analysis based on the Log_{10} element:Ca ratios Mg, Mn, Sr and Ba in the saggital otoliths. Fish were sampled from 36 rivers in 10 regions and RFA of their otolith microchemistry was used to determine whether fish could be assigned back to known region of origin.

	S-W Scotland	N-W England	North Wales	Mid Wales	South Wales	North Skerries	South Skerries	Celtic Sea	S-W Ireland	Isle of Man
S-W Scotland	**83**	8	2	5	3	1	6		2	2
N-W England	18	**74**	10		3	2				
North Wales	4	4	**51**	2	7	1	1	1	1	2
Mid Wales	3	1	5	**54**	2	1		4		2
South Wales	2	3	1	4	**54**		1			2
North Skerries	1	2		2		**27**	0			
South Skerries	2		2		2	2	**31**	1		7
Celtic Sea			1	9	2		5	**69**		1
S-W Ireland	1		1						**17**	1
Isle of Man				1	1		9	1		**35**
N^o	114	92	73	77	74	34	53	76	20	52
N^o correct	83	74	51	54	54	27	31	69	17	35
Proportion	73	80	70	70	73	79	59	91	85	67

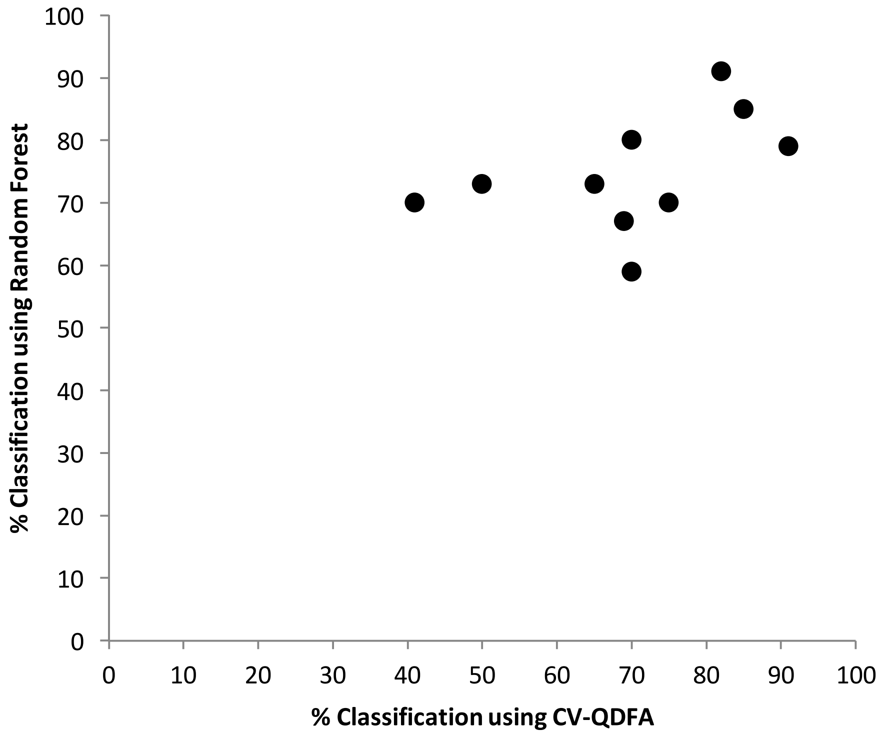


Figure 5.5.9 Scatterplot showing the relationship between the classification accuracies of assigning juvenile *Salmo trutta* back to river of origin using cross-validated Quadratic Discriminant Function Analysis (CV-QDFA) and Random Forest Analysis.

Table 5.5.10 Assignment of juvenile *Salmo trutta* to river of origin using the 36 river baseline established using otolith microchemistry (Mg, Mn, Sr and Ba). Each fish was assigned "blind" (*i.e.* with no prior knowledge of origin) based on the probability of belonging to a particular river. Fish highlighted in **bold** classify back to the correct river of origin in their first choice assignment whilst fish highlight in red classify based on their second choice assignment.

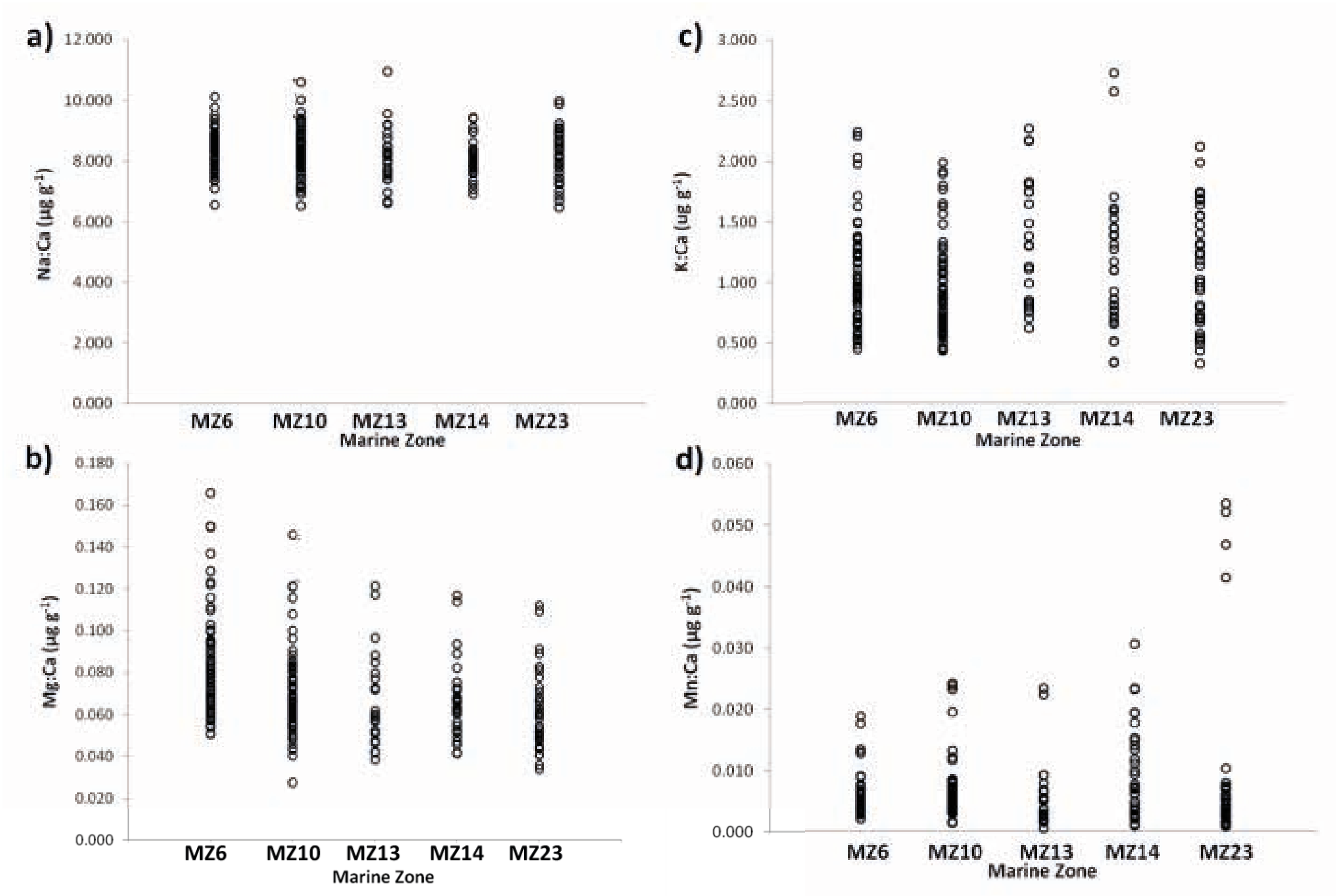
Fish ID	Actual Origin	Predicted 1st choice	Predicted 2nd choice	Predicted 3rd choice	Fish ID	Actual Origin	Predicted 1st choice	Predicted 2nd choice	Predicted 3rd choice
1	**Llyfni**	**Llyfni** P=0.999	-----	-----	**21**	**Glass**	**Glass** P=1.000	-----	-----
2	**Colligan**	**Colligan** P=0.887	Mawddach P=0.113	-----	**22**	**Derwent**	**Derwent** P=0.779	Tawe P=0.192	Dee (WR) P=0.016
3	Annan	Nith P=0.999	-----	-----	23	Conwy	Castletown P=0.854	Kent P=0.123	Ehen P=0.012
4	**Currane**	**Currane** P=0.540	Annan P=0.460	-----	**24**	**Llyfni**	**Llyfni** P=0.831	Avoca P=0.109	Luce P = 0.050
5	**Cree**	**Cree** P=0.999	Loughor P=0.001	-----	**25**	**Argideen**	**Argideen** P=0.995	Bandon P=0.005	-----
6	Conwy	Derwent P=0.999	Mawddach P=0.001	-----	26	Lune	Dargle P=0.464	Castletown P=0.224	Dyfi P=0.207
7	**Nith**	**Nith** P=1.000	-----	-----	27	Dyfi	Lune P=0.266	Dyfi P=0.229	Dargle P=0.171
8	**Glass**	**Glass** P=0.999	-----	-----	28	Dyfi	Dargle P=0.994	Mawdach P=0.006	-----
9	**Ribble**	**Ribble** P=0.958	Ehen P=0.041	Conwy P=0.001	29	Border Esk	Dee (WR) P=0.736	Border Esk P=0.247	Castletown P=0.006
10	**Annan**	**Annan** P=0.995	Currane P=0.005	-----	30	Neb	Dargle P=0.607	Neb P=0.388	Avoca P=0.003
11	**Tywi**	**Tywi** P=1.000	-----	-----	31	W. Cleddau	Mawddach P=0.691	W. Cleddau P=0.296	Clwyd P=0.010
12	**Ribble**	**Ribble** P=0.984	Conwy P=0.007	Ehen P=0.007	32	Fleet	Dargle P=0.324	Dyfi P=0.287	Castletown P=0.260
13	Ribble	Conwy P=0.729	Ribble P=0.257	Dee P=0.004	**33**	**Derwent**	**Derwent** P=0.792	Border Esk P=0.208	-----
14	**Border Esk**	**Border Esk** P=0.933	Ehen P=0.044	Derwent P=0.021	34	Llyfni	Avoca P=0.465	Llyfni P=0.362	Loughor P=0.102
15	**Clwyd**	**Clwyd** P=0.858	W. Cleddau P=0.138	Teifi P=0.004	**35**	**Avoca**	**Avoca** P=0.926	W. Cleddau P=0.024	Glass P=0.014
16	**Rheidol**	**Rheidol** P=1.000	-----	-----	**36**	**Sulby**	**Sulby** P=0.954	Loughor P=0.015	Currane P=0.011
17	**Kent**	**Kent** P=0.979	Loughor P=0.021	-----	**37**	**Kent**	**Kent** P=0.944	Loughor P=0.027	Castletown P=0.025
18	**Annan**	**Annan** P=0.999	Currane P=0.001	-----	**38**	**Cree**	**Cree** P=0.999	Loughor P=0.001	-----
19	**Sulby**	**Sulby** P=0.946	Currane P=0.037	Castletown P=0.012	**39**	**Clwyd**	**Clwyd** P=0.785	W. Cleddau P=0.148	Teifi P=0.042
20	**Llyfni**	**Llyfni** P=0.915	Avoca P=0.073	Sulby P=0.005					

5.5.2 Microchemical Analyses of Marine-Caught Adult *Salmo Trutta*

5.5.2.1 Otolith Microchemistry of The Marine Phase of the Otolith

The element:Ca concentrations in the section of the otolith transect corresponding to the marine phase of the lifecycle (determined from viewing the Strontium profile, see Figure 5.4.4) for the adult sea trout caught in the five different marine zones are presented in Figure 5.5.10 and Table 5.5.11. Significant differences were observed in the elemental concentrations of the Log_{10} transformed elements Na, Mg, K, Zn, and Ba (which exhibited normality and homoscedascity) in the marine phase of the adult sea trout otoliths between the five marine zones (MANOVA: using Wilks' criterion: $F_{(20,\ 730)} = 3.922$; $P < 0.001$). Individual ANOVA's conducted using each of the five elements indicated significant differences between marine zones for Log_{10}Mg ($F_{(4,\ 228)} = 8.26$; $P <$ 0.001) and Log_{10}Ba ($F_{(4,\ 228)} = 5.36$; $P < 0.001$) but not for Log_{10}Na ($F_{(4,\ 228)} = 1.08$; $P = 0.37$) and Log_{10}Zn ($F_{(4,\ 228)} = 0.51$; $P = 0.73$). *Post-hoc* pairwise comparisons (Bonferroni-corrected) indicated that otolith concentrations of Mg:Ca in the marine zone of the otoliths of sea trout caught in Marine Zone 6 were significantly higher than those in the other 4 marine zones (all $P < 0.01$) and otolith concentrations of Ba:Ca in the marine zone of the otoliths of sea trout caught in Marine Zone 10 were significantly higher than those caught in marine zones 6 ($P < 0.001$) and 13 ($P = 0.031$). Although ANOVA indicated a significant difference between marine zones for K ($F_{(4,\ 228)} = 2.43$; P = 0.048), *post-hoc* pairwise comparisons (Bonferroni-corrected) did not reveal any significant differences between marine zones. Assessment of the elements Mn, Sr and Sn conducted using the non-parametric Kruskal-Wallis test indicated no significance between the five marine zones in their elemental:Ca concentrations for Sr and Sn (Sr: $K_{(4,228)} = 9.42$; $P = 0.051$; Sn: $K_{(4,228)} = 3.08$; P = 0.554). Mn:Ca otolith concentrations were significantly between marine zones ($K_{(4,228)} = 10.67$; P = 0.030), however, pairwise comparisons between marine zones using a Mann- Whitney U Test indicated no significant differences (Table 5.5.12). Thus, very few differences were observed in the microchemistry in the marine section of the otolith transect for the adult sea trout caught in the five different marine zones.

Using principal component analysis (PCA) the standard correlation matrix indicated the Mg and Ba were the most important elements in explaining the variation and discrimination between the five marine zones (0.528 and -0.128 respectively), with the Eigenvalues indicating 33% of the variance explained by function 1 with only 23% explained by function 2. Results for the PCA plot (see Figure 5.5.11) indicated no zonal separation could be observed between each of the five marine zones for the sea trout using the elemental concentrations of Mg, K, Mg, Sr and Ba.


a)
Na:Ca (µg g-1)
12.000
10.000
8.000
6.000
4.000
2.000
0.000
MZ6
MZ10
MZ13
MZ14
MZ23
Marine Zone
c)
K:Ca (µg g-1)
3.000
2.500
2.000
1.500
1.000
0.500
0.000
MZ6
MZ10
MZ13
MZ14
MZ23
Marine Zone
b)
Mg:Ca (µg g-1)
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
MZ6
MZ10
MZ13
MZ14
MZ23
Marine Zone
d)
Mn:Ca (µg g-1)
0.060
0.050
0.040
0.030
0.020
0.010
0.000
MZ6
MZ10
MZ13
MZ14
MZ23
Marine Zone

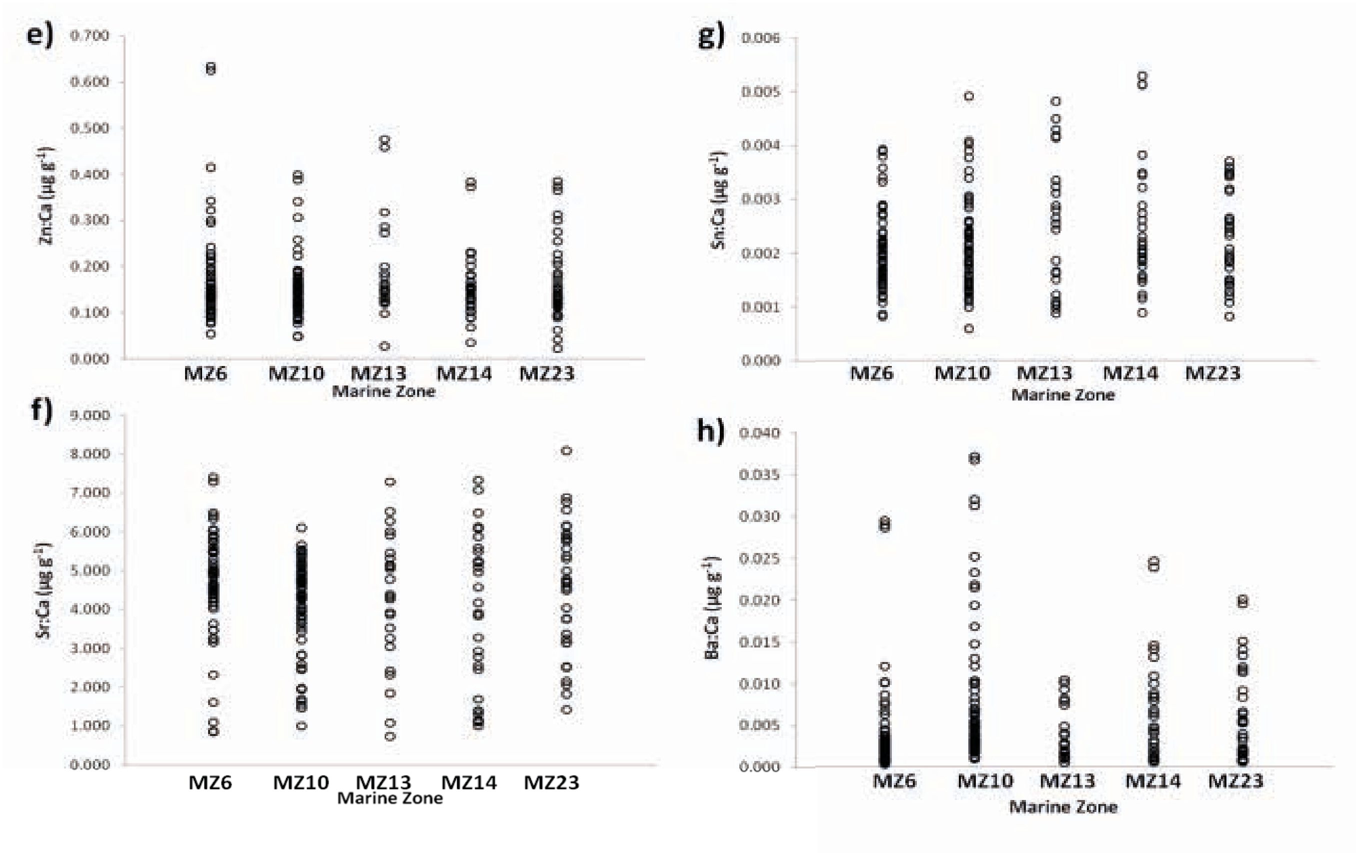


Figure 5.5.10 Element:Ca ratios (µg g^{-1}) for (a) Sodium, (b) Magnesium, (c) Potassium and (d) Manganese (e) Zinc, (f) Strontium, (g) Tin and (h) Barium in the section of the otolith corresponding to the period of marine residency in marine-caught adult sea trout *Salmo trutta* caught in 5 different marine zones in the Irish Sea. See Figure 5.4.2 for the location of each Marine Zone.

Table 5.5.11 Element:Ca ratios (μg g^{-1}) in the section of the otolith corresponding to the period of marine residency in marine-caught adult sea trout *Salmo trutta* caught in 5 different marine zones in the Irish Sea. Data are presented as mean ± SD. See Figure 5.4.2 for the location of each Marine Zone.

	Na:Ca	Mg:Ca	K:Ca	Mn:Ca	Zn:Ca	Sr:Ca	Sn:Ca	Ba:Ca
MZ06 N = 64	8.404 ± 0.642	0.08304 ± 0.02520	1.032 ± 0.430	0.00554 ± 0.00337	0.17156 ± 0.10476	4.748 ± 1.324	0.00198 ± 0.00078	0.00412 ± 0.00600
MZ10 N = 69	8.337 ± 0.746	0.07044 ± 0.02003	0.954 ± 0.393	0.00630 ± 0.00456	0.15199 ± 0.06418	4.210 ± 1.1586	0.00206 ± 0.00089	0.00765 ± 0.00857
MZ13 N = 23	8.203 ± 0.970	0.06654 ± 0.02248	1.293 ± 0.522	0.00559 ± 0.00586	0.18587 ± 0.10622	4.253 ± 1.719	0.00241 ± 0.00135	0.00368 ± 0.00328
MZ14 N = 30	8.120 ± 0.612	0.06584 ± 0.01782	1.143 ± 0.560	0.00964 ± 0.00753	0.16092 ± 0.07299	3.800 ± 2.008	0.00230 ± 0.00128	0.00630 ± 0.00627
MZ23 N = 34	8.232 ± 0.852	0.06205 ± 0.01913	1.095 ± 0.481	0.00899 ± 0.01437	0.16968 ± 0.09043	4.630 ± 1.609	0.00208 ± 0.00096	0.00551 ± 0.00560

Table 5.5.12 Results conducted for the Non-parametric Mann-Whitney test to assess the Log_{10} element Mn concentrations in Marine Zones 06, 10, 13, 14 and 23.

					95% C.I.		
Marine Zone	**Zone**	**N**	**Median**	**W**	**Lower**	**Upper**	***P***
MZ-06		**64**	-2.7072				
	MZ-10	**69**	-2.7017	4219.0	-0.0614	0.0465	0.7577
	MZ-13	**23**	-2.5935	2692.5	-0.1832	0.0559	0.2365
	MZ-14	**30**	-2.6869	2872.5	-0.1250	0.0204	0.1756
	MZ-23	**34**	-2.7114	3074.0	-0.0963	0.0476	0.4853
MZ-10		**69**	-2.7017				
	MZ-13	**23**	-2.5935	3098.0	-0.1703	0.0687	0.3213
	MZ-14	**30**	-2.6869	3293.5	-0.1256	0.0288	0.2349
	MZ-23	**34**	-2.7114	3509.5	-0.0934	0.0531	0.5844
MZ-13		**23**	-2.5935				
	MZ-14	**30**	-2.6869	619.5	-0.1383	0.1456	0.9857
	MZ-23	**34**	-2.7114	702.0	-0.0915	0.1586	0.5747
MZ-14		**30**	-2.6869				
	MZ-23	**34**	-2.7114	1031.0	-0.0684	0.1323	0.4553

Using quadratic discriminant function analysis (QDFA) with the elements that were normally distributed, but with / without equal variance (i.e. Na, Mg, K, Mn, Zn, Sn and Ba) and with marine zone set as the variable and the elements set as the predictors, classification of adult sea trout back to their region of capture was low with only 116/229 adults (51%) correctly classified back to their marine zone of capture (Table 5.5.13). CV-QDFA classification accuracy was even lower with 72/229 (31%) marine-caught sea trout correctly classifying back to their marine zone of capture **(**

Table 5.5.14). Cohen's kappa statistics indicated that the chance-corrected classification accuracy of trout parr to marine zone of capture using QDFA was 0.45 (C.I. 0.36 – 0.54) but was very low when using the leave-one-out CV-QDFA approach reducing to 0.13 (C.I. 0.05 – 0.21) which suggests that some correct classifications are chance-associated.

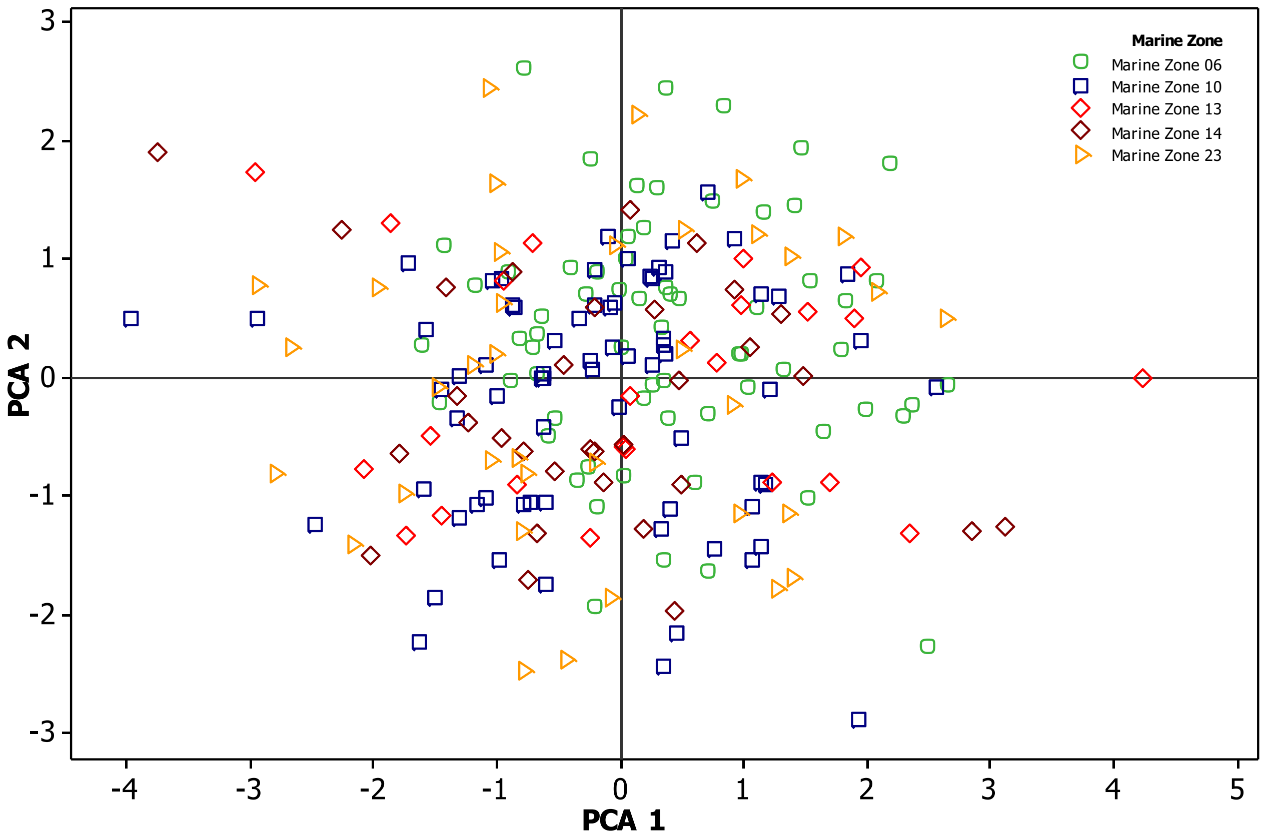


Figure 5.5.11 PCA plots indicating both the first and second component scores using the elemental concentrations of Na, Mg, K, Zn and Ba for adult *Salmo trutta* caught in each of the five marine zones (MZs 6, 10, 13 14 and 23).

Table 5.5.13 QDFA using log_{10} element:Ca concentration of Na, Mg, K, Mn, Zn, Sn and Ba to predict marine zone of capture of adult sea trout *Salmo trutta* using the material ablated from the marine phase of the otoliths.

	Marine Zone 06	Marine Zone 10	Marine Zone 13	Marine Zone 14	Marine Zone 23
Marine Zone 06	**35**	15	2	5	3
Marine Zone 10	13	**36**	2	6	8
Marine Zone 13	9	7	**15**	3	4
Marine Zone 14	7	8	3	**14**	4
Marine Zone 23	2	5	3	4	**15**
N^o	66	71	24	32	36
N^o correct	35	36	15	14	15
Percentage	53	51	63	44	42

Table 5.5.14 CV-QDFA using log_{10} element:Ca concentration of Na, Mg, K, Mn, Zn, Sn and Ba to predict marine zone of capture of adult sea trout *Salmo trutta* using the material ablated from the marine phase of the otoliths.

	Marine Zone 06	Marine Zone 10	Marine Zone 13	Marine Zone 14	Marine Zone 23
Marine Zone 06	**25**	15	5	7	4
Marine Zone 10	18	**33**	2	7	10
Marine Zone 13	13	8	**6**	6	13
Marine Zone 14	8	8	4	**5**	6
Marine Zone 23	2	7	7	7	**3**
N^o	66	71	24	32	36
N^o correct	25	33	6	5	3
Proportion	38	47	25	16	8

5.5.2.2 Otolith Microchemistry of the Parr (Freshwater) Phase of the Otolith

Mean element: Ca ratio concentrations of the juvenile parr phase sampled from the adult sea trout otoliths varied between marine zones (MZ) for two elements Sr and Ba, most notably MZ 23 (Sr) and MZ-10 (Ba) but showed less variability across each of the five zones for Mg and Mn (see Table 5.5.15 and Figure 5.5.12). Elemental concentrations of Log_{10} transformed elements Mg, Mn, Sr and Ba indicated significant differences between the juvenile parr phase of the adult sea trout otoliths from the different marine zones (MANOVA: using Wilks' criterion: $F_{(16, 681)} = 8.066$; $P < 0.001$)

with one or more of the four elements indicated highly significant differences in their elemental concentrations. Individual ANOVA's conducted using the elements Mg, Mn, Sr and Ba between each of the five MZs indicated highly significant differences in elemental concentrations for three of the elements (Mg: $F_{(4, 230)} = 4.07$; $P = 0.003$, Sr: $F_{(4, 230)} = 7.89$; $P < 0.001$ and Ba: $F_{(4, 230)} = 16.42$; $P < 0.001$). However, no significant effect of elemental concentration was observed between the 5 MZs and the element manganese (Mn: $F_{(4, 230)} = 1.26$; $P = 0.288$).

Table 5.5.15 Elemental concentrations (as a an element:Ca. µg g^{-1}) for the parr phase of the adult sea trout otoliths using the most commonly used elements Mg, Mn, Sr and Ba in microchemistry. Concentrations are shown as mean ($\bar{x}$) ± 1 standard deviation (sd).

Marine Zone	n	Mg: Ca $\bar{x} \pm$ sd	Mn: Ca $\bar{x} \pm$ sd	Sr: Ca $\bar{x} \pm$ sd	Ba: Ca $\bar{x} \pm$ sd
06	67	0.057 ±0.013	0.020 ±0.015	1.245 ±0.404	0.020 ±0.016
10	72	0.058 ±0.018	0.020 ±0.019	1.284 ±0.528	0.035 ±0.022
13	24	0.051 ±0.013	0.020 ±0.015	1.183 ±0.568	0.012 ±0.007
14	32	0.052 ±0.013	0.023 ±0.017	1.130 ±0.386	0.014 ±0.009
23	36	0.047 ±0.012	0.021 ±0.013	1.780 ±0.573	0.018 ±0.010

Post-hoc pairwise comparisons (Bonferroni-corrected) between the $\log_{10}$ element:Ca data for Mg, Sr and Ba in the freshwater region of the otoliths of adult sea trout caught in each of the five MZs indicated that Mg was significantly lower for fish caught in MZ23 compared to MZ6 ($P = 0.011$) and MZ10 ($P = 0.013$), Sr was significantly higher for fish caught in MZ23 compared to all other MZs (all $P \leq 0.003$) and Ba was significantly higher for fish caught in MZ10 compared to all other MZs (all $P \leq 0.001$).

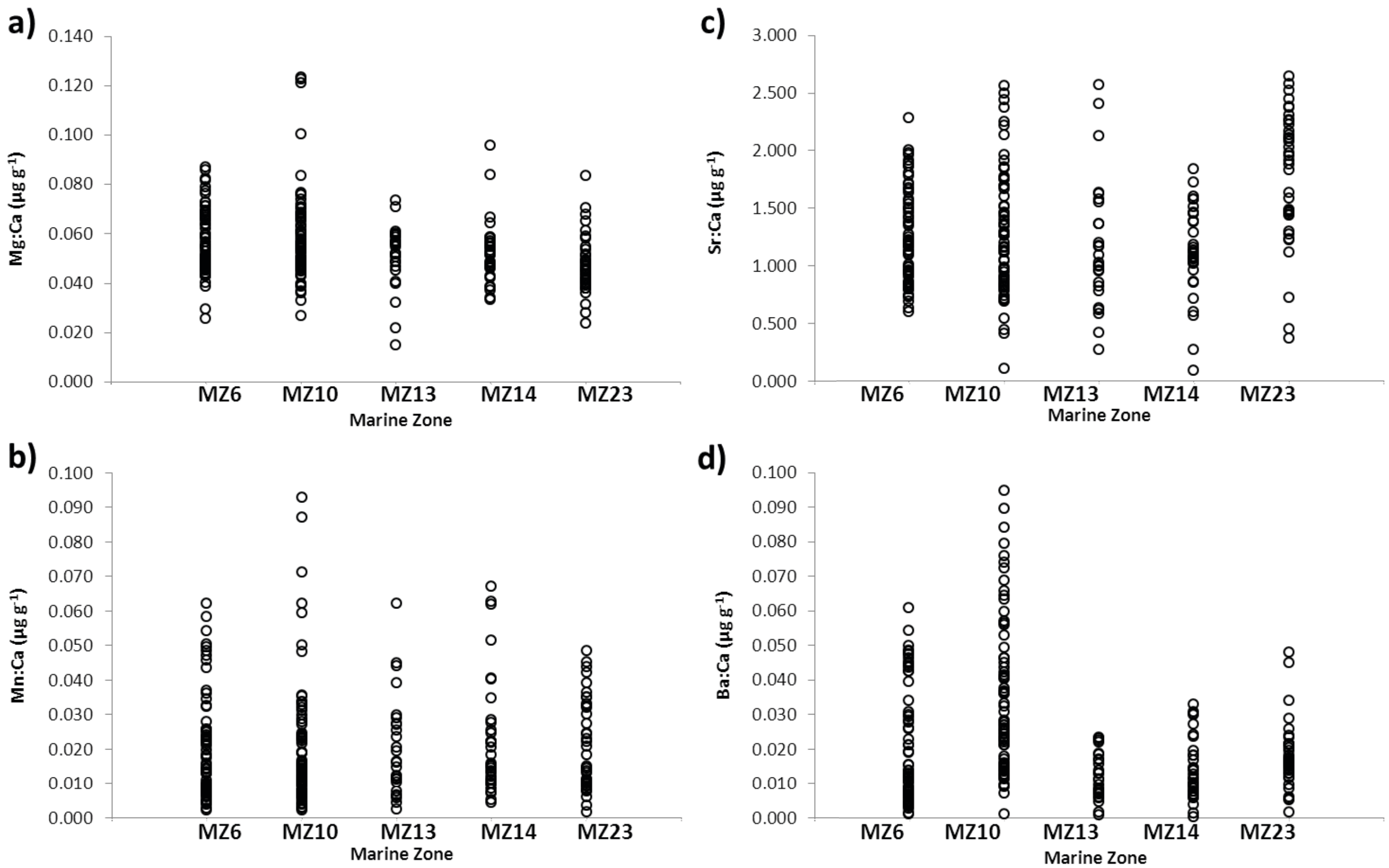


Figure 5.5.12 Mean element concentrations (expressed as element:Ca ratios, µg g^{-1}) for a) Mg, b) Mn, c) Sr, and d) Ba in the parr (central) section of the otoliths of adult sea trout otoliths from each of the five marine zones (MZ) of capture.

5.5.2.3 Assignment of Adult Sea Trout Back to Region of Origin Based on Their Parr Otolith Chemistry

Mean element:Ca ratio concentrations for the juvenile parr phase in the centre of the adult sea trout otoliths from the five marine zones, which represents the chemistry of the freshwater inhabited by each fish as a juvenile, are plotted together with the data for the parr from the 36 rivers sampled in the Irish Sea region in Figure 5.5.13 and presented alongside the average regional data in Table 5.5.16. If adult sea trout remain in the coastal waters close to their natal river of origin to feed prior to returning to spawn then it would be expected that the otolith chemistry for the juvenile parr phase in the centre of the adult sea trout otoliths would be similar to the otolith chemistry for parr from the rivers in the adjacent coastal region. However, for each of the element plots in Figure 5.5.13 it can be seen that there is considerable scatter in the freshwater chemistry for the adult sea trout with their range of parr chemistry values overlapping with much of the freshwater baseline data. There was no correlation between the average element:Ca ratios for Mg, Mn and Sr in central (parr) section of the otoliths the adult sea trout caught in each marine zone and the average freshwater value for the adjacent coastal region (indicated by the boxes in Table 5.5.16; all $P > 0.40$), however, a significant correlation was reported for Ba ($r = 0.987$, $P = 0.002$).

Using the established juvenile trout parr microchemical baseline (Table 5.5.2) created from juvenile parr sampled in the 10 regions around the Irish Sea, each adult sea trout was assigned to a putative region of origin based on the chemistry of the juvenile parr phase in the centre of their otolith using QDFA. If adult sea trout remain in the coastal waters close to their natal river of origin to feed prior to returning to spawn then it would be expected that they would classify back to the coastal region adjacent to their MZ of capture. In fact, classification back to adjacent coastal region was low at 17.7% with 41/231 adult trout correctly assigned to adjacent coastal region based on their freshwater chemistry in the centre of their otolith (see Table 5.5.17). The chance-corrected QDFA classification accuracy to region for the adult sea trout using Cohen's kappa statistic was low at 0.15 (± C.I 0.048), indicating that many of the correct classifications recorded may have been a result of chance. However, it is interesting to note that a large number of the MZ23 fish (25/36, 69%) classified to the nearby SW Scotland region.

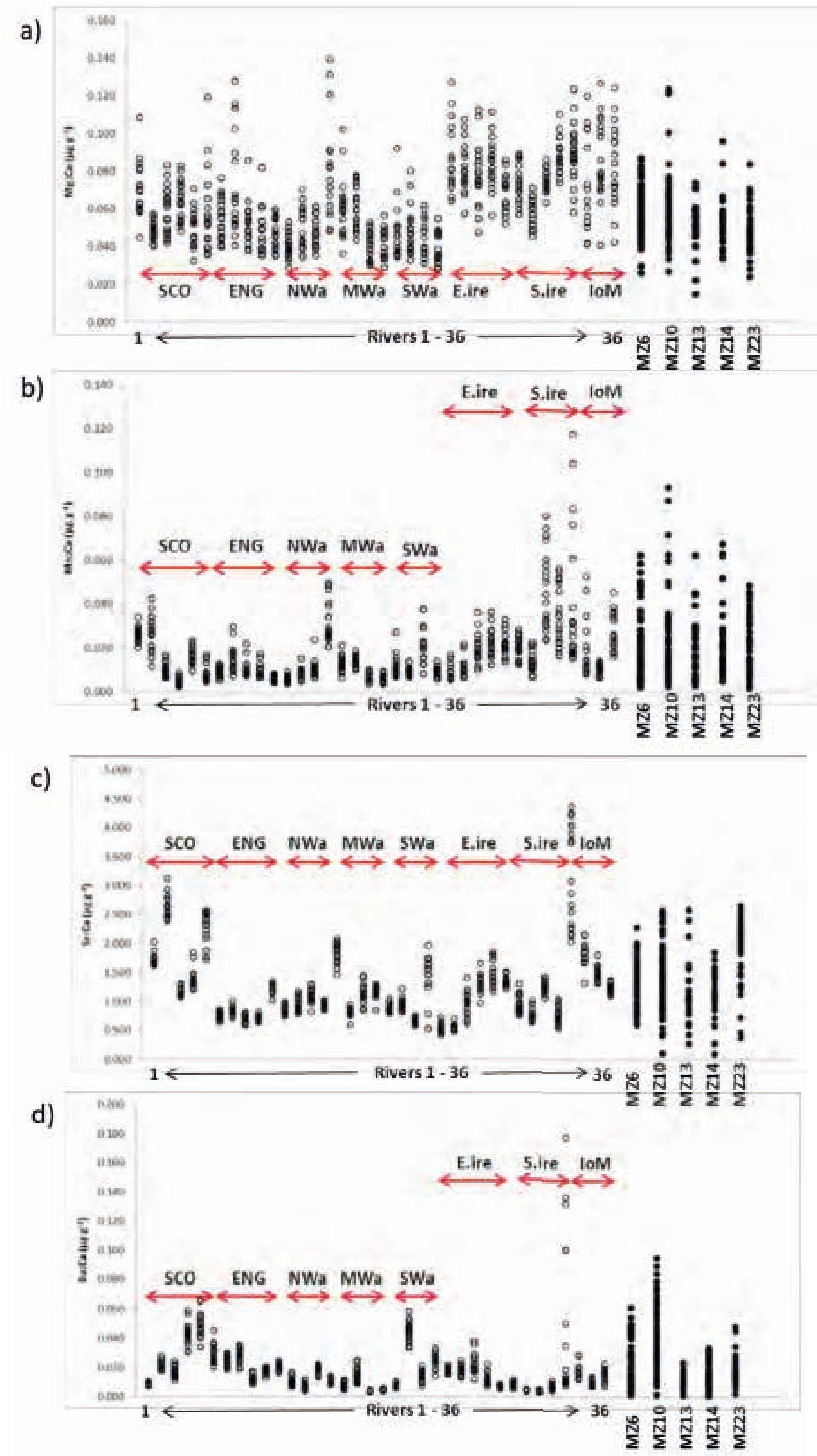


Figure 5.5.13 Mean element concentrations (expressed as element:Ca ratios, µg g^{-1}) for a) Mg, b) Mn, c) Sr and d) Ba in the otoliths of parr from the 36 rivers sampled to establish the freshwater baseline (open circles; listed in order from 1-36, see Table 5.4.1 for river codes) and in the central section (parr phase) of the otoliths of adult sea trout (solid circles) from each of the five marine zones of capture.

Table 5.5.16 Freshwater element:Ca ratios (µg g^{-1}) for Mg, Mn, Sr and Ba measured in the otoliths of juvenile and adult *Salmo trutta* from the Irish Sea region. Data are presented as mean values ± 1 standard deviation for the juvenile parr baseline data for each freshwater region (see Figure 5.4.1 and Table 5.4.1 for details) and for the section of the otolith corresponding to the freshwater period of residency in marine-caught adult sea trout *Salmo trutta* caught in the five marine zones within the Irish Sea (rows highlighted in grey). See Figure 5.4.2 for the location of each Marine Zone. The boxes link each Marine zone to its adjacent coastal region(s).

	Mg	Mn	Sr	Ba	Total N^{o}
S-W Scotland	0.05860 ± 0.015	0.01543 ± 0.009	1.66763 ± 0.662	0.02780 ± 0.016	114
MZ10 (SW-Scotland)	0.05832 ± 0.018	0.02020 ± 0.019	1.28361 ± 0.528	0.03495 ± 0.022	73
N-W England	0.05529 ± 0.018	0.00970 ± 0.005	0.84514 ± 0.197	0.02036 ±0.006	92
North Wales	0.05436 ± 0.021	0.01359 ± 0.011	1.18482 ± 0.389	0.01114 ± 0.004	73
MZ13 (N-Wales)	0.05090 ± 0.013	0.02037 ± 0.015	1.18274 ± 0.568	0.01201 ± 0.007	26
MZ14 (N-Wales)	0.05232 ± 0.012	0.02285 ± 0.017	1.13042 ± 0.386	0.01370 ± 0.009	34
Mid Wales	0.05075 ± 0.015	0.00964 ± 0.004	1.00811 ± 0.188	0.00741 ± 0.005	77
South Wales	0.04442 ± 0.012	0.01218 ± 0.007	0.86174 ± 0.390	0.02319 ± 0.015	74
North Skerries	0.08407 ± 0.016	0.00997 ± 0.004	0.77621 ± 0.264	0.01764 ± 0.003	34
South Skerries	0.07770 ± 0.015	0.02079 ± 0.006	1.38772 ± 0.172	0.01416 ± 0.008	53
MZ06 (S-Skerries)	0.05693 ± 0.013	0.01962 ± 0.015	1.24542 ± 0.404	0.01985 ± 0.016	69
Celtic Sea	0.07353 ± 0.014	0.02860 ± 0.017	0.93652 ± 0.243	0.00555 ± 0.002	76
S-W Eire	0.08916 ± 0.015	0.03933 ± 0.031	3.12573 ± 0.862	0.04388 ± 0.054	20
Isle of Man	0.08120 ± 0.024	0.01882 ± 0.011	1.49572 ± 0.272	0.01365 ± 0.005	52
MZ23 (Isle of Man)	0.04739 ± 0.012	0.02134 ± 0.013	1.77980 ± 0.573	0.01784 ± 0.010	37

Table 5.5.17 QDFA-predicted classification of adult marine caught sea trout *Salmo trutta* using the freshwater growth phase (Adult P-$_{PHz}$) to their region of origin by means of the biogeochemistry baseline established using Mg, Mn, Sr and Ba obtained from the 36 rivers. Adult fish were assigned based on the probability of belonging to a particular region. Fish classified to coastal regions adjacent to their marine zone of capture are highlighted in bold (deemed to be correct classification), whilst fish classifying to nearby coastal regions indicated by shading (Figure 5.5.4)

	MZ-10	MZ-13	MZ-14	MZ-06	MZ-23
Region					
S-W Scotland	**25**	3	3	14	25
N-W England	13	2	3	6	1
North Wales	3	**4**	**1**	8	3
Mid Wales	3	0	2	14	2
South Wales	14	4	8	8	1
North Skerries	0	0	0	0	0
South Skerries	5	0	2	**3**	0
Celtic Sea	0	6	5	5	1
S-W Ireland	5	1	1	2	0
Isle of Man	4	4	7	7	**3**
Total N^{o}	72	24	32	67	36
N^{o} correct	25	4	1	8	3
Proportion	0.347	0.167	0.031	0.119	0.083

5.5.3 Stable Isotope Analysis of Adult Sea Trout Scales

5.5.3.1 Preliminary Calibration Work

The masses of the samples sent off to determine the effect of sample mass on measurability and reproducibility of $\delta^{15}N$ and $\delta^{13}C$ in adult sea trout scale material are presented in Table 5.5.18. Actual scale sample masses in the calibration work ranged from 0.22 to 0.8 mg.

Table 5.5.18 The effect of sample mass on measured $\delta^{13}C$ and $\delta^{15}N$ isotope values for adult sea trout *Salmo trutta* scales. Data are presented as mean values ± standard deviation with within-group variability expressed using the coefficient of variation (CV). Note: isotopic analysis was conducted on excised scale material corresponding to the last period of marine growth

Sample Group	Sample size	Measured sample mass (mg)	$\delta^{13}C$ (‰)	CV (%)	$\delta^{15}N$ (‰)	CV (%)
0.2	5	0.22 ± 0.02	-16.03 ± 0.20	1.26	15.50 ± 0.12	0.79
0.3	5	0.33 ± 0.01	-15.87 ± 0.38	2.37	15.40 ± 0.18	1.19
0.4	5	0.42 ± 0.01	-15.67 ± 0.40	2.54	15.37 ± 0.16	1.13
0.6	14	0.65 ± 0.03	-15.29 ± 0.12	0.77	15.76 ± 0.11	0.68

Scatter plots of the $\delta^{15}N$ and $\delta^{13}C$ values for the four mass calibration groups are presented in Figure 5.5.14. Within-group variability was low with coefficients of variation ranging from 0.68 – 1.19% for $\delta^{15}N$ and 0.77 – 2.54% for $\delta^{13}C$ respectively, however, precision appeared best using samples masses of *ca.* 0.6 mg. $\delta^{15}N$ values were significantly different between mass calibration groups (ANOVA, $F_{(3,28)} = 16.15$, $P < 0.001$) and *post-hoc* comparisons indicated that the $\delta^{15}N$ value for the 0.6 mg group was significantly higher than the other 3 mass calibration groups (Scheffe's test, all $P \leq 0.012$). Similarly, $\delta^{13}C$ values were significantly different between mass calibration groups (ANOVA, $F_{(3,28)} = 14.54$, $P < 0.001$) and *post-hoc* comparisons indicated that the $\delta^{13}C$ value for the 0.6 mg group was significantly higher than the value for the 0.2 mg group (Tamhane's T2 test, P = 0.003). The results of this calibration work indicated that using sample masses of greater than *ca.* 0.4 mg were advised for measuring the ^{15}N and ^{13}C isotopic composition of adult sea trout scales. All scale masses from in-river caught sea trout analysed in this study were < 0.4 mg with only 6/92 (*i.e.* 6.5%) samples analysed weighing less than 0.5 mg sample mass.

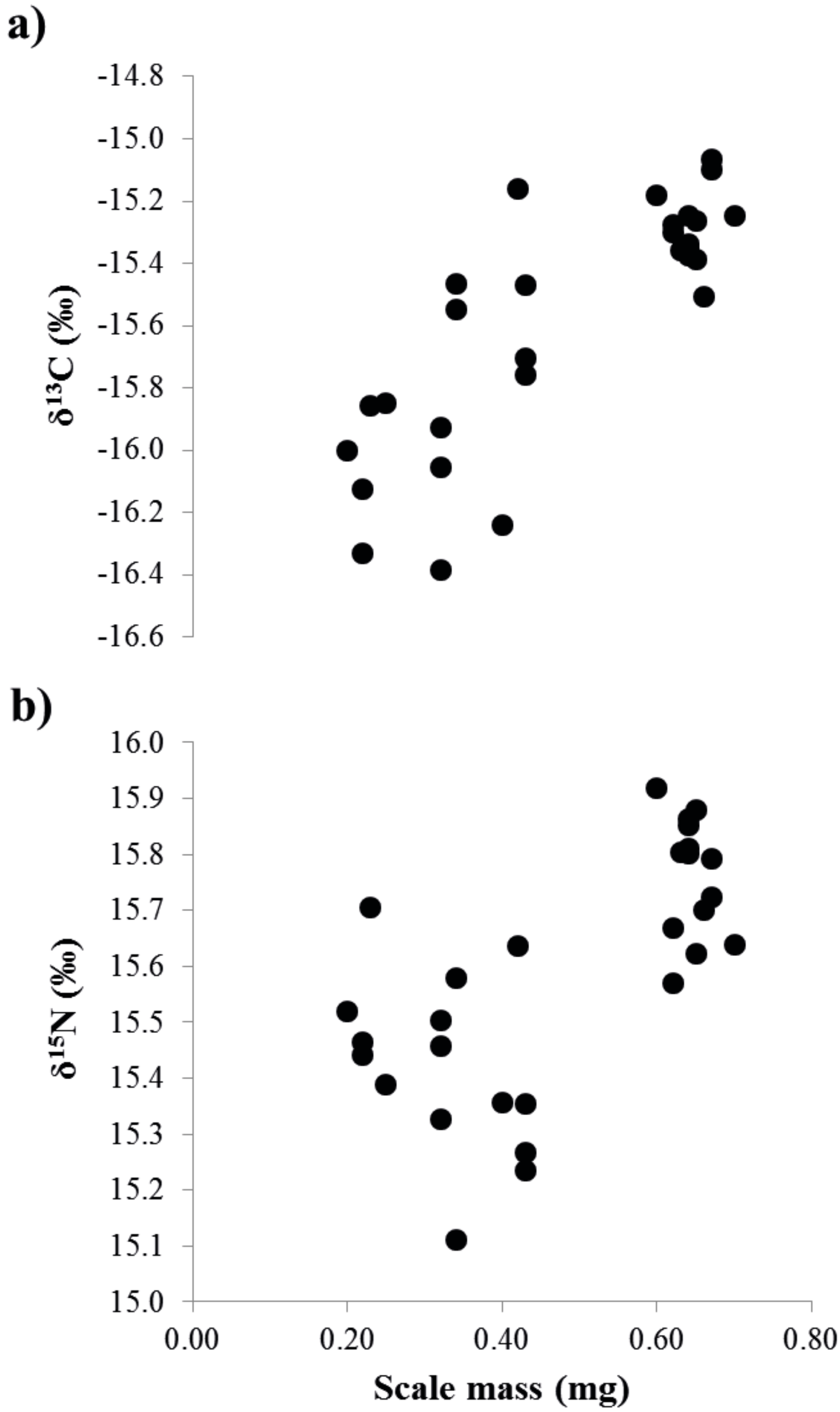


Figure 5.5.14 Sample calibration data showing the relation between sample mass (mg) and scale (a) $\delta^{13}C$ and (b) $\delta^{15}N$ isotope values for adult sea trout *Salmo trutta*. Note: isotopic analysis was conducted on excised scale material corresponding to the last period of marine growth.

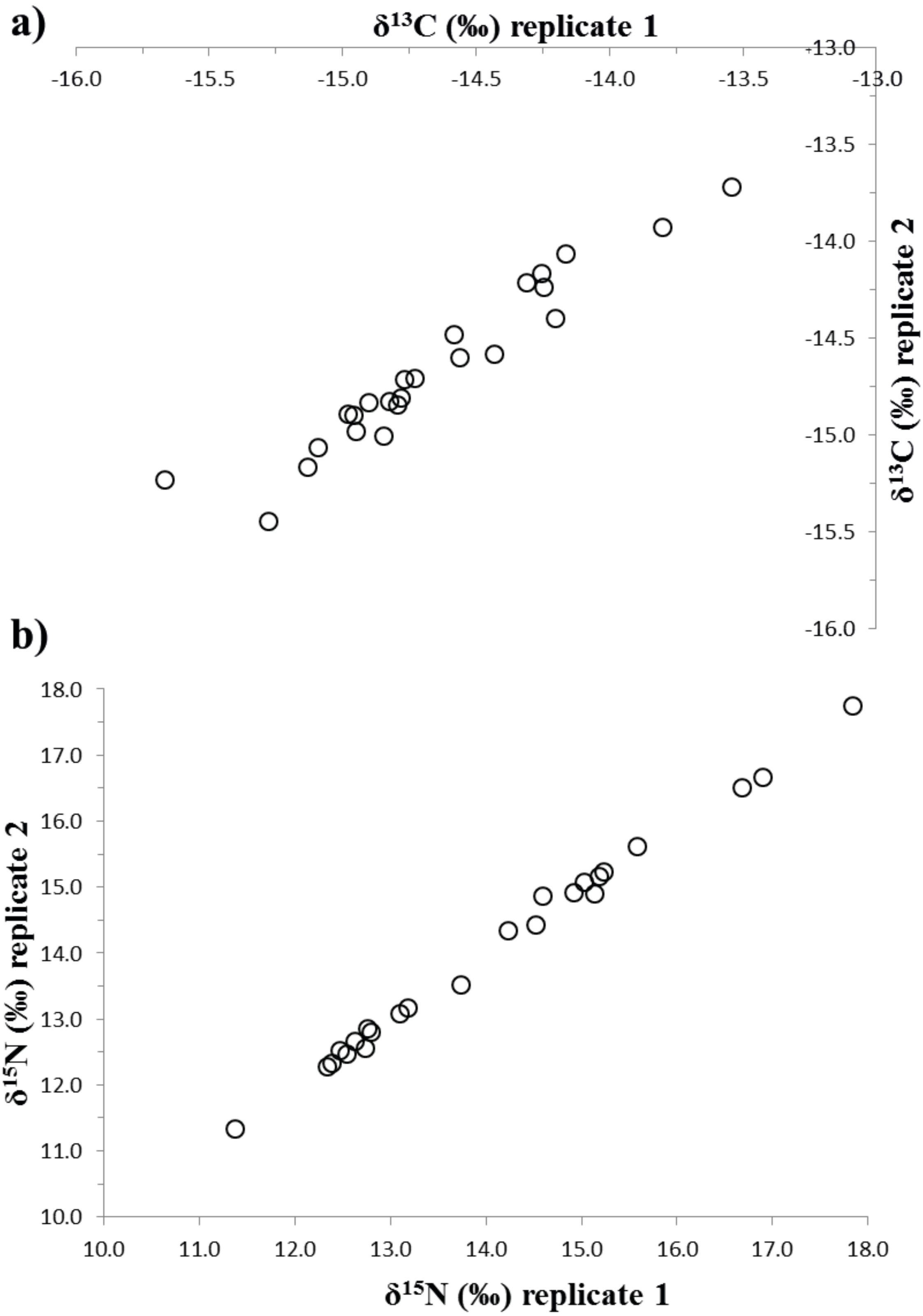


Figure 5.5.15 Sample calibration data showing (a) $\delta^{13}C$ and (b) $\delta^{15}N$ isotope values (n = 24) for replicate measures of scale isotope chemistry for adult sea trout *Salmo trutta*. Note: isotopic analysis was conducted on excised scale material corresponding to the last period of marine growth.

Repeat measures of $\delta^{15}N$ or $\delta^{13}C$ values for scales samples (n = 24; 21 pairs of original scale measurements and 3 pairs of regrowth scale measurements) taken from the last period of marine growth derived from the analysis of original or regrowth scales are presented in Figure 5.5.15. For $\delta^{15}N$ (Figure 5.5.15b), the repeat measures were highly correlated (r_{23} = 0.992, P< 0.0001) and were not significantly different from each other (paired *t* test, t_{22} = 0.36, P = 0.72). The repeat measures of $\delta^{13}C$ were more variable, particularly for the most depleted measurements (Figure 5.5.15a), however, the repeat measures were highly correlated (r_{23} = 0.949, P < 0.0001) and were not significantly different from each other (paired *t* test, t_{22} = 0.42, P = 0.68). These analyses indicate that where it was only possible to obtain enough excised scale material to make a single measurement using EA-IRMS, this would provide an accurate measure of scale isotope chemistry during the last period of marine growth.

Scatter plots showing the relation between the $\delta^{15}N$ or $\delta^{13}C$ values for the last period of marine growth derived from the analysis of original or regrowth scales for 10 adult sea trout are presented in Figure 5.5.16. For $\delta^{15}N$ (Figure 5.5.16b), the values obtained using original (14.73 ± 1.29 ‰) or regrowth (14.85 ± 1.34 ‰) scales were highly correlated (r_{10} = 0.988, P < 0.0001) and were not significantly different from each other (paired *t* test, t_9 =-1.80, P=0.11). The repeat measures of $\delta^{13}C$ (Figure 5.5.16a) were a little more variable, but the values obtained using original (-14.59 ± 0.36 ‰) or regrowth (-14.61 ± 0.38 ‰) scales were also highly correlated (r_9 = 0.949, P < 0.0001) and not significantly different from each other (paired *t* test, t_9 = 0.45, P = 0.66). The results of this calibration work indicated that scale samples comprising entirely of regrowth scales, or a mix of regrowth and original scales, can be used to measure the ^{15}N and ^{13}C isotopic composition of adult sea trout scales during the last period of marine growth.

The $\delta^{13}C$ and $\delta^{15}N$ values for the last marine growth period of scales from in-river caught adult sea trout are presented in

Table 5.5.19. Data for the Tywi consisted of fish caught in 2010 (n = 5; $\delta^{13}C$ = -14.96 ± 0.15; $\delta^{15}N$ = 12.83 ± 0.45) and 2011 (n = 14; $\delta^{13}C$ = -14.80 ± 0.48; $\delta^{15}N$ = 12.82 ± 0.66), however, there were no significant differences in the scale isotope chemistry between the two years (*t* test; $\delta^{13}C$, t_{17} = 0.73, P = 0.47; $\delta^{15}N$, t_{17} = 0.01, P = 0.99) and the data were combined into a single data set for the river in subsequent statistical analyses.

$\delta^{15}N$ values in the last period of marine growth on the scales were significantly different between the adult sea trout caught in-river in the seven rivers examined in this study (ANOVA, $F_{(6,57)}$ = 16.15, P < 0.001) and *post-hoc* comparisons (using Tamhane's T2 test) indicated that the scale $\delta^{15}N$ values for the Twyi fish were significantly lower than those recorded for the Nith (P = 0.002), Luce (P < 0.001), Lune (P < 0.001) and Conwy (P = 0.03). In contrast, $\delta^{13}C$ values in the last period of marine growth on the scales were similar between the different rivers (ANOVA, $F_{(6,57)}$ = 1.71, P = 0.14). Since the $\delta^{13}C$ ANOVA analysis may have been biased by a single outlying point from the Conwy (Figure 5.6.2) the ANOVA was repeated with this fish excluded. However, no significant differences in $\delta^{13}C$ values in the last period of marine growth on the scales was observed between rivers (ANOVA, $F_{(6,56)}$ = 2.01, P = 0.08).

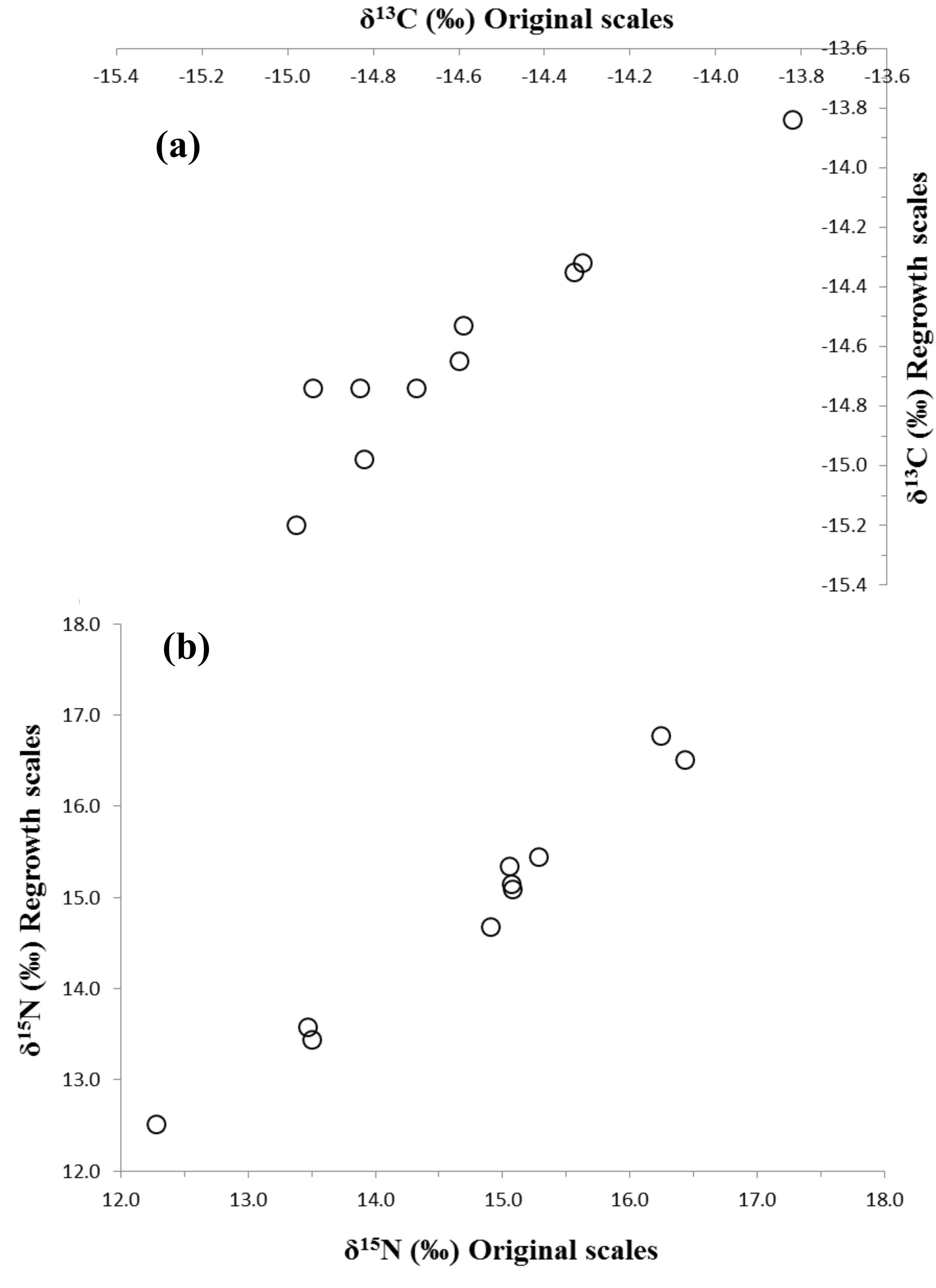


Figure 5.5.16 Sample calibration data showing the relation between sample mass (mg) and scale (a) δ^{13}C and (b) δ^{15}N isotope values for adult sea trout *Salmo trutta*. Note: isotopic analysis was conducted on excised scale material corresponding to the last period of marine growth.

5.5.3.2 $\delta^{13}C$ and $\delta^{15}N$ values for adults sea trout scales in the Irish Sea region

Table 5.5.19 $\delta^{15}N$ and $\delta^{13}C$ values for the last marine growth period in the scales of in-river caught adult sea trout *Salmo trutta*. Values in the $\delta^{15}N$ column with the same letter are significantly different from the River Tywi.

River	Sample size	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)
Luce	5	15.32 ± 0.57[a]	-14.87 ± 0.25
Nith	8	14.67 ± 0.60[a]	-14.37 ± 0.20
Lune	10	15.82 ± 0.97[a]	-14.28 ± 0.52
Dee	5	14.68 ± 1.73	-14.71 ± 0.67
Conwy	5	15.72 ± 0.96[a]	-15.28 ± 1.72
Dyfi	6	13.93 ± 1.17	-14.73 ± 0.93
Tywi	19	12.82 ± 0.60	-14.84 ± 0.42

The adult sea trout were grouped according to geographical region to examine whether isotopic differences in scale chemistry were related to region (Figure 5.5.18). The fish were grouped according to the putative coastal region in which they were hypothesized as most likely to have been feeding at sea – Solway Firth for the Luce and Nith fish, Liverpool Bay for the Lune, Dee and Conwy fish, Cardigan Bay for the Dyfi fish and South Wales for the Twyi fish (Table 5.5.20). The mean $\delta^{15}N$ values varied by up to 2.7‰ between regions and were ranked (highest to lowest): Liverpool Bay > Solway Firth > Cardigan Bay > South Wales (Table 5.5.20). The mean $\delta^{13}C$ values for the 4 regions were less variable and the maximum difference between region was < 0.3‰ (Table 5.5.20).

When grouped by region, $\delta^{15}N$ values in the last period of marine growth on the scales were significantly different between the in-river caught adult sea trout from the 4 regions (ANOVA, $F_{(3,57)} = 29.21$, $P < 0.001$). *Post-hoc* comparisons (using Tamhane's T2 test) indicated that the scale $\delta^{15}N$ values for the South Wales fish were significantly lower than those recorded for the Solway Firth ($P < 0.001$) and Liverpool Bay ($P < 0.001$) and the scale $\delta^{15}N$ values for Liverpool Bay and Cardigan Bay were significantly different ($P = 0.008$). $\delta^{13}C$ values in the last period of marine growth on the scales were similar between the four regions (ANOVA, $F_{(3,57)} = 0.46$, $P = 0.71$). Repeating the $\delta^{13}C$ ANOVA analysis excluding the single outlying point from the Conwy in the Liverpool Bay group (Figure 5.22), also produced a non-significant ANOVA result (ANOVA, $F_{(3,56)} = 2.05$, $P = 0.12$) for the $\delta^{13}C$ values in the last period of marine growth on the scales.

When fish were grouped according to the 4 coastal regions, the classification success using QDFA was 65.5% with 39/58 adult sea trout correctly classified back to their putative coastal region based on the scale $\delta^{15}N$ and $\delta^{13}C$ laid down in the last period of marine growth (Table 5.5.21). CV-QDFA classification accuracy was similar with 62.1%, i.e. 36/58, adult sea trout correctly classified back to their putative coastal region of origin based on scale isotope chemistry (Table 5.5.22). Cohen's kappa statistic indicated that the chance-corrected classification accuracy of trout parr to region using QDFA was 0.53 (C.I 0.36-0.70) and 0.48 (C.I 0.30-0.65) using CV-QDFA.

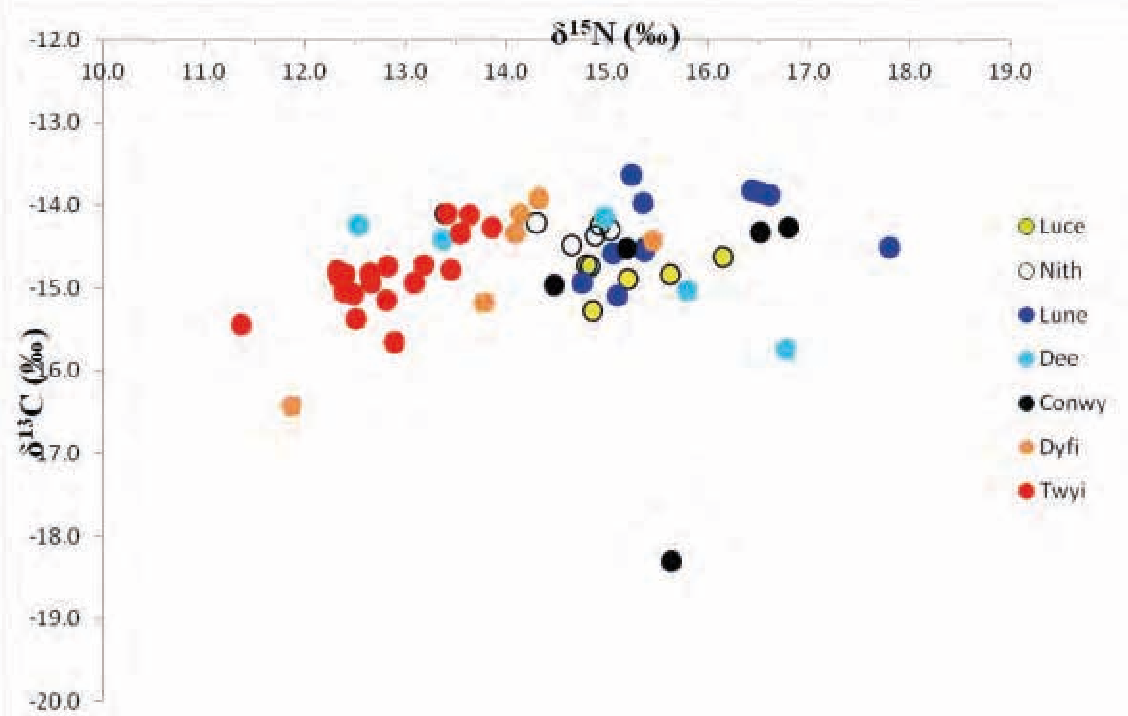


Figure 5.5.17 Isotopic biplot of the $\delta^{15}N$ and $\delta^{13}C$ values for the last marine growth period in the scales of in-river caught adult sea trout *Salmo trutta* from 7 rivers from the Eastern Irish Sea. Sample size data are presented in Table 5.5.19.

Table 5.5.20 $\delta^{15}N$ and $\delta^{13}C$ values for the last marine growth period in the scales of in-river caught adult sea trout *Salmo trutta* from 4 regions in the Eastern Irish Sea. Values in the $\delta^{15}N$ column with the same letter are significantly different from each other.

Region	Sample size	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)
Solway Firth	13	14.92 ± 0.65^{a}	-14.56 ± 0.33
Liverpool Bay	20	$15.51 \pm 1.23^{b,c}$	-14.64 ± 1.01
Cardigan Bay	6	13.93 ± 1.17^{c}	-14.73 ± 0.93
South Wales	19	$12.82 \pm 0.60^{a,b}$	-14.84 ± 0.42

The assignment analyses showed that fish from rivers draining into the Solway Firth (i.e. Luce, Nith) or Liverpool Bay (i.e. Lune, Dee and Conwy) that did not classify back to their putative coastal region tended to assign to the other coastal region (Table 5.5.21 and Table 5.5.22; 12/13 [92%] for the Solway Firth and 16/20 for Liverpool Bay). For example, 8 fish (40%, 8/20) correctly classified back to the Liverpool Bay coastal region with a further 8 classifying to the Solway Firth. For the Solway Firth rivers, 2 of the 3 fish not assigning back to the Solway Firth region were assigned to the Liverpool Bay coastal region.

Table 5.5.21 Classification of adult in-river caught sea trout (see Table 5.4.3 for rivers of capture) to putative coastal region of feeding using quadratic discriminant function analysis (QDFA) based on scale $\delta^{15}N$ and $\delta^{13}C$ signatures.

	Solway Firth	Liverpoo l Bay	Cardigan Bay	South Wales
Solway Firth	**10**	8	3	1
Liverpool Bay	2	**8**	0	0
Cardigan Bay	0	2	**3**	1
South Wales	1	2	0	**17**
N^{o}	13	20	6	19
N^{o} correct	10	8	3	17
Percentage	0.769	0.400	0.500	0.895

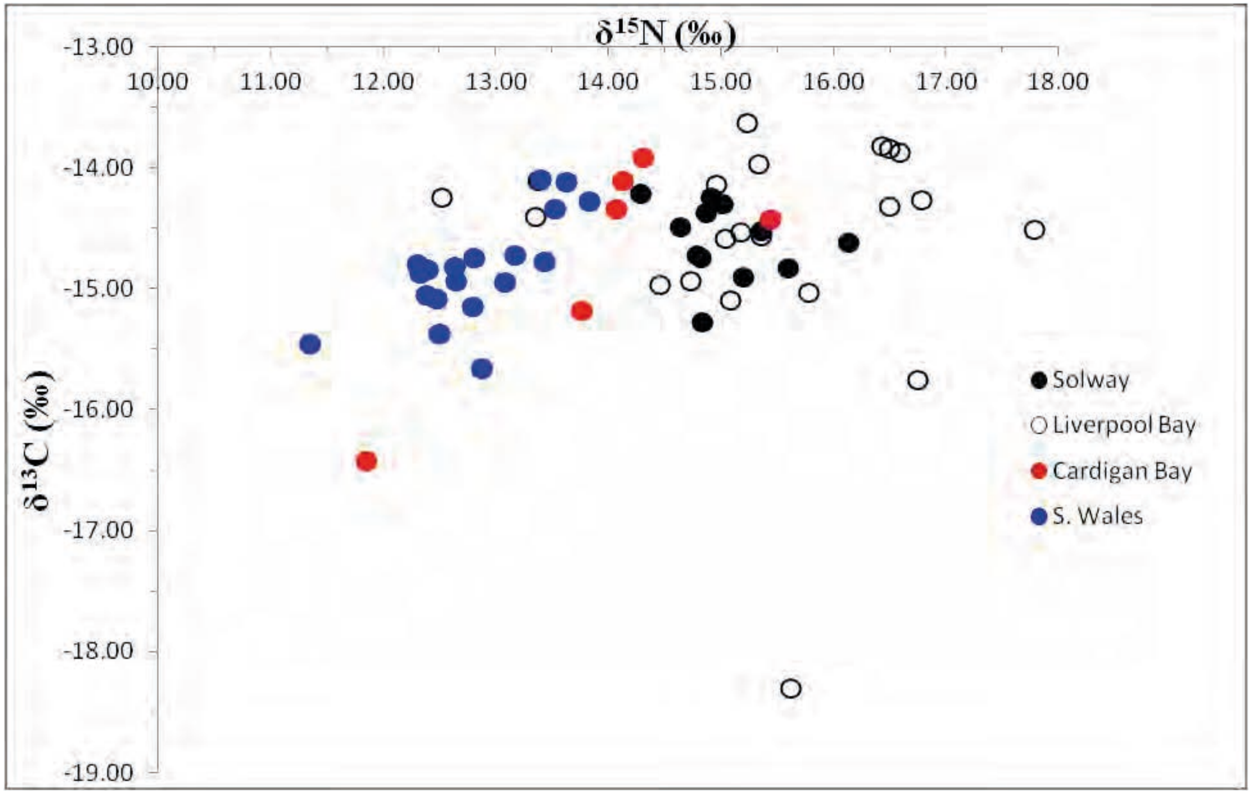


Figure 5.5.18 Isotopic biplot of the $\delta^{15}N$ and $\delta^{13}C$ values for the last marine growth period in the scales of in-river caught adult sea trout *Salmo trutta* from 4 regions in the Eastern Irish Sea. Sample size data are presented in Table 5.5.20.

Table 5.5.22 Classification of adult in-river caught sea trout (see Table 5.4.3 for rivers of capture) to putative coastal region of feeding using cross-validated quadratic discriminant function analysis (CV-QDFA) based on scale $\delta^{15}N$ and $\delta^{13}C$ signatures.

	Solway Firth	**Liverpool Bay**	**Cardigan Bay**	**South Wales**
Solway Firth	**10**	8	4	1
Liverpool Bay	2	**8**	1	0
Cardigan Bay	0	2	**1**	1
South Wales	1	2	0	**17**
N^{o}	13	20	6	19
N^{o} correct	10	8	1	17
Percentage	0.769	0.400	0.167	0.895

5.6 Discussion

Tracking and understanding the movement patterns of fishes and identifying individuals back to their natal origins or juvenile nursery grounds are central to understanding the ecology of a fish species and for their effective management. The use of multi-elemental otolith microchemistry is becoming a useful tool for stock discrimination purposes and the reconstruction of individual migratory histories (Elsdon and Gillanders, 2003*a*). This approach has enabled spatial geochemical differences and discrete populations within local areas to be identified and assisted in the reconstruction of the movement patterns and intermixing of fishes from these different populations (*e.g.* Elsdon and Gillanders, 2003*a*; Swearer *et al*., 2003; Veinott and Porter, 2005; Elsdon *et al*., 2008; Ramsay *et al*., 2011; Tanner *et al*., 2012; Veinott *et al*., 2012). More recently, scale stable isotope signatures have also been applied to determine the origins and movement pattern of fishes although the use of this tool is still in its infancy (*e.g.* Rooker *et al.*, 2008; Mackenzie *et al.*, 2011; Ramsay *et al.*, 2012)

5.6.1 Spatial Variability in Multi-Elemental Otolith Microchemistry

The results of this study have shown that otolith element:Ca ratios of Mg, Mn, Sr and Ba varied significantly between trout parr from the 36 rivers. Moreover, a distinct geographical pattern was observed with elevated Mg:Ca and Mn:Ca ratios in the otoliths of parr sampled from Irish and Manx rivers draining into the Irish Sea compared to those sampled from Western UK rivers (see Figure 5.5.1 and Figure 5.5.3; Table 5.5.1.). Similarly, Sr:Ca ratios showed elevated levels in the otoliths of trout parr sampled from the six rivers in southwest Scotland, the three rivers on the Isle of Man and the Currane in southwest Ireland compared to the other river samples (see Figure 5.5.1 and Figure 5.5.3). One river in particular, the Currane in southwest Ireland, exhibited a very distinctive chemical signature and showed elevated concentration levels of Mn:Ca, Sr:Ca and Ba:Ca ratios when compared to the remaining rivers. Taken together, these elemental differences indicate evidence of a possible trans-Irish Sea concentration gradient within the otolith chemistry of trout parr.

Element:Ca ratios observed in fish otoliths are thought to be largely determined by water chemistry (Veinott and Porter, 2005; Martin and Wuenscel, 2006), with studies by Wells *et al*. (2003), Walther and Thorrold (2008) and Ramsay *et al*. (2011) indicating a correlation between ambient stream water chemistry and the concentrations of Mg, Mn, Sr and Ba in fish otoliths and scales. However, it is thought that otolith concentrations of some elements may also be influenced by dietary intake (see

Buckel *et al*., 2004 and references therein). In addition, studies in the marine environment have also found a direct correlation between Sr:Ca and Ba:Ca ratios in seawater and otoliths (Bath *et al*., 2000) and between Sr:Ca in the otoliths of fish and estuarine water (Kraus and Secor, 2004). It is the transfer of these spatially-unique geochemical signals from the water to the otolith that allows fish to be identified back to their natal origin based on a unique otolith fingerprint (*e.g.* Veinott and Porter, 2005; this study).

The geological bedrock within the geographic area covered in the present study has been shown to vary with the west coast of Scotland comprising primarily of metamorphic bedrock compared to a mixture of Carboniferous and Triassic bedrock in northwest England and a mixture of both Carboniferous and Silurian bedrock in Wales (British Geological Survey, 2013). The bedrock for the rivers and streams sampled from the east coast and the south west coast of Ireland comprises mainly of Carboniferous, Devonian and Silurian geology (British Geological Survey, 2013). These differences in underlying geological bedrock that differ in their elemental composition, and in the rates at which the rocks erode and release elements into the surface sediments and stream water, are probably one of the drivers behind the elevated concentrations for Mg and Mn observed in Ireland and the Isle of Man compared to the west coast of the UK. An evaluation of the bedrock underlying these rivers and their water chemistry were beyond the scope of the present study. However, spatial geological heterogeneity, together with land use, have been identified as the major drivers of differences in ambient water chemistry (British Geological Survey, 1999) and therefore the key factor in discriminating between fish using element:Ca ratios within otolith aragonite (see Campana, 1999; Vasconcelos *et al*., 2007). Thus, in the present study spatial heterogeneity in Mg, Mn, Sr and Ba chemistry has presented a unique chemical fingerprint in trout parr otoliths with fish being correctly classified back to their river of origin with an accuracy in excess of 70% (and up to 100%, *e.g.* Nith, Annan, Tywi, Argideen and Currane) for 21/36 rivers studied (see Figure 5.5.6, Table 5.5.4). These elements are amongst a small suite of trace metals which substitute for Ca and, in the case of Mn, Sr and Ba, have a similar ionic radii and ionic charge which matches the free Ca^{2+} cation within the aragonite matrix of otoliths (Swearer *et al*., 2003; Hedges *et al*., 2004; Clarke *et al*., 2007). In addition Mg, which has been described by some authors as being resilient to reabsorption and is assumed to substitute for Ca within the lattice structure of the otoliths (Rooker *et al*., 2001; Swan *et al*., 2006), is another trace metal which is important in discriminating between geographic locations and is routinely used as a biogeochemical tag in fish otolith microchemistry studies (*e.g.* Wells *et al*., 2000, 2003; Muhlfeld *et al*., 2005; Ramsay *et al*., 2011).

The ability to identify individual fish back to a specific water body will require a minimum residence time in order to for the unique chemical tag to be deposited in the otolith. Previous studies have indicated fish need to be resident in a particular location for at least one month (see Elsdon and Gillanders 2003*b*, 2005) to allow the chemistry of the local environment to be taken up within calcified structures. However, residence time will also be dependent on the size of the otolith, its growth rate and the technique used to measure elemental concentrations since LA- or sb-ICPMS will require different sample sizes of otolith material. Previous studies have worked with species where habitat residence times have been assumed to anything from a few months up to a few years dependent upon the species (see Beck *et al*., 2001; Elsdon and Gillanders 2003*b*; Able, 2005; Vasconcelos *et al*., 2008). In the present study *S trutta* parr were sampled before undergoing smoltification and although not aged during the present study, were assumed to have resided in their natal rivers for 1-2 years prior to capture.

5.6.2 Classification to River Based on Otolith Microchemistry

In Biogeochemical Tagging Studies Divalent Trace Elements Such Mg, Mn, Sr and Ba are often the most important elements identifying fish back to source using discrimination analysis (*e.g.* see Muhlfeld *et al*., 2005; Veinott and Porter, 2005; Ramsay *et al*., 2011). In the present study, the concentrations of these elements in the otoliths of *Salmo trutta* parr were found to be excellent natural tags in identifying the natal origin of fish back to the 36 rivers which drain into the Irish and Celtic Seas. Overall cross-validation classification accuracy was high with 74% of the trout parr correctly assigned back to their source river; for most rivers used in this study (*i.e.* 21/36) assignment success ranged between 70% - 100%. The use of the Cohen's Kappa statistic (see Barnett-Johnson *et al*., 2008; Ramsay *et al*., 2011) in the present study, with a calculated value of 0.73 ± 0.04 C. Is, provides confidence that the high level of correct assignment has not occurred as a result of chance.

The methodological approach adopted in this study - *i.e.* the collection of fish from a number of potentially geochemically distinct sources, the assessment of the trace element composition in the otoliths of these fish and the use of an assignment test (such as discriminant function analysis) to attempt to identify fish back to source – is a standard approach that has been adopted in many fish studies in the last decade. Studies using this approach have shown that classification accuracies of between 70 % and 100% (*i.e.* similar to that achieved in the present study) are not unusual (*e.g.* Thorrold *et al*., 1998a; Gillanders and Kingsford, 2000; de Pontual *et al*., 2000; Gillanders and Kingsford, 2003; Dorval *et al*., 2005; Vasconcelos *et al*., 2007).

Although many studies show classification successes ranging between 70 and 100% it is important to note that these studies have differed in their spatial coverage and the number of source populations being studied. To the authors' knowledge, the present study is one that includes one of the largest number of source populations (*i.e.* 36) and covers one of the largest geographical areas covered (2,400 km of coastline). Spatial variation in otolith microchemistry and its use as a biogeochemical tag has been frequently reported: see Gillanders *et al*. (2001) for an extensive summary and Elsdon *et al*. (2008) and Table 5.28 for more recent reviews. However, most studies have sampled from sites distributed over relatively small spatial scales, for example from sites separated by a few hundred metres (*e.g.* Gillanders and Kingsford, 2000) or by < 1 km to locations separated by < 10 km (see Table 5.6.1). It is interesting to note that sampling sites separated by as little as a few metres can be distinguished based on discrete otolith elemental signatures (Gillanders and Kingsford, 2000) and fish from these sites can be classified with a high degree of accuracy (60% - 100%), highlighting the sensitivity of this technique. Regional differences in otolith microchemistry signatures within freshwater catchments have suggested that it might be possible to identify fine-scale movement patterns of fishes, as suggested by Ramsay *et al*. (2011) based on work conducted in the River Dee (a small upland river catchment) on 6 sampling sites (approximately 7.5 km separating neighbouring sampling sites). In future studies, the combination of otolith trace element and strontium isotope chemistry may present a powerful technique in examining the in-river migrations of fishes (see Walther and Thorrold, 2008; Walther *et al*., 2008).

As expected, with an increase in spatial scale (i.e. > 10 km between sampling sites), discrete, distinct trace elemental signatures can be identified (see Table 5.6.1). For example, Wells et al. (2003) sampled westslope cutthroat trout *Oncorhynchus clarki lewisi* from 3 streams within the Coeur d'Alene River system in Idaho, USA covering a 60 km spatial scale and analysed the microchemistry (Mg, Ca, Sr and Ba) of their otoliths and scales.

The accuracy with which individual fish were classified back to their stream of origin was 100% based on otolith chemistry and 82% when using scale chemistry (Wells *et al*., 2003). Studies conducted over greater geographical scales (*i.e.* > 500 km) are less common (see Table 5.6.1) but have indicated high classification rates The present study covers one of the largest spatial scales covered to date, encompassing a geographical distance of approximately 2,400 km (1,490 miles) of coastline including the western UK and the east and south-west coast of Ireland and the Isle of Man (see Figure 5.4.1 for geographical area). To the authors' knowledge, the only study covering a larger spatial scale is that of Walther and Thorrold (2008) who studied 13 populations of shad *Alosa sapidissima* along the 2700 km Atlantic coastline of the USA.

In addition to varying in the spatial scale over which samples were collected, studies which have used otolith microchemistry to identify fish to source have also varied in the number of source populations that have been sampled. In the present study, 36 separate sources (rivers) were sampled with an estimated average distance between rivers of approximately 72 km (45 miles). To the authors' knowledge this is one of the largest data sets used in a microchemistry study to date (as well as covering one of the largest geographical scales). Previous studies using biogeochemical tags have tended to sample from a small number of sources (usually 2 – 10; Table 5.6.1). A meta-analysis of published classification success rates using discriminant function analysis (DFA) shows that there is a tendency for % classification accuracy (%) to decrease as the number of sampled sources increases (see Figure 5.6.1). This may be because when the number of sources is low, the probability that some fish may be correctly assigned to their source population by chance is greater (see White and Ruttenberg, 2007). The results of the present study do not follow the trend for decreasing classification success with increasing number of source populations (Figure 5.6.1) with an average CV-QDFA classification success of 74%. The sample sizes per source (river) in the present study ranged between 15 and 20 with a total sample size of 665 from 36 separate sources. However, the fact that comparable assignment rates were obtained using the Random Forest technique (Breiman, 2001) and the calculated Cohen's Kappa coefficients (Titus *et al*., 1984) were high, provide confidence that the QDFA analysis is robust and that the classification of juvenile trout parr back to their source population (see Table 5.5.4 and Table 5.5.5) is not occurring as a result of chance assignments.

Table 5.6.1 Summary of recently published data examining spatial variability in otolith chemistry over a range of geographical scales and its potential to infer movement patterns of fish. Data are organised by year of reference. Freshwater studies are shaded blue.

Study Location	Sample design	Geographical Range	Species	Sampling Year/s	Sample N^o	Chemicals Analysed	Differences	Classification success	Author/s
East coast New South Wales, Australia	7 estuaries 2-5 sites/estuary	600 km	*Pelates sexlineatus*	1998-1999	10 / site	Mn, Sr, Ba	Difference within and amongst estuaries	Within among estuaries 60 – 100 %	Gillanders and Kingsford, 2000
South-eastern Australia	6 Inlets Between 1-9 sites / inlet	300 km	*Pagrus auratus*	2000-2001	Range 2-56 / inlet	Mn, Sr, Ba	Difference between Inlets and year classes	Between inlets 85-98 %	Hammer *et al.*, 2003
Idaho USA	3 streams	60 km	*Oncorhyncus clarki lewisi*	2000	10 / stream	Mg, Ca, Sr Ba	Between locations	Between rivers 100 %	Wells *et al.*, 2003
Newfoundland and Labrador Canada	4 Streams	130 km	*Salmo salar*	2002	Range 22-25 / stream	Mg, Mn, Sr, Ba	Between streams	Between streams 84 – 100 %	Veinott and Porter, 2005
South-east coast Australia	6 Inlets 1-9 sites/inlet	10-760 km	*Pagrus auratus*	2000-2001	Range 2-56 / site	Mn, Sr, Ba	Among bays	85% - 98%	Hamer *et al.*, 2003
Portuguese coast	8 Estuaries	500 km	*Solea solea* *S. senegalensis* *Platichthys flesus* *Diplodus vulgaris* *Dicentrarchus labrax*	2005	Range 30-50/sp.	Li, Na, Mg, K, Mn, Ni, Cu, Zn, Sr, Cd, Ba, Pb	Difference between Species and estuaries	Dependant on Species 70 – 92 %	Vasconcelos *et al.*, 2007
Portuguese coast	8 Estuaries	500 km	*Solea solea* *S. senegalensis* *Platichthys flesus* *Diplodus vulgaris* *Dicentrarchus labrax*	2006	10 / sp. / site	Li, Na, Mg, K, Mn, Ni, Cu, Zn, Sr, Ba, Pb	Difference between 4 species and estuaries	Dependant on Species 6 – 53 %	Vasconcelos *et al.*, 2008

Atlantic coast USA	12 Rivers	1900 km	*Alosa sapidissima*	2000-2002	Range 18-29 / river	Mg, Mn, Sr, Ba	Between rivers	91 %	Walther *et al.*, 2008
Atlantic coast USA	13 Rivers	2700 km	*Alosa sapidissima*	2004	Range 18-59 / river	Mg, Mn, Sr, Ba	Between rivers	93 %	Walther and Thorold 2008
North Wales UK	7	7 km	*Salmo trutta*	2008-2009	Range 11-16 / river	Mg, Mn, Sr, Ba	Between sites	89 %	Ramsay *et al.*, 2011
E-Newfoundland and Canada	4 Rivers 2 estuaries	170 km	*Salmo trutta*	2007-2009	Range 7-16 / river	Mg, Ca, Mn, Zn, Sr, Ba	Between rivers	97 %	Veinott *et al.*, 2012
Newfoundland and Labrador Canada	4 Locations	1100 km	*Gadus morhua*	1998-1999	Range 15-40 Site	Mg, Mn, Sr, Ba	Between groups	66 % 78 % spawning sites merged	D'Avignon and Rose, 2013
Central California	3 Coastal areas Multiple stations	200 km	*Sebastes jordani*	2009	200 total	Mg, Sr, Ba	Between upwelling centre's	-	Woodson *et al.*, 2013
NW- coast UK and E- coast Eire	36 rivers	2,400 km	*Salmo trutta*	2010	Range 15-29 / river	Mg, Mn, Sr, Ba	Between rivers	74 %	Present Study

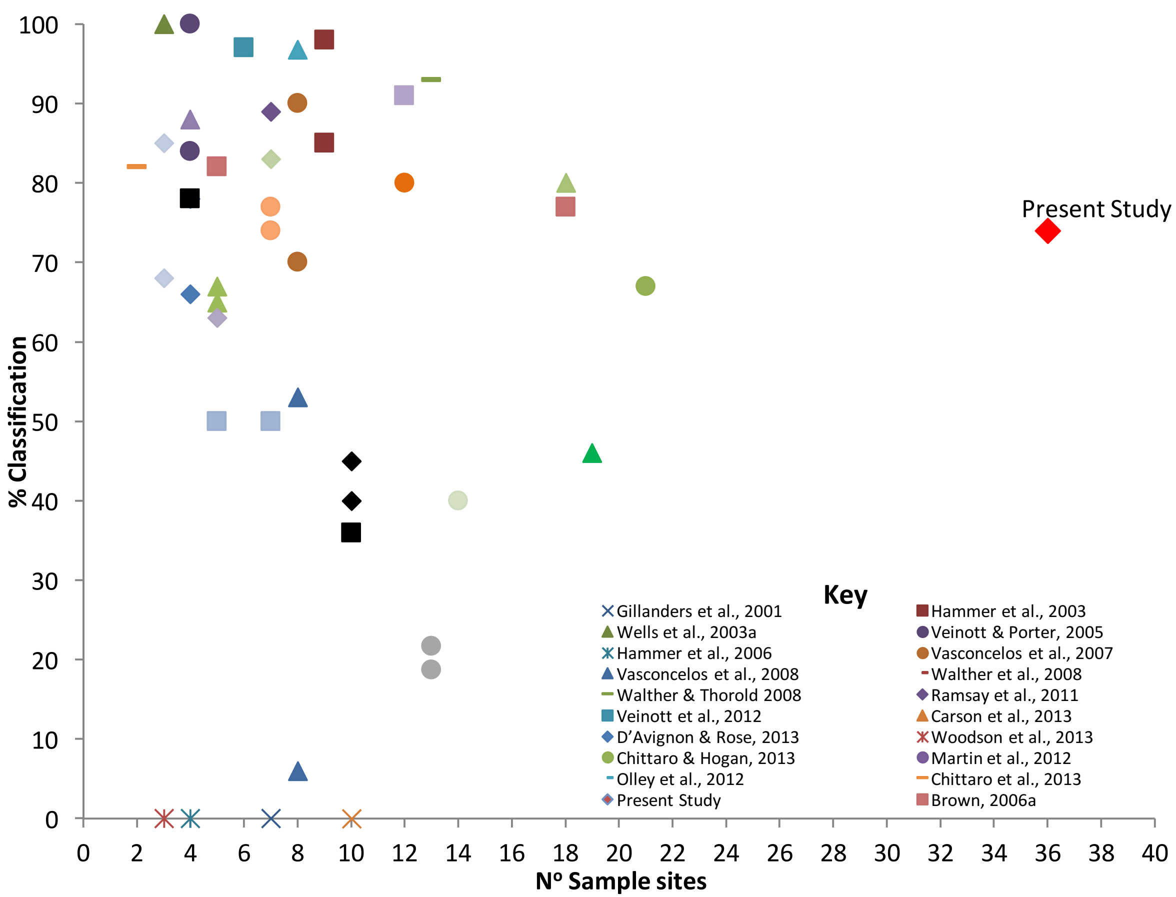


Figure 5.6.1 Summary of recently published data indicating number of sample locations/sites in regards to percentage classification success using discriminant function analysis and otolith element: Ca ratios.

5.6.3 Classification to Region Based on Biogeochemical Tags

In comparison to the river assignments (74%), regional classification accuracy was reduced to 66% when the 36 rivers were assigned to their respective sub-regions (see Table 5.5.8; 3-6 rivers per sub-region), with classification success ranging from 41% for North Wales to 91% for North Skerries (Table 5.5.8). Regional classification relied on the pooling of parr from a number of rivers to determine whether a strong regional chemical tag could be used to assign fish back to origin. The rationale for this was to determine whether the parr baseline could be used to assign marine-caught adults back to region of origin based on the microchemistry of the freshwater region of their otolith. However, a regional signal based on pooled data derived from 3-6 rivers per sub-region could produce a weaker "regional" signal as there will clearly be more catchments in each sub-region that contain *S. trutta* and produce sea trout. In addition, the distinct chemical signatures observed for some rivers exhibiting *ca.* 100% assignment could be masked or "diluted" by overlapping with other rivers in the sub-region to produce a more mixed (heterogeneous) chemical fingerprint which may have been represented in more than one of the sub-regions resulting in a reduced classification assignment. On reflection, a better sampling approach might have been to reduce the sample size per river and obtain otolith samples from more rivers per sub-region although in doing so this could have reduced the classification accuracy of fish back to their river of origin. In the present study, the effect of site-pooling (*e.g.* merging rivers to sub-regions) effectively reduced the classification accuracy for the trout parr. Similarly, Gillanders and Kingsford (2003) observed no improvement in assignment accuracy when multiple sites within each estuary were pooled by estuary for 3 species of fish. However, in some studies the effect of site-pooling has, conversely, been shown to improve classification accuracy (Fodrie and Herzka, 2008; D'Avignon and Rose, 2013). It is possible that pooling samples from a number of sampling sites that are closely co-located in the marine environment may produce a more homogeneous chemical signature compared to more distant sites due to tidal and current mixing of water. However in freshwater, sampling sites that are separated by <10 km can present distinctive chemical signatures as a result of the local geology and land use (*e.g.* Ramsay *et al*., 2011). In addition, reducing the number of potential sources to which a fish needs to be assigned can increase the number of individuals that are allocated correctly, and therefore the classification success, as a result of chance (see White and Ruttenberg, 2007)

5.6.4 Testing the baseline through "blind" assignment

As discussed in Section 5.6.2 using the element:Ca ratios of Mg, Mn, Sr and Ba in trout parr otoliths a biogeochemical base-line was produced where site-specific chemical signatures were observed between the 36 rivers included in the study. In order to test the robustness of this baseline, otoliths from trout parr collected from the same rivers used to establish the baseline were analysed and their putative origin assigned based on the existing freshwater parr baseline. In total 39 fish, randomly selected from the pool of unanalyzed otoliths were assessed and 27/39 fish were successfully allocated to their correct river of origin (Table 5.5.10). These results provide greater confidence in the base-line assignments recorded in the present study. To the authors' knowledge there have been no other studies using the same approach to assign "blind" run samples to source using a biogeochemical base-line, especially with such a large sampling data set covering a large geographical area.

5.6.5 Adult Classification: Microchemistry of The Marine Growth Phase of the Otolith

Classification success to the five marine zones of capture using the marine growth phase of the otolith for adult sea trout was poor with only 33% of adult trout correctly assigned to their capture zone using otolith concentrations of 7 elements: Na, Mg, K, Mn, Zn, Sn and Ba (Figure 5.6.2). However, although classification assignment was low, individual classification of adults caught from marine zones MZ-10 and MZ-06 indicated a classification accuracy of 47% and 38% respectively back to their zones of capture (see Table 5.5.14), with the remaining marine zones (MZs 13, 14, and 23) indicating a more mixed distribution of adult trout within each zone. The lack of distinct marine phase chemical tags between adult sea trout caught in each marine zone indicates that either (1) the water chemistry in the Irish Sea is fairly homogenous and the water within each marine zone does not have a distinctive chemical signature or (2) spatial heterogeneity in water chemistry may exist in the Irish Sea between some/all marine zones but individual sea trout undertake extensive feeding migrations around the Irish sea and thus the integrated signature obtained from the entire transect of the marine phase of the adult otolith does not share a strong similarity to the marine zone of capture.

The period of marine residency and marine movement patterns of sea trout are little understood with sea trout spending anything from a few months up to 3 years at sea before returning to spawn (Klemetsen *et al*., 2003). The distances travelled by individual fish are thought to be an energetic trade-off where they will only go as far as required to gain the maximum potential benefits from sea migration (Solomon, 2006). The actual movement patterns of sea trout within coastal and open (*i.e.* marine migration) water are little understood (Gargan *et al*., 2006). It has been assumed that movement patterns tend to be more localized, with most adult trout migrating no further than the coastal waters near to their natal river where they may return to overwinter (Gargan *et al*., 2006) and recent work would appear to confirm this assumption (Veinott *et al*., 2012). However, there can be considerable variation between individuals in terms of their life history strategy (*i.e.* how long they stay at sea and where they go; Klemetsen *et al*., 2003) and previous studies have shown that sea trout have the capacity to migrate longer distances (see Berg and Berg, 1987; Okumuş *et al*., 2006 and references therein) although most, would appear to refrain from doing so (Gargan *et al*., 2006; Veinott *et al*., 2012).

By ablating the last period of growth on the adult trout otolith it can be assumed that the most recently deposited aragonite will be measured to produce an estimate for any chemical signal derived from the most recently visited marine environment (see Veinott and Porter, 2005). If this assumption is correct for the adult trout otoliths from the present study then measurements of the marine growth signal have indicated a somewhat mixed biogeochemical signal. This could suggest extensive pan-Irish Sea migrations, however, the 'spatial homogeneity' hypothesis cannot be discounted as the water chemistry of the Irish Sea may be a relatively homogeneous environment with respect to its elemental composition (see Vincent *et al*., 2004) and as such adult sea trout may reside in a particular area of coastal water which may or may not be near to their natal rivers but no distinctive chemical tag may be deposited within the otolith (Thresher, 1999; Gillanders *et al*., 2001; Vasconcelos *et al*., 2007). Such an occurrence of this type of phenomenon has been suggested by Gillanders *et al*. (2001) who found a lack of elemental differences within the otolith chemistry of two-banded sea bream *Diplodus vulgaris* between locations sampled along the south-west coast of Spain. Spatial homogeneity in otolith chemistry was reported for fish sampled at different locations and the lack of differentiation between locations was suggested to be due to very few differences in water chemistry at these sites due to a lack of freshwater input from major rivers or from rainfall in the region (Gillanders *et al.*, 2001). Therefore, any environmental influences due to freshwater runoff and its effects on the ambient water chemistry (*e.g.* temperature, salinity and trace element concentrations) within the study area were considered to be minimal resulting in a more uniform biogeochemical signal.

5.6.6 Adult Classification: Microchemistry of the Freshwater Growth Phase of the Otolith

Based on previous work suggesting that adult sea trout remain in coastal waters close to their natal river and do not undertake extensive migrations (Gargan *et al*., 2006; Veinott *et al*., 2012), it would be expected that adult sea trout caught in a particular marine zone would classify to the sub-region adjacent to that marine zone based on the chemistry of the freshwater section of their otolith and using the freshwater parr baseline (see Figure 5.4.1 and Figure 5.4.2). For example, one would hypothesise that adult sea trout caught in MZ10 should classify back to SW Scotland and those caught in MZ6 should classify to one of the two sub-regions on the east coast of Ireland (north or south of the Skerries). However, based on this hypothesis overall classification accuracy was poor with only 17.5% correctly classifying to the sub-region(s) adjacent to their marine zone of capture (see Figure 5.6.3 and Table 5.6.2). There are several possible explanations for the poor assignment success of adult fish to the freshwater region adjacent to their marine zone of capture: (1) the freshwater baseline established in the present study may not be an accurate descriptor of the freshwater microchemistry signal for each sub-region, (2) issues of temporal stability may affect the accuracy of the freshwater microchemistry baseline or (3) the baseline may predict freshwater sub-region of origin and the results show that some adult sea trout may be undertaking more extensive migrations than previously thought.

5.6.6.1 Is the Baseline Accurate?

The results of the present study have shown that 74% and 66% respectively of the parr could be correctly classified back to their river and region of origin: given that the present study comprises one of the largest data sets in terms of geographical coverage and number of sources this is a high classification success. In addition, 69% of the fish in the "blind" allocation were also correctly assigned to their river of origin. In this study, the main sea trout producing rivers in each region were sampled, however, there are clearly more than 36 sea trout-producing streams/rivers in the Irish Sea region, a geographical area covering approximately 2,400 km of coastline (UK: Solomon, 1995; Harris; 2006; Ireland: McGinnity *et al*., 2003; Isle of Man: Anon, 2012). The exact number is not known and previous studies have tended to only identify the major catchments that are known to contain migratory salmonid populations (*i.e.* including Atlantic salmon or sea trout). For example, 261 discrete migratory salmonid producing rivers have been listed in Ireland (McGinnity *et al.*, 2003), over 80 rivers in the western UK (*i.e.* including south- west Scotland, north-west England and Wales; Solomon, 1995; Harris, 2006) and 8 major and 18 smaller rivers and tributaries found in the Isle of Man (Anon, 2012). In addition, it is important to note that small coastal streams can also be important and productive sea trout habitat (Jonsson *et al*., 2001; Klemetsen *et al.*, 2003) and so the true number of potential sources of sea trout in the Irish Sea region is likely to number in the hundreds. This phenomenon of unidentified systems not included in those sources contributing to the sampled data has been termed as "ghost" populations (see Veinott *et al*., 2012). It is important to note that a major restriction on the present study was the limitation placed on the number of fish that could be retained for otolith microchemistry. The licences to retain juvenile trout parr issued by the relevant agencies in the UK and Ireland only allowed a maximum of 25 parr to be killed from a limited number of rivers within the sampling area (*i.e.* the Irish and Celtic Seas). Therefore, because of the restrictions imposed, samples were only collected from the main sea trout producing rivers within each of the 10 sub-regions (also allowing for a good geographical spread) based on the assumption that these rivers would be more likely to be represented in any marine catches of adults. It should be noted that this could result in weak regional signals being observed. Although one must be aware of the potential limitations of the composition of the baseline, it must be stressed that high classification accuracy was achieved (despite the large number of source populations and large spatial scale of the study) and that it provides a suitable baseline against which to try to allocate marine-caught adult sea trout.

5.6.6.2 Is the Baseline Stable?

A second reason why adult sea trout caught in a particular marine zone may classify poorly to their adjacent freshwater sub-region could be due to temporal instability in the biogeochemistry of the freshwater baseline. Although they were not aged in the present study, the parr collected to establish the freshwater baseline in 2010 were likely to be 1 and 2 year old fish based on their size frequency distribution (see Table 5.4.1). This would mean that these fish were born in 2008 or 2009 and so the time period 2008-2010 would be included in the chemistry used to establish the freshwater baseline. Adult sea trout were caught in 2010-2012 (with the majority caught in 2010-11; see Table 5.4.2). It was not possible to age these fish within the timeframe of the present study in order to determine for each fish the period of time spent in freshwater and in the marine environment and so determine the calendar years when each fish was resident in freshwater. Therefore, it is possible that some fish may have been resident in freshwater pre-2008, although it is thought that this is unlikely as given the size of the sea trout most fish are likely to have spent 1-3 years at sea prior to capture. However, previous studies have shown that although long term temporal stability in chemical tag may not occur, temporal stability between consecutive years is often present (Rooker *et al*., 2001; Gillanders, 2002; Kerr *et al*., 2007; Walther *et al*., 2008; Marriott, 2013). Therefore, it is likely that even if the freshwater residency period for some marine-caught adults does not include the calendar years 2008-2010 (*i.e.* they migrated to sea prior to 2008) then they would have been resident in freshwater in the years immediately preceding (*i.e.* 2006-2007) and temporal stability is more likely to be present. Therefore, it is concluded that temporal instability of the freshwater baseline is unlikely to explain the poor classification of adult sea trout caught in a given marine zone to the adjacent freshwater sub-region.

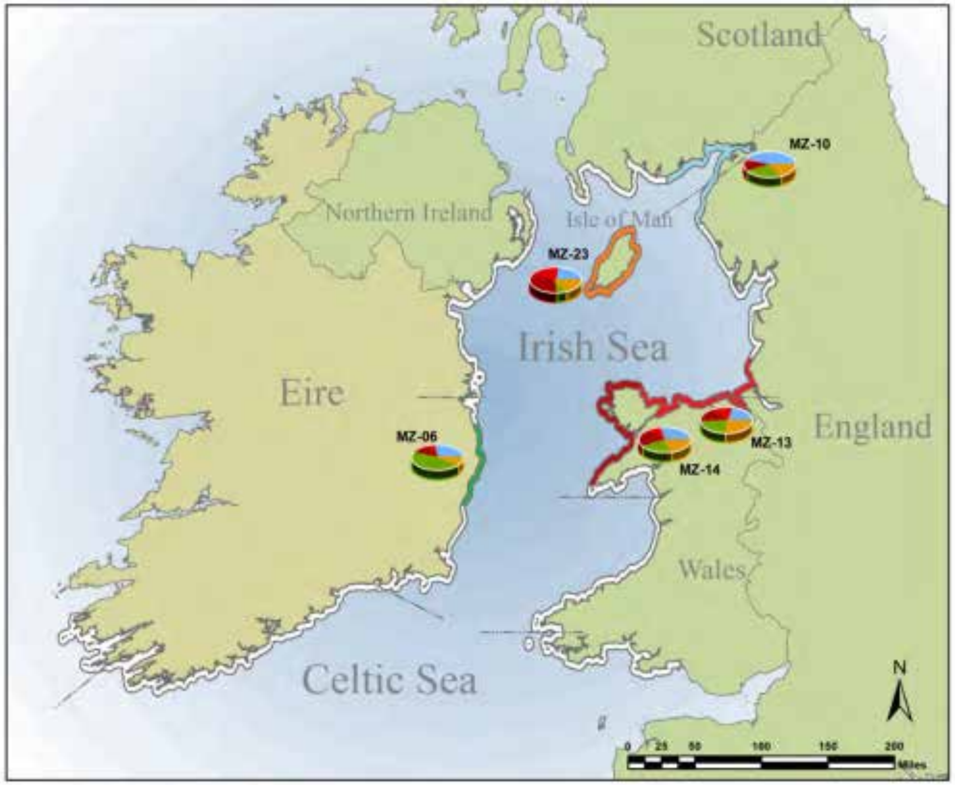


Figure 5.6.2 Map of the Irish Sea indicating the 5 marine zones sampled for adult sea trout *S. trutta*. Adult sea trout were assigned to their marine zone of capture using CV-QDFA and the Log_{10} elements Na, Mg, K, Mn, Zn, Sn and Ba in the marine phase of the otolith. Pie chart segments represent each of the 5 marine zones.

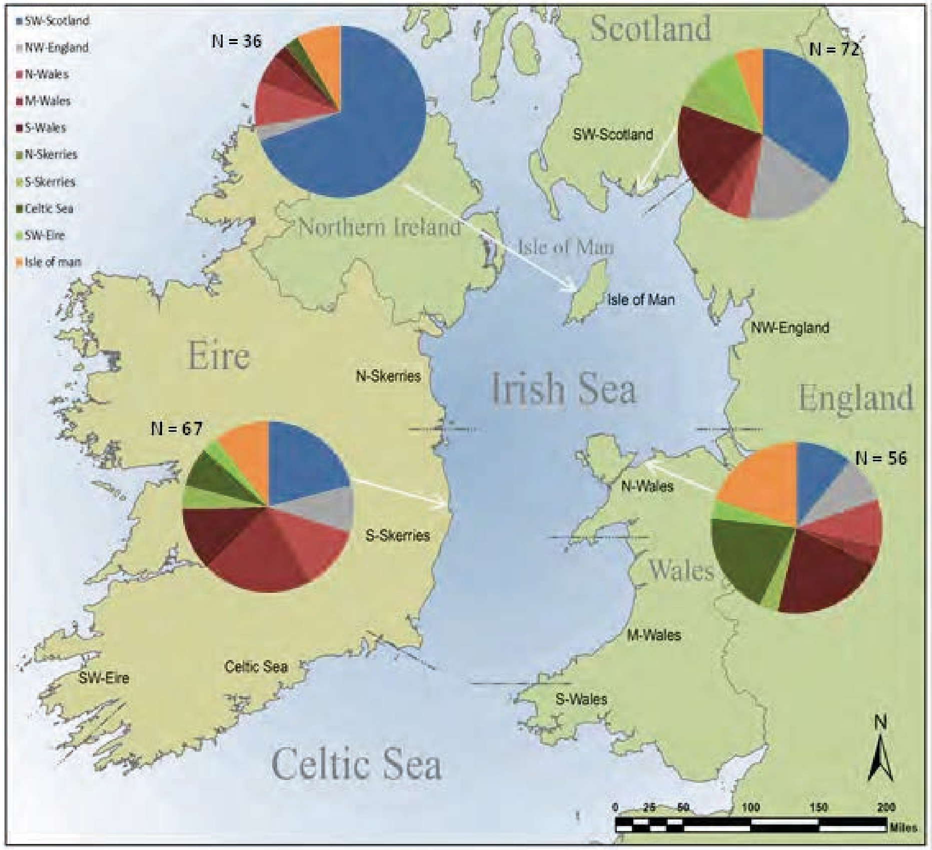


Figure 5.6.3 Classification accuracy of marine caught adult sea trout to their sub-region of origin using the freshwater parr base-line created from Mg, Mn, Sr and Ba. Pie charts indicate sub-region to which adult trout were assigned using their freshwater residency period (see Table 5.4.1).

5.6.6.3 *Are Some Sea Trout Migrating Further than Previously Thought?*

Based on previous work which suggested that adult sea trout tend to remain in coastal waters close to their natal rivers to feed (Pemberton, 1976; Elliott, 1994; Knutsen *et al.*, 2001; Klemetsen *et al.*, 2003; Jonsson and Jonsson, 2011; Jensen and Rikardsen, 2012), it was hypothesized in the present study that fish caught in a particular marine zone would classify back to the freshwater sub-region adjacent to that marine zone. For example, fish caught in MZ10 would tend to classify back to southwest Scotland and fish caught in MZs 13 and 14 would tend to classify back to north Wales. If this assumption is correct then the classification from marine zone to adjacent freshwater sub-region was poor at 17% (Table 5.22). However, if the classification to freshwater sub-region of origin is correct then the results suggest that some adult sea trout may be undertaking more extensive migrations than previously thought.

Table 5.6.2 reinterprets the classification data presented in Table 5.5.17 to determine what percentages of fish putatively derived from each freshwater sub-region are captured in each Marine Zone. Using these data it is possible to derive the putative movement patterns within the Irish Sea for fish from each freshwater sub-region and these are presented in Figure 5.26 for sub-regions where the sample size of fish is ca. 20 or larger and presents the movement patterns where ≥ 20% of the fish are caught in a given marine zone. The data presented in Table 5.29 and Figure 5.26 would indicate that the movement patterns of adult sea trout in the Irish Sea could be more extensive than suggested from earlier studies where fish tended to remain in coastal waters close to their river of origin (Pemberton, 1976; Elliott, 1994; Knutsen et al., 2001; Klemetsen et al., 2003; Jonsson and Jonsson, 2011; Jensen and Rikardsen, 2012). The movement patterns of adult sea trout putatively derived from SW-Scotland (Figure 5.26A) indicated shorter migratory patterns with most adults remaining within the coastal waters of the Solway (36%) or migrating to the coastal waters off the Isle of Man (36%), a distance of approximately 76 km (calculated as a linear distance, see Table 5.30). However, some distances were more extensive with 20% of adults from SW-Scotland migrating to the east coast of Ireland, a linear distance of some 238 km.

Similar results could be observed for adults from the Isle of Man with 28% indicating a similar movement pattern to Ireland (a distance of 162 km) and 44% to North Wales (122 km) (see Figure 5.6.4A, Table 5.6.2 and Table 5.6.3). In contrast, more extensive patterns of migration could be inferred for adult fish putatively derived from the Southern Irish Sea regions (Figure 5.6.4B). Adult sea trout from South Wales appeared to exhibit extensive patterns of migration, with 23% of adults travelling a 117 km linear distance to the South Skerries region (MZ6) and 34% travelling 157 km to the coast of North Wales (Table 5.6.2). The longest linear distance recorded for a putative adult sea trout migration was approximately 355 km from South Wales to the Solway Firth marine zone (Figure 5.6.4B, Table 5.6.2 and Table 5.6.3). For adult sea trout putatively derived from North West England, 52% appeared to migrate to South West Scotland (a linear distance of 71 km), 20% moved into the coastal waters of North Wales (127 km) and 24% of adults were caught into the coastal waters off the South East coast of Ireland (a linear distance of 167 km) (Figure 5.6.4B, Table 5.6.2 and Table 5.6.3).

Table 5.6.2 QDFA Predicted Classification of adult marine caught sea trout *Salmo trutta* using the freshwater growth phase to their region of origin from the biogeochemistry baseline established using Mg, Mn, Sr and Ba. Adult fish were assigned based on the probability of belonging to a particular region. Correct numbers of parr per region are shown with percentage classification of sub-region to marine zone (row total %) highlighted in bold. MZ-13 and MZ-14 are combined. Sub-regions highlighted represent the colours used to indicate the movement patterns of fish in Figure 5.6.4.

	Marine Zone				
Sub-Region	**MZ-10**	**MZ-13-14**	**MZ-06**	**MZ-23**	**Row Total**
SW-Scotland	25 (**36%**)	6 (**9%**)	14 (**20%**)	25 (**36%**)	70
NW-England	13 (**52%**)	5 (**20%**)	6 (**24%**)	1 (**4%**)	25
N-Wales	3 (**16%**)	5 (**26%**)	8 (**42%**)	3 (**16%**)	19
M-Wales	3 (**14%**)	2 (**10%**)	14 (**67%**)	2 (**10%**)	21
S-Wales	14 (**40%**)	12 (**34%**)	8 (**23%**)	1 (**3%**)	35
N-Skerries					0
S-Skerries	5 (**50%**)	2 (**20%**)	3 (**30%**)		10
Celtic Sea		11 (**65%**)	5 (**29%**)	1 (**6%**)	17
SW-Eire	5 (**56%**)	2 (**22%**)	2 (**22%**)		9
Isle of man	4 (**16%**)	11 (**44%**)	7 (**28%**)	3 (**12%**)	25

Table 5.6.3 Calculated linear distances (in km) of adult sea trout *Salmo trutta* putative movement patterns within the Irish Sea for fish from each freshwater sub-region.

Region	**Assigned Region**	**Linear distance (km)**
SW-Scotland	Isle of man	76
	S-Skerries	238
NW-England	SW-Scotland	71
	N-Wales	127
	S-Skerries	167
N-Wales	S-Skerries	39
M-Wales	S-Skerries	50
S-Wales	SW-Scotland	355
	N-Wales	157
	S-Skerries	117
Celtic Sea	N-Wales	159
	S-Skerries	120
Isle of man	N-Wales	122
	S-Skerries	162

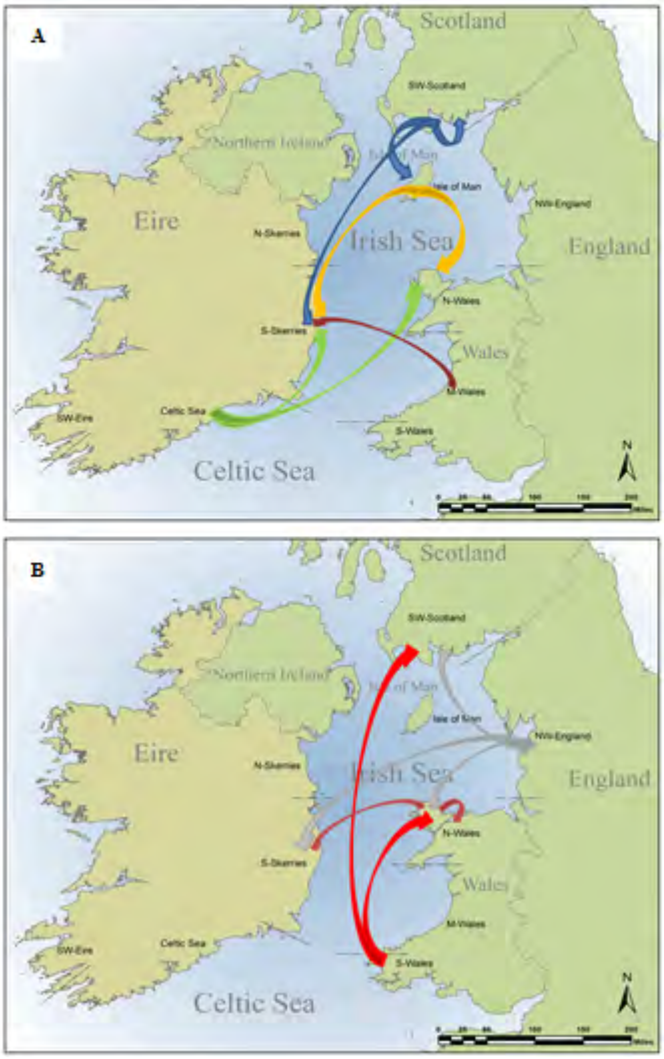


Figure 5.6.4 Estimated putative movement patterns of adult sea trout *Salmo trutta* within the Irish Sea for fish from each of the freshwater sub-regions using the QDFA classification data presented in Table 5.6.2. Data is taken where sample size is *ca.* 20 or larger and where ≥ 20% of adult fish were caught in a given marine zone. Arrows are colour coded to identify sub-region (see Table 5.6.2).

5.6.7 Assessing Marine Movement Patterns Using Scale Stable Isotope Chemistry

In the present study, the scale stable isotope chemistry of in-river caught adult sea trout was studied in order to determine whether there were differences in the $\delta^{15}N$ and $\delta^{13}C$ isotope chemistry between fish from different Irish Sea catchments which would be suggestive of these fish feeding in isotopically-distinct parts of the Irish Sea. This isotopic approach has recently been adopted (*e.g.* Mackenzie *et al.*, 2011) as one tool in the portfolio of techniques used to try to trace the movement patterns of fishes in the marine environment (*e.g.* Graham *et al.*, 2010; Cooke *et al.*, 2011 Cadrin *et al.*, 2013). The analytical approach adopted in this study involved cleaning scales and removing the last summer growth section under low power binocular microscopy for CFC-IRMS analysis. This work was extremely time-consuming and as a result it was only possible to clean, cut and analyse scales from 58 fish collected from UK rivers on the eastern side of the Irish Sea within the timeframe available in the study with small sample sizes (5 – 8 fish) for most rivers.

Preliminary calibration work was conducted to determine the minimum sample mass required for analysis and the repeatability of the measurement to determine whether a single measurement from each fish would provide a representative "signal" for the scale $\delta^{15}N$ and $\delta^{13}C$ isotope chemistry. Previous studies that have measured ^{15}N and ^{13}C stable isotope ratios in scales to look at feeding ecology or movement patterns have usually used between 0.6 mg and 1.5 mg of scale material (*e.g.* Mackenzie *et al.*, 2011; Quinn *et al.*, 2012, Trueman *et al.*, 2012b; 1.5 mg, Sinnatamby *et al.*, 2008; Hammond and Savage, 2009, Ramsay *et al.*, 2012) although recent work has utilized as little as 0.2 mg (Roussel *et al.*, 2014). The calibration work in the present study, using the instrumentation at NOC Southampton (a GV Instruments Isoprime IRMS) showed that a sample mass of *ca.* 0.6 mg was required for isotopic analysis (see Table 5.23, Figure 18) as has been used for earlier scale isotope studies using this instrumentation (MacKenzie *et al.*, 2011; Trueman *et al.*, 2012b). The isotopic data exhibited a very high repeatability for both carbon (r = 0.95) and nitrogen (r = 0.99) with no differences between the two repeat measures (see Figure 5.19). This is to be expected as the large numbers of scales necessary to obtain a sample mass of *ca.* 0.6 mg would, by default, provide an accurate measure of the $\delta^{15}N$ and $\delta^{13}C$ isotope chemistry of the scales for each fish. It was found that regrowth scales provided a suitable source of material for isotopic analysis (see Figure 5.5.16). This is a promising result since it removes the potential conflict between the use of scales for determining age and growth patterns (which require intact scales and are often archived as a historical record) and for isotopic analysis to study feeding ecology and movement patterns (requiring a destructive approach for isotopic analysis). Therefore regrowth scales, which to date have often been deemed "unusable" due to their incomplete record of age and growth do have the potential to be used for scale isotope analysis. Also, if the regrowth has occurred within the recent lifetime of the fish, and if a larger proportion of the scale has been regrown within the time period of study interest, it may present more material available for use in isotopic analysis thereby reducing the number of scales that are required.

The scale isotopic analysis in the present study showed regional variation in $\delta^{15}N$ signature with returning in-river caught adult sea trout from the Solway Firth and Liverpool Bay rivers tending to have $\delta^{15}N$ values above 14.5‰ whilst adults from Cardigan Bay and South Wales had $\delta^{15}N$ values below 14.5‰ (Figure 5.5.17 and Figure 5.5.18). In contrast, there were little regional differences (*i.e.* overlap) in $\delta^{13}C$ signatures between fish from the different rivers/regions (Figure 5.5.17 and Figure 5.5.18). These results reflect the same patterning seen in the spatial variation of $\delta^{15}N$ and $\delta^{13}C$ isotope signatures in scallop adductor muscle observed in the Irish Sea by Jennings and co-workers (Jennings and Warr, 2003; Barnes *et al.*, 2009) and presented in Figure 5.6.5 and Table 5.6.4. In their study, Jennings and co-workers sampled queen scallop *Aequipecten opercularis* from 42 different sites in the coastal shelf seas around the UK and measured the $\delta^{15}N$ (Jennings and Warr, 2003) and $\delta^{13}C$ (Barnes *et al.*, 2009) in the adductor muscle. Both isotopic signatures were related to one or more environmental variables, such as depth, salinity, surface and bottom temperature, and linear models were used to predict scallop $\delta^{15}N$ and $\delta^{13}C$ isoscapes in the North Sea, English Channel and Irish Sea (Figure 5.6.5). These data show clearly that scallop $\delta^{15}N$ is enriched (i.e. higher) in the Eastern Irish Sea compared to other regions of the Irish Sea (Figure 5.6.5a; Table 5.6.4).

(a) (b)

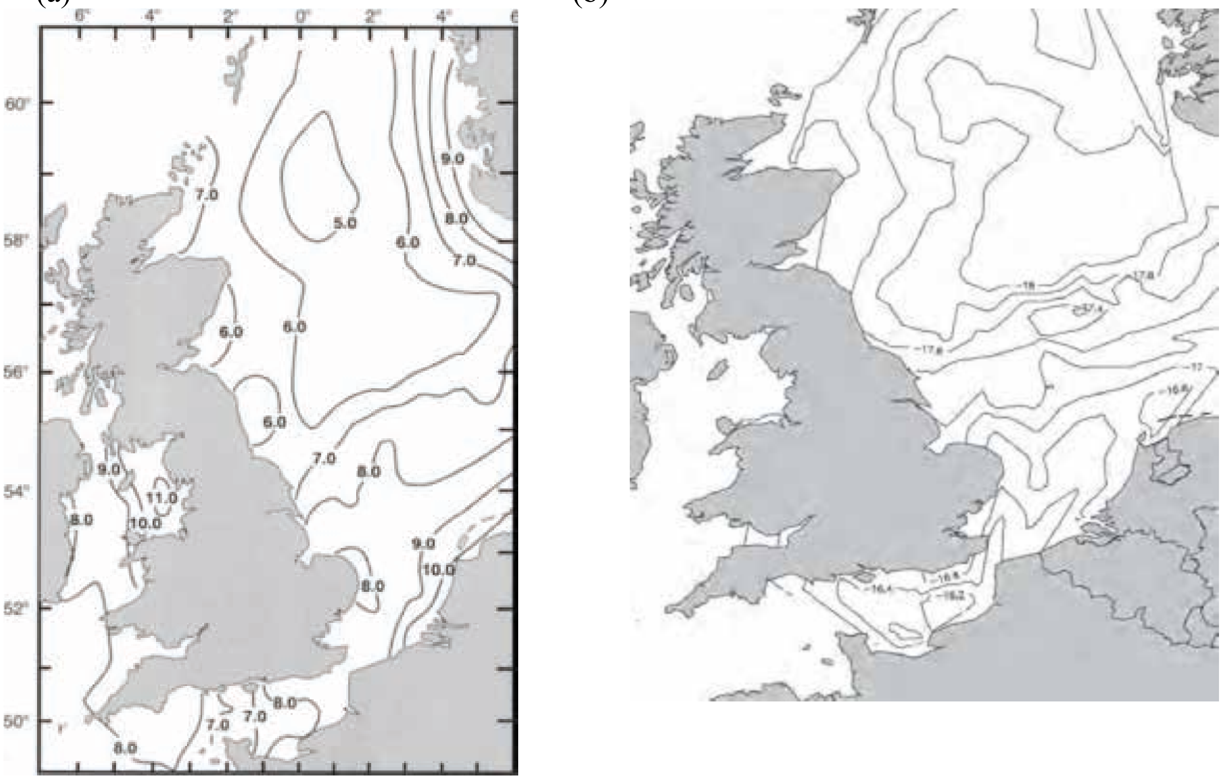


Figure 5.6.5 Predicted spatial variation in (a) δ15N and (b) $\delta^{13}C$ in the adductor muscle of the queen scallop *Aequipecten opercularis* in the North Sea, Celtic Sea and English Channel. [Taken from (a) Jennings and Warr (2003) and (b) Barnes *et al.,* 2009].

Table 5.6.4 δ^{15}N and δ^{13}C values for queen scallop *Aequipecten opecularis* and dab *Limanda limanda*, whiiting *Merlangius merlangus* and sea trout *Salmo trutta* in different regions of the Irish Sea. δ^{15}N and δ^{13}C values are presented as mean values ± sd. Data for dab and whiting are calculated from data provided in Jennings and Warr (2003) and Barnes *et al.* (2009).

Region		Trophic level[3]	δ^{15}N (‰)	δ^{13}C (‰)
Solway Firth and Cumbria	Scallop	2.0	9.52 ± 0.37	-16.30
	Dab	3.5	14.79 ± 0.67	-17.78 ± 0.69
	Whiting	4.21	16.09 ± 1.05	-17.91 ± 0.45
	Sea trout	4.45	14.92 ± 0.65	-14.56 ± 0.33
Liverpool Bay	Scallop	2.0	9.56 ± 1.15	-16.85 ± 0.62
	Dab	3.5	15.74 ± 1.26	-16.99 ± 1.19
	Whiting	4.21	15.96 ± 1.31	-17.23 ± 0.46
	Sea trout	4.45	15.51 ± 1.23	-14.64 ± 1.01
Central Irish Sea[1]	Scallop	2.0	8.01 ± 0.21	-16.45 ± 0.73
	Dab	3.5	13.59 ± 2.30	-15.89 ± 1.46
	Whiting	4.21	14.35 ± 0.96	-16.94 ± 0.49
Western Irish Sea[2]	Scallop	2.0	8.00 ± 0.85	---
	Dab	3.5	12.71 ± 0.70	-16.52 ± 1.05
	Whiting	4.21	---	---
Cardigan Bay	Scallop	2.0	8.31 ± 0.42	-17.57 ± 0.41
	Dab	3.5	13.48 ± 0.37	-17.30 ± 0.51
	Whiting	4.21	---	---
	Sea trout	4.45	13.93 ± 1.17	-14.73 ± 0.93
South Wales	Scallop	2.0	7.88 ± 0.65	-16.24
	Dab	3.5	12.56 ± 0.28	-15.40 ± 0.44
	Whiting	4.21	14.29 ± 0.67	-16.14 ± 0.80
	Sea trout	4.45	12.82 ± 0.60	-14.84 ± 0.42

Note: 1 - The Central Irish Sea region is defined as the central section of the Irish Sea running south east from the Isle of Man to St George's Channel. Note 2 - the Western Irish Sea region corresponds to the coastal region off the east coast of Ireland. Note 3 - trophic level values are average values from data presented in Araújo et al. (2005), Lees and Mackinson (2007), Mackinson and Daksalov (2007), Ciancio *et al.*, (2008) and Froese and Pauly (2011).

In order to test the accuracy of their modelled baseline isoscapes, Jennings and co-workers collected demersal fish, dab *Limanda limanda* and whiting *Merlangius merlangus,* from various locations within the North Sea, English Channel and Irish Sea and measured δ^{15}N and δ^{13}C in white muscle tissue (Jennings and Warr, 2003; Barnes *et al.*, 2009). Their results showed that predicted baseline δ^{15}N and δ^{13}C values were highly correlated with dab and whiting muscle δ^{15}N and δ^{13}C and that accounting for spatial differences in baseline δ^{15}N reduced the variability in trophic level estimation based on muscle δ^{15}N isotopic analysis. Having shown that (a) there is spatial variation in baseline δ^{15}N in the Irish Sea and (b) that δ^{15}N signatures of fish in the Irish Sea also exhibit spatial variation and, after enrichment as a result of increased trophic level, correlate significantly (all $P < 0.001$) with baseline values, it is possible to examine the regional differences in δ^{15}N and δ^{13}C of fish within the Irish Sea and to compare these with the data obtained from isotopic analysis of sea trout scales in the present study. The average δ^{15}N and δ^{13}C values for the scallop baseline and for dab and whiting in different regions of the Irish Sea are presented in Table 5.6.4 and Figure 5.6.6. The same regional patterning in δ^{15}N values observed in the scallop data is also apparent in the regional fish δ^{15}N values with higher δ^{15}N values observed in the Eastern Irish Sea (Solway Firth and Cumbria and Liverpool Bay regions; Table 5.6.4, Figure 5.6.6). Unfortunately, the Irish Sea was not included in the ^{13}C isoscape map produced by Barnes *et al.* (2009), although this may be because the data suggests very little spatial variation in scallop δ^{13}C values in the Irish Sea with the exception of Cardigan Bay (Table 5.6.4). The relationship between latitude (*i.e.* capture location) and muscle δ^{15}N signature for the dab and whiting samples collected by Jennings and Warr (2003) are presented in Figure 5.6.6 together with the sea trout scale $\delta^{15}N$ signatures measured in the present study. This plot shows a similar geographical variation in $\delta^{15}N$ values for the three fish species despite the differences in the tissue measured (white muscle vs. scale) trophic level and a 10 year difference in capture time (2001 *vs.* 2010-11).

As predicted from the Jennings and Warr (2003) isoscape, fish from the eastern Irish Sea tend to have higher $\delta^{15}N$ values compared to those fish captured in the western or southern Irish Sea (Figure 5.28), although the relative positioning of $\delta^{15}N$ values is dependent on trophic level (TL) with dab (TL = 3.5; Table 5.6.4) tending to have lower $\delta^{15}N$ values compared to whiting (TL = 4.21; Table 5.6.4). This is as a result of an increase in $\delta^{15}N$ with increasing trophic level as a result of diet-tissue isotope discrimination (previously known as fractionation) (Caut *et al.*, 2009). It is interesting to note that both whiting and sea trout which feed at a similar trophic level (whiting 4.21 vs. sea trout 4.45; Table 5.6.4) exhibit similar $\delta^{15}N$ values (Table 5.6.4; Figure 5.6.6) despite a 10 year difference in sampling time suggesting a degree of temporal stability in the Irish Sea isoscape. It should be noted that different tissues were sampled in the dab/whiting (white muscle) and sea trout (scales). Previous work by Sinnatamby *et al.* (2008) has shown significant differences in $\delta^{15}N$ values between muscle and scale in Atlantic salmon *Salmo salar*, however, values for the two tissues in adult salmon differed by about 1 ‰ (muscle, 12.74 ± 0.45 (sd) ‰; scale, 11.60 ± 0.51 (sd) ‰). Comparing the differences in whiting muscle $\delta^{15}N$ values and the sea trout scale $\delta^{15}N$ values (*i.e.* the two species feeding at a similar tgrophic level), an average difference of 1.03 ‰ (range 0.45 – 1.47 ‰; seeTable 5.6.4) was observed between the isotopic values for the two tissues.

The last 10 years has seen an increase in the use of isoscapes to track the movement patterns of fishes within freshwater (*e.g.* Kennedy *et al.*, 2005; Barnett-Johnson *et al.*, 2008; Muhlfield *et al.*, 2012 and Martin *et al.*, 2013a and 2013b) and marine habitats (see reviews by Graham *et al.*, 2010; Trueman *et al.*, 2012a and McMahon *et al.*, 2013). Marine isoscape/movement studies have tended to focus on the large-scale, *i.e.* pan-oceanic, movement of large apex predators such as marine mammals (Newsome *et al.*, 2010; Gimenez *et al.*, 2013), turtles and scombrids (Ménard et al., 2007; Rooker et al., 2008; Graham *et al.*, 2010). Due to their large-scale geographical coverage, large spatial variations in isotopic concentrations have been determined. For example, modelled global spatial variation in otolith $\delta^{18}O$ signatures in fish otoliths (based on global surface water $\delta^{18}O$ values) are reported to range between -8 ‰ and 4 ‰ (Trueman et al., 2012a). McMahon *et al.* (2013) present modelled isoscapes in the Atlantic Ocean for surface seawater $\delta^{18}O$ (O_{SW}) and zooplankton (ZPL) $\delta^{13}C$ and $\delta^{15}N$ values which range between -15 ‰ and 2.5 ‰ (O_{SW}), -30 ‰ and -30 ‰ ($^{13}C_{ZPL}$) and 0 ‰ and 12 ‰ ($^{15}N_{ZPL}$) respectively. Such spatial variation can facilitate the tracking the origins and movement patterns of animals within the modelled isoscape for marine animals that undertake large-sclae geographic movements. In the present study, a combination of limited geographical coverage of rivers assessed (due to time-constraints in sample preparation for analysis) and limited spatial variation in the $\delta^{15}N$ and $\delta^{13}C$ Irish Sea isoscapes (Figure 5.6.5) limits the conclusions that can be drawn about the putative movement patterns of adult sea trout during their marine feeding migration. However, although the samples sizes are small for each river (see Table 5.4.3), the $\delta^{15}N$ results of the scale stable isotope analysis would suggest that most of the in-river caught adult sea trout fish sampled in this study from the eastern Irish Sea rivers spent the last period of marine feeding within the eastern Irish Sea. However, Figure 5.5.18 does suggest that some of the fish may be undertaking more extensive movements based on their scale $\delta^{15}N$ signature.

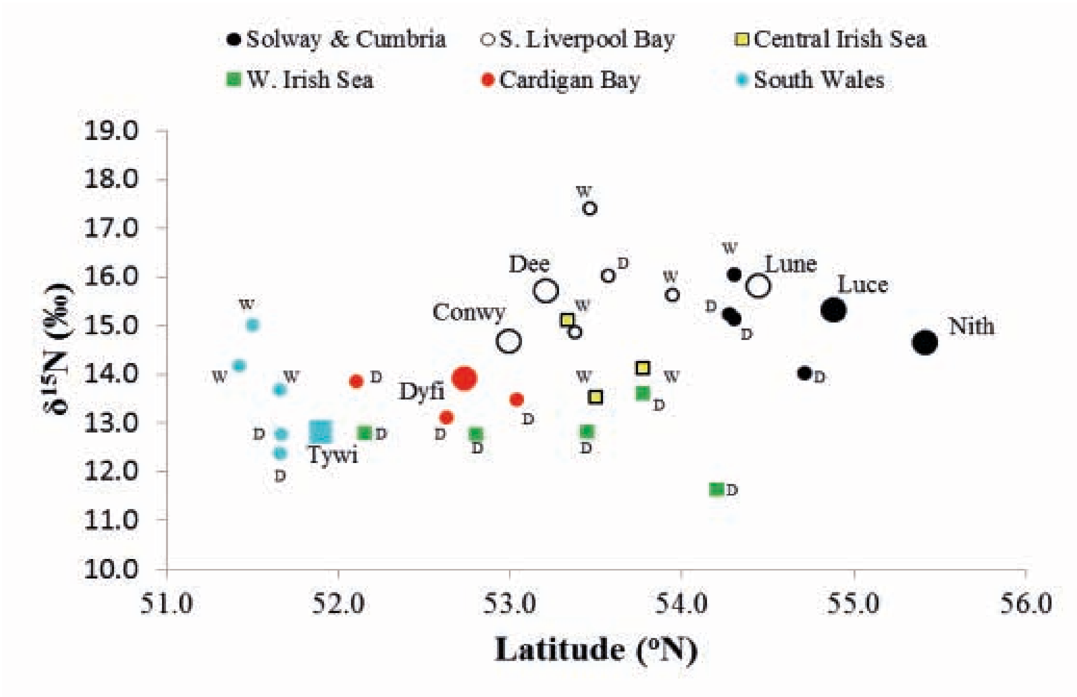


Figure 5.6.6 Latitudinal differences in average $\delta^{15}N$ (‰) values of dab *Limanda limanda* (indicated on plot by letter D; Trophic level (TL) = 3.5), whiting *Merlangius merlangus* (indicated on plot by letter W; TL = 4.21) and adult in-river caught sea trout *Salmo trutta* (indicated on plot by large symbols and river of origin; TL = 4.45) from different regions of the Irish Sea. $\delta^{15}N$ values for dab and whiting are derived from white muscle and from scales for sea trout. Dab and whiting samples were collected in measured in 2001 (derived from Jennings and Warr, 2003). Sea trout data are from the present study for fish collected in 2010-2011. Trophic level values are average values from data presented in Araújo et al. (2005), Lees and Mackinson (2007), Mackinson and Daksalov (2007), Ciancio *et al.*, (2008) and Froese and Pauly (2011). Latitude value corresponds to capture location.

5.6.8 Synthesis: Integrating the Different Internal Tags to Determine the Movement Patterns of Adult Sea Trout in the Irish Sea

In the present study, two internal bigeochemical tags, otolith microchemistry and scale stable isotope chemistry, were used to try to determine the movement patterns of adult sea trout within the Irish Sea based on the assumption that contemporaneously sampled individuals that exhibit differences in otolith or scale chemistry are likely to exhibit spatial segregation at sea. Taken together, the results of the present study indicate that some sea trout may undertake extensive movements within the Irish Sea. However, it is important to note that for the marine-caught fish it is only possible to identify location of capture and putative freshwater region of origin and the linear distance between these two locations and it is not possible to identify the actual migration route for each individual or to indicate the period(s) of time spent by individuals in chemically-distinct bodies of water. Also, due to the sample sizes of marine-caught fish used for otolith microchemisry (n = 231) and scale isotope chemistry (n = 58) in this study, it is important to highlight that the results should be used to indicate the extent of the putative movement patterns within the Irish Sea for *Salmo trutta* from the different freshwater sub-regions and should not be used to determine the proportions of fish within each region that migrate to different areas of the Irish Sea.

The more extensive movement patterns suggested from the otolith microchemistry data are supported by the individual assignment results for the marine-caught adult sea trout based on the genetic analysis of microsatellite markers in Task 4 of the Celtic Sea Trout project. The microsatellite data collected from fry/parr sampled from >100 rivers indicated that *Salmo trutta* in the Irish Sea region consist of 9 regional populqtions (Table 5.6.5). Although these 9 regional populations are not exactly the same as the 10 geographic sub-regions adopted in the present study they are sufficiently similar (*i.e.* there are 7 regional groupings that are common to both studies and the remaining 3 geographic sub-regions are grouped as one genetic regional population; Table 5.6.5) to examine the general movement patterns of sea trout in the Irish Sea. Despite the differences approach and sample size, both assignment techniques reveal that the extent of the putative movement patterns for adult sea trout from different freshwater regions within the Irish Sea are similar (Table 5.6.5). These can be summarized as follows:

- Sea trout from the eastern Irish Sea region, *i.e.* north Wales, northwest England and southwest Scotland, appear to remain in the eastern Irish Sea (*i.e.* between Liverpool Bay and the Solway Firth) or migrate to the Isle of Man or the East Coast of Ireland. Similar putative movement patterns were observed using both techniques, with the exception that movement into Manx coastal waters is only suggested by the microchemistry data.

- Sea trout from the Isle of Man appear to stay in Manx waters (as indicated by the genetic data) or move southeast to the coastal waters of north Wales (as indicated by the microchemistry data) or move southwest to the east coast of Ireland (as indicated by both techniques).

- Sea trout from mid Wales appear to move across the Irish sea to the east coast of Ireland (as indicated by both techniques). [Note that sample sizes for this region are very small].

- Sea trout from South Wales appear to either move across the Irish Sea to the east coast of Ireland or undertake extensive movements into the eastern Irish Sea (as indicated by both techniques). [Note that sample sizes for this region are very small].

- Sea trout from rivers on the southern coast of Ireland appear to move up the east coast of Ireland or undertake more extensive movements into the Eastern Irish Sea (Liverpool bay, Solway Firth) (as indicated by both techniques).

- Sea trout from the east coast of Ireland either remain in the coastal waters of the east coast or Ireland or move into the eastern Irish Sea (as indicated by the genetic data).

- Sea trout from Northern Ireland either remain in the coastal waters of the east coast or Ireland or move into the eastern Irish Sea (as indicated by the genetic data).

The putative movement patterns of adult sea trout within the Irish Sea summarised above may be the result of the adult fish following the main surface water currents and utilising these currents to assist in shoreward migration. Sea surface currents for the Irish Sea tend to travel up from the south and circulate clock-wise around the inshore coastal waters of North Wales and South-West England (Figure 5.6.7). Surface waters from south west Scotland however, tend to show an anti-clock-wise directional movement and indicate waters tend to flow along the coast of Ireland (Lee and Ramster, 1981; Dickson, 1987; Humphries, 2004).

Previous studies have shown that it is not uncommon for salmonids to use surface water currents to assist in migration in the marine environment. For example, surface currents are thought to assist the migrations patterns of Pacific salmonids in the north east (*e.g.* sockeye salmon *Oncorhynchus nerka*; Thomson *et al*., 1992) and northwest Pacific (*e.g.* chum salmon *Oncorhynchus keta*; Groot and Margolis, 1991). Similar observations have been recorded for post-smolts of Atlantic salmon (*Salmo salar*) by Holm *et al*. (2000) who observed that post-smolts were found to follow the main surface currents northward towards the Norwegian Sea and the recent SALSEA-MERGE project has also modelled how surface water currents aid in the movement patrens of post-smolt salmon at sea (SALSEA-MERGE, 2012). In addition, a recent study by Lacroix (2013) with the aid of pop-up satellite archival tags identified changes in oceanic migration of Atlantic salmon kelts transported using the North Atlantic current from three distinct Canadian populations.

Table 5.6.5 A summary of the putative movement patterns of adult sea trout *Salmo trutta* in the Irish Sea based on the assignment to freshwater sub-region of origin using genetic microsatellite analysis (Celtic Sea Trout Project Task 4 report) or the otolith microchemistry (Mg, Mn, Sr and Ba) of the freshwater region of the sagittal otolith (this study).

Microsatellite analysis	**N = 1,200**	**Microchemistry analysis**	**N = 231**
Sub-Region of origin	Sub-Region of capture	Sub-Region of origin	Sub-Region of capture
South West Scotland + North West England + North Wales	South West Scotland > North West England > East coast of Ireland	South West Scotland	South West Scotland = Isle of Man > East coast of Ireland
		North West England	South West Scotland > East coast of Ireland = North Wales
		North Wales	North Wales = East coast of Ireland
Mid Wales	East coast of Ireland > South West Scotland	Mid Wales	East coast of Ireland
South Wales	South West Scotland > North West England > East coast of Ireland	South Wales	South West Scotland > North Wales > East coast of Ireland
Isle of Man	Isle of Man > North West England > East coast of Ireland	Isle of Man	North Wales > East coast of Ireland
Northern Ireland	Northern Ireland = South West Scotland > East coast of Ireland		Not part of the microchemistry freshwater baseline
North East Ireland	Little data, no clear patterns	North of Skerries	Small sample size from baseline assignment, not assessed
South East Ireland	East coast of Ireland > South West Scotland > NW England	South of Skerries	Small sample size from baseline assignment, not assessed
Southern Ireland	South West Scotland > East coast of Ireland > South Ireland > North West England	Celtic Sea	North Wales > East coast of Ireland
Currane	No fish assigned to this sub-region	Currane	Small sample size from baseline assignment, not assessed

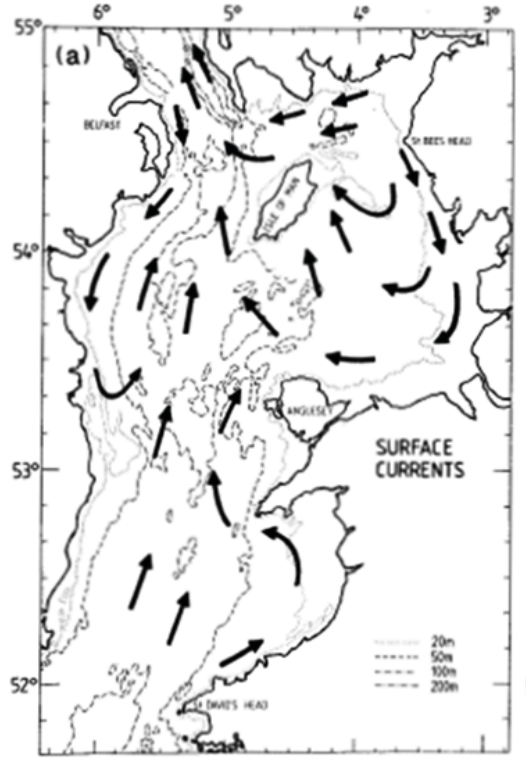


Figure 5.6.7 Map indicating the near sea surface current directional flow within the waters of the Irish Sea. (Taken from Dickson, 1987)

5.6.9 Concluding Comments

The results of this study have provided novel information on the otolith / scale chemistry of *Salmo trutta* parr and adults from the Irish Sea region. A freshwater sampling programme has produced a microchemistry baseline for juvenile *Salmo trutta* that is one of the largest to date in terms of the number of source popeulatio (36 rivers) and the spatial scale of its coverage (*i.e.* covering an entire coast shelf sea region with a coastline of *ca.* 2500 km). In addition, two novel extensions of the microchemistry technique have been applied – firstly the robustness of the baseline was tested using trout parr obtained from the same source populations but not used in establishing the baseline and secondly the established freshwater baseline was used to ret to assign marine-caught sea trout back to their putative freshwater region of origin using the chemistry of the otolith corresponding to their freshwater residence period. To the authors' knowledge, the first extension has not been attempted before and the second extension has only recently been applied during the lifetime of this project (Olley *et al.*, 2011; Veinot *et al.*, 2012; Veinott and Porter, 2013). In addition, the scale isotope chemistry work is an application of a recently developed technique to examine putative feeding locations of salmonids at sea (Mackenzie *et al.*, 2011). Taken together, the results indicate that although some sea trout may stay in coastal waters close to their river / region of origin, other sea trout may undertake pan-Irish Sea migrations. Clearly any management policies implemented for sea trout in the Irish Sea will need to be transnational in nature in order to account for these suggested pan-Irish Sea movement patterns.

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6 Modelling Freshwater Production of Sea Trout, *Salmo Trutta*

6.1 Description of Task

The overall aim of Task 6 is to describe the freshwater production capacity of sea trout (*Salmo trutta*) in rivers in the Celtic Sea zone and evaluate the quantity and quality of principal sea trout spawning and rearing habitats in each. In layman's terms this could be expressed as the question "What makes a good sea-trout river as opposed to a good brown trout river?"

6.2 Summary

Mapping the Abundance and Distribution of Sea Trout

A combination of juvenile survey data, rod-catch/effort data and information gathered for a previous project, the National Trout Inventory Project, allowed the distribution of trout in England & Wales to be mapped. This recorded if sea trout are known to be present, possibly present or where only non-migratory brown trout occur. Limited data were available from Scottish and Irish rivers to perform this task.

Quantity and Quality of Sea Trout Spawning Areas

For some rivers there was detailed information on known sea trout spawning areas, principally in North Wales and parts of Cumbria. It was not possible to obtain most of the information on specific spawning areas in a consistent form from across the Celtic Sea Region.

Barriers to Migration

The task mapped the **locations of potential barriers to migration** and identified the impassable barriers, along with many other potentally significant ones. Except for known impassable barriers, it was not possible to assess passability to upstream migrating adult sea trout in a consistent manner across the region.

Modelling Sea Trout Productivity

For England and Wales this task has produced a **general linear model** relating adult sea trout rod catch per unit effort during the years 2000-2010 to catchment-scale environmental variables:

- ***Ln CPLD = -1.727 +0.306 BLW + 0.235CW + 0.332 IG -0.210 ALK - 0.560 CSL***
- **Where CPLD is mean adult sea trout rod catch per licence –day**
- **BLW - % land cover broadleaved woodland (in catchment)**
- **CW - % Coniferous Woodland**
- **IG – Improved Grassland**
- **ALK – alkalinity**
- **CSL- total catchment stream length**

Important predictor variables were total catchment stream length, alkalinity and land cover by coniferous and broadleaved woodland, and improved grassland. This shows that generally, shorter rivers of low alkalinity in catchments that are relatively poor in nutrients and less-intensively farmed, with good spawning and nursery areas easily accessible from the sea, tend to be the better sea trout rivers. Conversely larger rivers whose headwaters are distant from the sea, with calcareous geology and productive, more intensively-farmed catchments are more likely to be salmon and/or brown trout –dominated.

Other exploratory analyses using Random Forest ® also highlighted the importance of lower productivity and calcium availability in creating favourable conditions for good runs of sea-trout, but also the difficulty in separating environmental and angling-related effects in determining sea trout rod catch.

A lack of catch per unit effort data from rod fisheries in Scotland and Ireland has meant that data from these rivers did not contribute to the predictive model, though it was possible to trial the England and Wales model on the Irish rivers, for which data for the relevant environmental features was available.

Factors Influencing Juvenile Trout Production and Its Relationship with Rod Catch
For England and Wales, data on **juvenile trout abundance and environmental characteristics** at river-reach scale were examined to see whether the relationships vary between rivers with high adult sea trout returns and those with relatively few sea trout. There were no significant relationships between reach characteristics and juvenile trout abundance, though abundance of trout seemed generally lower in reaches where salmon parr were prolific. There was no significant relationship between estimated total juvenile trout production in catchments and sea-trout rod catches, indicating that sea trout production in rivers is driven by the propensity of trout to become anadromous rather than sheer numbers of trout available.

What Do These Findings Mean for Sea Trout Management?
It is questionable whether the models produced reflect true production of sea trout in rivers. This is primarily for two reasons. Firstly, the task team recognize that a large proportion of the variation in sea trout rod catch between rivers is due to differing characteristics of the fishery rather than the catchment. Secondly, there is increasing evidence from other studies that anadromy – propensity for becoming a sea-trout as opposed to a resident brown trout – is at least partly under genetic control. Hence in observing how adult sea trout catches relate to catchment features, it was not possible account for adaptive genetic differences between stocks from different rivers, which may influence how trout from those populations interact with their environment.

Future Research
Better understanding of the influence of environmental features on sea-trout production will only be gained by undertaking catchment-specific, detailed studies of trout production and movement using a combination of marking and trapping, stable isotope analysis, scale microchemistry and genetics. In this way the nursery origins in a catchment of sea trout smolts and adults could be identified and more detailed studies those areas undertaken to elucidate key features relevant to sea trout production and anadromy.

6.3 Previous Studies and Theoretical Background

6.3.1 Environmental Factors Governing Distribution and Abundance of *Salmo Trutta*

In order to understand the basis of sea-trout production it is necessary to understand the basic environmental requirements of *Salmo trutta*. A river cannot produce a significant sea-trout run unless there is a viable trout population there in the first place.

Brown trout are widely distributed throughout England & Wales; a previous Environment Agency study showed brown trout to be present in 67% of total river lengths (Gray & Mee, 2002). Brown trout are also found in lakes and due to their ability to complete their lifecycle entirely within freshwater, populations may also be present above waterfalls. The physical habitat requirements of trout, as with all salmonids, vary by season and by stage in their life cycle. This section will therefore consider the requirements of trout at the key stages of their lifecycle (spawning, nursery and rearing) in relation to key habitat variables (depth, current/velocity and substrate).

Spawning

Whilst the spawning habitat of brown trout and Atlantic salmon overlap, in general, brown trout select shallower and slower flowing spawning sites than Atlantic salmon (Louhi et al. 2008). They tend to spawn earlier than salmon and make more use of headwater steams (Armstrong et al. 2003). In their review, Armstrong et al. (2003) identified that trout spawning occurred in depths ranging from 6-82 cm, water velocities of 10–80 cms^{-1} and in substrate size between 8 and 128 mm.

A more recent and extensive literature review by Louhi et al. (2008) further refines these criteria finding that trout redds were mainly located in depths of 15–45 cm, velocities of 20–55 cm s^{-1} and in substrate between 16 and 64mm. The authors also compared the habitat preferences for trout in small and large streams (measured by discharge) and found that in large streams, spawning occurred in deeper water (20–55 cm) and at lower velocities (20–40 cm s^{-1}).

It is generally accepted that fish will not spawn in water shallower than its own body depth (Bjornn & Reiser, 1991; Armstrong et al. 2003). Trout are known to spawn in streams of varying widths reported to be as narrow as 50 cm (Crisp 1995). All conditions, particularly substrate choice, are likely to be influence by on the size of the individual fish. Fish can spawn in gravels with a median diameter up to about 10% of their body length (Kondolf and Wolman, 1993).

The quality and productivity of spawning habitat is significantly influenced by the proportion of fine sediments. Infiltration of fine sediments within spawning gravels inhibits oxygen exchange and reduces egg survival (Sear 1993, Soulsby et al 2001; Heywood & Walling 2007). Evidence suggests that where fine sediment (<2 mm) exceeds approximately 15% of the channel bed material, salmonid embryo survival reduces to less than 50% (Milan *et al.*, 2000).

Nursery

The first few months after emergence are a critical period in the life of juvenile salmonids. Dispersal from redds is generally limited (Armstrong et al. 2003) and survival is dependent on good nursery habitat close to spawning location.

The nursery areas of juvenile salmon and trout also overlap although in general, trout occupy lower velocities and deeper water, with depth increasing as fish grow in size (Armstong et al. 2003). Newly emerged fry require water velocities <10cms^{-1}. Thereafter, young-of-the year trout generally occupy habitat with a depth less than 20-30 cm, water velocities between 0 – 20 cms^{-1} and a substrate size between 50 – 70 mm. Ayllon et al. (2008) reports slightly greater values of habitat preference of depth 20-35 cm and velocities between 50 and 80 cm^{-1}. The coarser gravel substrate provides interstitial refuges and decreases water velocities (Armstrong et al. 2003; Ayllon et al. 2008).

Rearing

As older juveniles, trout continue to occupy deeper and slower flowing water than salmon. They have a preference for water velocities <20 cms^{-1} (nose velocity), although are found at a range of mean velocities between 0 – 70 cms^{-1} (Armstrong et al. 2003). Depth is reported to range between 40 and 75 cm (Armstrong et al. 2003). Velocity and depth preferences may change seasonally with slower and deeper water sought during winter months (Bjornn & Reiser, 1991). Vehanen et al. (2000) observed a change in preference of water velocity from 21-29 cms^{-1} in early summer to 10-17 cms^{-1} in winter.

Juvenile trout tend to be found in areas of gravels and cobbles between 8 – 128 mm and actively avoid areas of bedrock (Armstrong et al. 2003). Habitat heterogeneity plays an important role in carry capacity; trout actively defend territories within the channel and it is hypothesised that higher densities can be supported in more complex habitats (Northcote, 1992). As with velocity and depth, there may also be seasonal change in substrate size with preference for cobble habitat in autumn when in-channel and bankside cover is reduced (Armstrong et al. 2003).

There are a number of other variables that have been considered in relation to brown trout productivity in general. As a cold-water species, temperature plays an important role in the health and productivity of populations. The optimal growing temperature for is trout is ~13°C with growth occurring between 3.5 and 19.5°C (Solomon & Lightfoot 2008). Optimal egg incubation occurs between 8-12 °C with significant mortality above 13°C. Reduced abundance of trout has been observed in relation to warming climates (Hari et al. 2006).

Cover for salmonids is provided by overhanging vegetation, undercut banks, submerged vegetation, submerged objects such as logs and rocks, floating debris, deep water, turbulence and turbidity. The proximity of cover to suitable spawning habitat is likely to influence success and therefore productivity.

Productivity of trout populations has been linked to alkalinity and therefore underliying catchment geology. Almodóvar et al (2006) found that more alkaline rivers (limestone bedrock) had greater productivity than more acidic (siliceous bedrock). Brown trout production and biomass were positively correlated with levels of inorganic nutrients and thus productivity. Similarly, Kwak & Waters (1997) apportioned over a third of variation in productivity to differences in alkalinity. Other studies have also related differences in trout productivity in temperate streams to water chemistry (e.g. Eggleton & Morgan, 2000).

Productivity has also been shown to decrease with increasing elevation/altitude (Almodóvar et al. 2006; Eggleton & Morgan, 2000). However, this may be linked with interrelated factors that occur with increasing altitude such as depth, food availability and temperature, rather than altitude itself.

6.3.2 Role of environmental factors in driving anadromy in *Salmo trutta*

Salmo trutta is a phenotypically plastic species and exhibits a range of life history strategies in order to maximise population fitness in any given environment. The two contrasting strategies which are the subject of this study are those of full residency, in which the trout completes its entire life cycle in the river reach of its birth, versus anadromy, in which the trout spends the few years of its life in the natal stream and then smoltifies and migrates to the sea where it remains for varying lengths of time before returning to spawn in its natal stream. In reality the scene is more complex, since many trout do leave the river reach of their birth and spend time feeding lower down the same river, or in a lake, or in the estuary, though not going as far as the open sea, returning to the upper reaches of the river to spawn. Hence the trout should be seen as exhibiting a continuum of migration strategies between the two extremes of the fully anadromous sea trout and the stream-resident brown trout. Amongst fully anadromous trout there is again a range of strategies based upon time spent at sea prior to returning to spawn in freshwater and these are the subject of the Task 7 report which follows. In addition, fully resident and migratory forms co-exist and interbreed.

The following section (after Milner, 2010) considers how anadromy might maximise fitness in differing situations.

"Following evolutionary biological principles, the number of sea trout (N_{st}) produced annually from a catchment section or reach is related to the probability (P_a) of juvenile brown trout becoming anadromous and the number of juvenile trout present (N_{bt})which can be expresses as:

$$N_{st} = P_a x\, N_{bt} \qquad \text{(Equation 1)}$$

If recruitment is unaffected by other factors, the abundance (N_{bt}) is equal to the section's carrying capacity. In typical empirical habitat modelling terms this might be HQS of the Habscore model. Thus:

$$N_{st} = P_a x\, HQS \qquad \text{(Equation 2)}$$

For a river system, N_{st} would be summed over the entire accessible rearing habitat.

P_a is a value linked to processes of evolutionary biology. It is some function of the benefits and risks (to lifetime fitness) of adopting the anadromous life history tactic, versus remaining in freshwater (see Table 6.3.1).

Table 6.3.1 Relative risks and benefits of residency versus anadromy

	Residency	Anadromy
Benefits	– *avoidance of large predators* – *better survival in early life stage* – *good growth in juvenile stage* – *(evolutionary benefit through frequency dependent selection)* – *Small size at maturity allows access to smaller spawning channels.*	– *access to better feeding, larger prey (inc fish)* – *larger size at maturity opens up wider range of spawning sites* – *greater fecundity, increased egg deposition* – *larger eggs, greater embryo survival*
Risks	– *limited habitat size affecting maximum fish size* – *limited feeding opportunity (e.g. 2^0production and / or prey size)* – *density dependent effects (normally lost after early juvenile stage, but may be limiting later at bottlenecks)*	– *exposure to more and larger predators in lower river, estuary and sea* – *energetic expenditure of long distance migration* – *physiological demands of changing osmoregulation* – *exposure to wider range of pathogens* – *exposure to fishing mortality*

Anadromy is sex-linked: more females undergo anadromy than males, probably because of the obvious fecundity benefits accompanying larger size for females (e.g. Jonsson and Jonsson, 2006). However, there is variation in the degree of migration probably reflecting the phenotypic plasticity of trout and a fitness adaptation to the variable environments of rivers and streams (a form of frequency dependent selection.

It is hypothesised that anadromy is also related to the early individual growth trajectory, and the energetic efficiencies influenced by metabolic rate, and thus to growth conditions in early juvenile stage (Forseth et al, 1999; Olsson et al, 2006; Wysujack et al, 2009). From this qualitative picture of anadromy (which is reasonably well-described in the literature, but still with areas of uncertainty) is it possible to propose hypotheses that link the probability of anadromy to habitat features in freshwater? For example, that anadromy might:

1) Decrease with increasing distance (D) of rearing area from the sea (not necessarily linearly) and altitude (H). Thus, $P_a \sim f(1/D)$, because this affects exposure to predation and the energetics of migration

2) Decrease with increasing difficulty and energy expenditure of migration (E_{mig}), $P_a \sim 1/(E_{mig})$

ln (catchment area), km²

3) Increase with increasing river water temperature (T) up to optimal growth temperature, $P_a \sim T$ (Temperature effects are clearly non-linear and complex).

4) Increase with decreasing productivity (Prod) (reduced feeding and growth opportunity), $P_a \sim f(Prod)$.

5) Increase with other "environmental pressures" (Env) that render the freshwater survival lower or more variable than other sites, $P \sim f(Env)$.

Combining these gives:

$$P_a \sim f(1/D) \text{ x} f(1/H) \text{ x } f(1/E_{mig}) \text{ x } f(T) \text{ x } f(prod) \text{ x } f(Env) \qquad (2)$$

Clearly this is very simplistic. There are other factors operating and they may not all be multiplicative. However, it illustrates a framework, based on scientific theory (see Section 6.3.3), which would link together the freshwater processes. Note that they link with the marine factors, including sea temperature and feeding opportunity and migrate distances. The simplest models we have, e .g. Figure 6.3.1, may be expressing some of these combined effects.

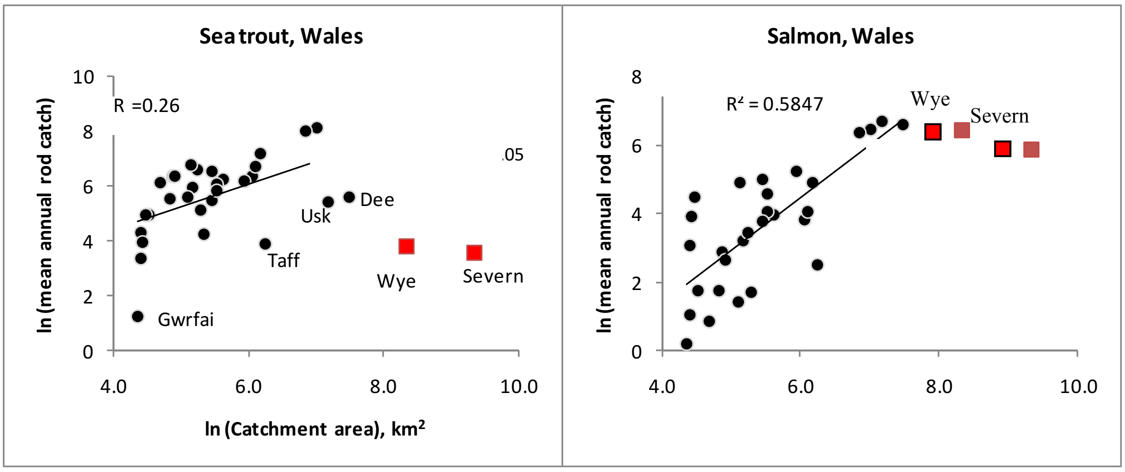

Figure 6.3.1 Relationship between catchment area and declared rod catch for sea trout (right) and Atlantic salmon (left) (mean 2003-07). Rivers named are examples where known factors, such as historical environmental impairment or obvious physical features would suggest low sea trout abundance (see also Task 7)

Assuming that rod catch is one index of run (Milner et al 2002), the simplest model for predicting sea trout productivity is rod catch versus catchment area (or wetted area, wetted length – all will provide similar results). Figure 6.3.1 presents this analysis for rivers in England and Wales and shows that, in general, larger catchments have more sea trout. Equally it can be shown that small catchments have smaller sea trout runs. The catch/area relationship for trout is less precise than for salmon (Figure 6.3.1). The hypothesis to account for this reduced precison is that habitat features, such as those noted above, influence anadromy in trout more than in salmon, which are (almost) always anadromous. Brown trout are facultatively anadromous, more phenotypically plastic, than salmon. If salmon can produce juveniles the females all go to sea (although resident mature males are quite common) – this is not necessarily so for trout. Thus wetted area (which is correlated with catchment area) works quite well as predictor for salmon, but less well for trout, because the other factors have been ignored in this simple model.

The cases of the Severn and Wye are informative. The well-known low abundance of sea trout in these rivers (e.g. Thornton, 2008) has been attributed to poor marine feeding conditions. It is equally plausible that it may also be due to the longer distances between good sea feeding and the location and quality of suitable sea trout spawning streams. For trout in most locations of the Severn and Wye anadromy might not offer fitness benefits, hence area alone is a poor predictor. Incorporation of distance, channel width, gradient, altitude, access, and other factors modelled across stream reaches may improve predictive capacity.

Task 6 was undertaken to develop a model to explain as much of the catch variance in Figure 6.3.1 as possible, based on understanding of the principles governing the balance between risk and benefits (in fitness terms) of anadromy. The key determining environmental factors arise in both marine and freshwater, however, it was not within the scope of Task 6 to incorporate marine factors, and models are based on freshwater variables only. Task 6 modelling did not incorporate additive genetic effects (reviewed in section 6.3.4); we are looking at the phenotypic response to environment and resources.

6.3.3 Evidence from Peer Review Literature

Milner's hypotheses have considerable support from the literature.

There have been a number of studies which have attempted to gain an understanding of the specific environmental drivers of anadromy in trout species. Many of these have looked at the rainbow trout *Oncorhynchus mykiss,* which is a similar and closely related species occupying a similar ecological niche to the brown trout but naturally geographically separated, the former associated with Pacific rim and the latter native only to the Atlantic.

Mills et al. (2012) investigated the ability of stream size (measured as mean annual run-off) to predict the probability of anadromy in populations of *Oncorhynchus mykiss*. As with catchment wetted area, this represents a simplified, broad-scale model for productivity with discharge representative of a wide number of environmental variables. The model had moderate (68%) prediction probability success and the authors found no additional evidence of the influence of spatial gradients having controlled for the influence of stream size. This provides further support for an important role of local rather than broad-scale environmental factors in determining anadromy. Furthermore, whilst stream size may provide some indication of migratory probability, the exact processes associated with stream size, and therefore anadromy, could not be elucidated.

So what evidence is there to help identify what these local variables might be and how do they relate to the predicted costs and benefits of anadromy? On the basis of the theories relating to costs and benefits of migration, we might predict that anadromy would:

– ***Decrease with increasing distance to sea***

The theory that the probability of anadromy decreases with increasing distance is supported by a number of studies in a variety of migratory salmonid species. Finstad & Hein (2012) found a negative relationship between anadromy and migratory distance in Arctic char. No anadromous populations were found to occur beyond a distance of 12.7 km from the sea. A number of studies have also shown that the proportion of the population migrating to sea decreases with increasing distance from the sea in Arctic Charr (Kristofferson et al. 1994) and sockeye salmon (Wood, 1995). Bohlin et al. (2001) also found that anadromous populations of trout were found in smaller streams closer to the coast than resident populations.

However, Jonsson & Jonsson (2006a) found no relationship between the ratio of anadromous to resident fish and distance to sea in brown trout in Norway. Instead, they found differences in body size and shape showing potential genetic adaptation to reduce the costs of anadromy which may explain the observation. Such adaptations to long migrations have also observed in sockeye salmon (Crossin et al. 2004). Alternatively, other factors influencing the probability of anadromy may have confounded the results (Almodóvar et al. 2006; Jonsson & Jonsson, 2006a).

Walker and Bayliss (2006) found that sea trout spawning areas in the River Kent were positively associated with altitude and distance from head of tide and negatively associated with upstream catchment area and distance from source, illustrating the need to consider these issues in the light of geographical scale: the Kent is a relatively short river compared to many studied by other authors.

There is also evidence that some other function related to distance, such as complexity and structure of the river system, could play a role in sea trout productivity. Champion et al. (1998) examined a number of attributes potentially influencing rod catches of both salmon and sea trout such as the number of tributaries within a given catchment, the length of main river and the average length of tributaries. The study found that rivers with a high ratio of main river to number of tributaries tended to produce greater numbers of salmon (as indicated by rod catch), whilst rivers with a low ratio of main river to number of tributaries produced greater numbers of sea trout. Similarly, Milner et al. (2006) noted that smaller catchments with a greater proportion of wetted stream area composed of channels <6 m wide, tended to be dominated by sea-trout rather than salmon.

– ***Decrease with increasing difficulty/cost***

Migration difficulty has been assessed in a variety of ways from estimating energy expenditure (reviewed in Hendry, 2004), to consideration of environmental factors such as altitude, gradient or slope as an index of difficulty (e.g. Bohlin et al. 2001). The difficulty of migration may also be influenced by physical barriers to migration, be they natural or man-made (HELCOM, 2011, Aarestrup & Koed, 2003). Traditionally, barriers such as weirs, dams and natural waterfalls have been seen as primarily a problem for upstream migrating adults but there is growing evidence that weirs and the impounded reaches upstream of them cause significant delay and loss of downstream migrating smolts (Svendsen et al. 2007, Gauld et al. 2013).

There are a number of studies that have directly assessed the cost of migration. This has most frequently been demonstrated in relation to distance which identifies the potential overlap between factors. Kinnison et al. (2001), compared energy expenditure and reproductive investment in experimentally produced full-sibling families with manipulated migrations of 17 km (17 m elevation) and 100 km (430 m elevation). Those with the more challenging migratory journey showed a 17% reduction in metabolizable energy and nearly 14% smaller ovaries (Kinnison et al. 2001).

Bohlin et al. (2001) hypothesised that if the migratory cost theory holds true, there would be a point along a stream beyond which selection would favour residency. Their results supported this theory in that juvenile densities were found to decrease with increasing elevation in migratory populations but not resident populations. The elevation at which differences were observed was approximately 150 m suggesting that this represents a threshold where the costs and benefits of the alternative life history tactics are equal. In a similar study, Finstad & Hein (2012) found that the probability of anadromy in Arctic charr decreased to almost zero beyond 50 m elevation. It is probable that the threshold level will vary by species and by river.

The presence of on-line lakes could also potentially influence the cost/benefit relationship of anadromy within a catchment. Lakes and reservoirs represent a potential time delay to migration (Hansen et al. 1984) and a high predation risk from fish and avian predators (Jepsen et al. 1998; Koed et al. 2006). In a 3 week radio-tracking study of 50 hatchery salmon smolts and 24 wild trout smolts in a 12 km long reservoir in Denmark, 90% of smolt died (Jensen et al. 1998). Pike accounted for 56% of the mortality and avian predators 31%. The mortality of salmonid smolts was also observed to increase following the creation of a lake during restoration of the River Skjern, Denmark, primarily associated with avian predation (Koed et al. 2006). The presence of on-line lakes could therefore be expected to increase the energetic cost and risks of migration and consequently decrease the likelihood of anadromy. This could be expected to vary given their size and position with the catchment. On-line lakes may act against anadromy in other ways – lakes with good feeding opportunities may present an alternative environment to the sea in which to grow quickly to maturity, hence trout with migratory tendencies may terminate their downstream migration in the lake rather than continue to the sea (Elliott, 1989), returning to tributaries to spawn (Naslund 1993). This is known to occur in Windermere and other Cumbrian lakes (Allen, 1938), and M. Farrell, pers. comm.) and in Lough Corrib (Fahy, 1989, Massa-Gallucci et al 2010; & P. Gargan, pers. comm.)

– ***Increase with increasing temperature***

Brown trout is a cold water adapted fish species. All aspects of their life history are linked to temperature from degree days for incubation to optimal temperatures for growth of juveniles and movement of adult fish (reviewed in Solomon & Lightfoot, 2008). Water temperature influences both growth and lipid content of trout which in turn influence the "decision" to migrate. Therefore it seems reasonable to suggest that thermal stress could increase the cost of remaining in freshwater and therefore drive migratory behaviour.

Evidence within the literature widely supports this theory. McMillan et al. (2012) found that the probability of early maturation in freshwater (i.e. becoming resident) was positively associated with greater growth and lipid storage in *O. mykiss*. Their findings support the theory that increased metabolic costs and stress caused by high summer temperatures result in increased use of lipid reserves to maintain growth (Tocher, 2003).

Conversely, Finstad & Hein (2012) showed that the probability of observing anadromous Arctic char populations decreased with increasing temperature. Warmer environments are likely to be more productive in terms of food availability (Finstad & Hein 2012) leading to more rapid growth and earlier maturation (see below), hence the relationship between anadromy and temperature may not be a simple one and may differ between geographical regions and over the full range of latitudes in which sea-trout occur.

– ***Decrease with increasing productivity***

The productivity of the juvenile freshwater environment may influence an individuals' decision to migrate. In theory, if conditions in freshwater are favourable, this results in higher growth rates and early maturity in rivers resulting in remaining resident. Alternatively, if freshwater conditions are restricting growth, and therefore maturity, there may be benefits to undertaking a more costly migration. Consequently, as the productivity of the freshwater environment declines, the drive to migrate is likely to be higher. A wide number of variables have been considered to represent productivity including: invertebrate mass/assemblages, terrestrial productivity, chlorophyll, geology and land-use.

This theory is widely supported within the literature. Finstad & Hein (2012) found that the incidence of anadromy in Arctic charr populations decreased with increasing productivity (as measured by terrestrial plant productivity). This decrease was less severe in populations with shorter migration distances indicating a trade-off between freshwater productivity and migration distance.

O'Neal & Stanford (2011) found similar differences in productivity when comparing rivers inhabited by resident with those of anadromous populations. They found higher biomass of invertebrates (particularly Ampihods) and soluble reactive phosphorous in resident populations, supporting the theory that higher productivity reduces the occurrence of anadromy. Gargan et al. (2006a) in their review of status of Irish sea trout stocks (chiefly the west coast rivers) point out that historically the important sea trout rivers were those draining acid blanket bog with nutrient-poor rivers and loughs.

An alternative method for studying the relationship between productivity and migration is through controlled laboratory experiments. Experiments where food availability is varied by experimental group have shown that restricted food availability leads to greater a propensity to migrate (Olsson et al. 2006; Wysujack et al. 2009). However, Forseth et al. (1999) and Cucherousset (2005) indicated that growth rate, body size and food availability alone may not entirely explain migration patterns and that metabolic rate and unfulfilled growth potential is higher in individuals that migrate.

– ***Increase with other pressures***

Competition could potentially influence the likelihood of anadromy given its potential impact on growth and survival. There is evidence that juvenile densities are higher in migratory populations than in resident ones resulting in greater competition for resources (Elliott 1994; Bohlin 2001; Keeley, 2001). Interspecific competition with other fish species may also influence the probability of anadromy. Jonsson & Jonsson (2006a) hypothesised that a complete lack of resident trout in two study streams may be the result of being out-competed by cyprinid species.

Due to habitat overlap, competition is also likely to occur between trout and Atlantic salmon. Milner et al. (2006) found that in streams <6m, juvenile trout were dominant over

Atlantic salmon. Consequently, channel width, either directly or indirectly, may be a possible determinant of sea trout production. The authors hypothesised that sea trout may also be more abundant in catchments with proportionally greater numbers of small streams.

– ***Decrease in the presence of adverse or unproductive conditions in the marine environment***

There has been relatively little research so far into the spatial variation in sea trout production in relation to local coastal environments, although research into the temporal variation in sea trout stocks by Gargan et al. (2006b) and Poole et al. (2006) strongly suggests that changing marine conditions off the West Coast of Ireland may have reduced sea trout adult spawning stock and caused populations to revert to freshwater residence-dominated life history.

This work has other implications for the present study as the authors noted that for a number of years there were substantial runs of sea trout smolts even when spawning escapement was low, indicating that freshwater resident brown trout have the potential to contribute considerably to sea trout production in a catchment. This might make estimation of true freshwater production of sea trout difficult in systems where only returning adult fish are monitored.

Whilst the above references are listed as specific to individual factors, many are interrelated and therefore it is difficult to determine which is having the primary influence. For example, higher altitude streams are likely to be further from the sea, have more costly migration routes, experience colder temperatures and therefore are less productive. The results of a number of the studies listed above, e.g. Finstad & Hein (2012), clearly demonstrate that the response of an individual or population to one variable may be influenced by another, e.g. productivity and distance.

6.3.4 The Role of Genetics in Determining Anadromy

In considering the possible environmental factors influencing migratory behaviour, it is also important to reflect on the potential role of genetics in the control of this behaviour. It has long been suggested that migratory behaviour in salmonids is influenced by a complex interaction of both environmental factors and genetics (reviewed in Metcalf, (1993), Jonsson & Jonsson 1993; Näslund 1993 and references therein & others). Indeed there is an assumption of a genetic basis for anadromy if it is to evolve in response to differential costs and benefits as detailed in Sections 6.3.2 and 6.3.3 (Hendry et al 2004; Olsson et al. 2006). However, the relative role of environment and genetics on an individual's "decision" to migrate to sea or become a resident are poorly understood (Hendry et al 2004; Olsson et al. 2006; Ferguson 2006; Thériault et al. 2007; Nichols et al. 2008).

Studies employing reciprocal transplantation and common-garden experiments, where genetic origin is (to some degree) controlled for, have clearly demonstrated that environmental factors do influence the decision to migrate. Olsson et al. (2006) demonstrated significantly higher migration rates in non-transplanted trout in a downstream section (previously found to produce mainly migrants) compared to those transplanted from the same location to an upstream site (previously found to produce mainly residents), and vice versa. Walker (2006) found that sea-trout progeny transferred to a previously fishless area upstream of an impassable waterfall resulted in establishment of a resident population within 20 years. Laboratory studies have further linked this to food availability and growth rates; a significantly greater number of migrant types are produced under limited food availability (Morinville & Rasmussen, 2003; Olsson et al. 2006; Wysujack et al. 2009).

However, the clear evidence that an individual's environment can influence its decision does not mean there is no genetic basis to migration. Body size, growth rate and metabolic rate are all indicated as factors governing the "decision" to migrate (Økland et al. 1993: Olsson et al. 2006; Wysujack et al. 2009). All such factors are likely to have a genetic basis (Ferguson, 2006). Additional evidence for the genetic basis of anadromy is reviewed in Ferguson (2006) but includes: selection against migration above impassable barriers (Hendry et al 2004), production of a lower proportion of migrants by resident parents (references within Jonsson & Jonsson 1993), and differential expression of anadromy between sexes (Jonsson & Jonsson, 1993; Hendry et al. 2004).

Advances in genetic mapping studies have more recently employed quantitative trait loci (QTL) analysis to identify the actual gene(s) involved in anadromy. Genetic crosses of migratory and non-migratory life-history types of *Onchorynchus mykiss* and *Salvelinus fontinalis* have estimated that potentially greater than one half of the phenotypic variation in smolt-related traits could be attributed to additive genetic variance (Thrower at al. 2004; Thériault et al. 2007). Nichols et al. (2008) suggest that one locus in particular is strongly associated with multiple smoltification traits body morphology, skin colouration, condition factor and growth rate. However, these studies consider the heritability of phenotypic traits associated with smoltification which may or may not be the same as those associated with the actual decision to migrate (Nichols et al. 2008).

Narum et al. (2011) similarly employed single nucleotide polymorphism (SNP) markers to identify candidate markers associated with anadromy. After accounting for loci linked to environmental conditions they identified 3 SNP markers potentially linked with anadromy. When applied to rivers outside the study area they correctly predicted the life-history type present, including mixed populations, in the majority of cases demonstrating a similar success rate through modelling genetics alone compared with environmental variables alone.

Consequently, anadromy is considered to be best described as a threshold quantative trait. That is, a trait controlled by multiple genes with small effect and environmental factors (Ferguson, 2006). There is likely to be a genetically determined threshold level that has to be passed (Jonsson & Jonsson, 1993), or failed, before an individual "decides" to migrate or reside. This is supported by a negative genetic correlation between smolting and sexual maturation (Thrower et al. 2004). Importantly, there are also likely to be differences between individuals and populations in whether a specific growth rate results in anadromy or non-anadromy (Hendry 2004; Thrower et al. 2004). However, Jonsson & Jonsson (2006b) considered that whilst there were genetic differences between populations of trout exhibiting varying degrees of anadromy, there was no consistent genetic difference between resident and migratory individuals in the same population.

The potential role of genetics in influencing migratory behaviour in combination with environmental factors has important implications for the modelling work of Task 6. Indeed, Ferguson (2006) advocates that genetic background needs to be taken into account when studying the influence of environmental factors on sea trout production. However, while the gene(s) responsible for anadromy remain unknown, it is not possible to include this aspect in a model. Instead, underlying heritability must be considered a possible contributor to unexplained variability in any model developed – when we look around the sea-trout rivers of the Celtic Sea Region, we are not dealing with the same animal in all locations.

6.4 Scientific Approach

The approach chosen in the early stages of the Celtic Sea Trout Project was to attempt to test the hypotheses above, relating to the drivers of anadromous behaviour in *Salmo trutta*, by reference to data on sea trout stocks and environmental characteristics of river catchments in the Celtic Sea Region. A number of earlier research initiatives by the Environment Agency and its predecessors helped to shape the approach chosen for this task.

Wyatt, Barnard and Lacey (1995), developed the HABSCORE system for evaluating stream habitat quality for salmonids and for assessing the degree to which habitat in streams is fully utilized. HABSCORE is used to assess the quantity and quality of salmonid habitat at site level (Habitat Quality Score) and to indicate where poor recruitment or water quality issues are limiting salmonid production (Habitat Utilisation Index). HABSCORE uses a combination of map-based and field-based variables including for example; altitude, distance from source of site, width, depth, substratum, flow type, overhead and instream cover. These variables were selected initially from a combination of literature evidence and expert opinion, followed by modelling of data from a set of sites throughout England and Wales considered relatively unimpacted. HABSCORE has separate models for brown trout of different sizes and for juvenile salmon, but has no model specifically related to production of sea trout.

National Inventory of Trout Fisheries (Gray & Mee 2002) provides a baseline description and inventory of trout stocks and fisheries in England and Wales. It presents a review of the current distribution and where possible, the status of such fish stocks. Of particular relevance to the present study, that project sought to identify the locations of different types of trout fishery in England and Wales, with reference to whether any given river reach or lake was predominantly sea trout, brown trout, or a mixture of both forms; and whether the fishery was self-sustaining or supported by hatchery stocking. The outputs included extensive Geographical Information System (GIS) maps of the distribution of resident brown trout and sea trout, at sub-catchment scale.

Harris (2002) compiled stock descriptions of adult sea trout populations in 16 English and Welsh rivers and identified that there were four distinct stock types with different life-history strategies in terms of growth, smolt age and maiden sea-age; two of these types were relevant to the Celtic Sea Region although some rivers studied did not readily fit any of the four types. This reinforces the observations that the response of *S. trutta* to environmental conditions varies between regions and is complex, not being merely a case of whether or not to migrate, but when and for how long.

Coley (2003) undertook exploratory work on using GIS to investigate the relationships between juvenile salmonid abundance and catchment features, which whilst not specifically focussed on sea trout, indicated a methodological approach which might help elucidate the factors influencing freshwater output of sea trout.

Thornton (2008) sought to provide information to enable development of biological reference points to support:

- optimising the freshwater production of trout;
- optimising recruitment to homewater fisheries, in stocks with a major migratory trout component;
- maintenance and improvement of the diversity and fitness of stocks;
- identification of sustainable catch potential (for both rod and net catches).

A biological reference point in these contexts aims to provide an expected level of abundance of a particular life-stage of trout, in a given environment, against which actual observed levels of abundance can be judged, in order to guide actions to manage and protect stocks. Generation of expected levels of abundance of trout and an understanding of factors influencing freshwater production of sea-trout are intimately related.

Thornton (2008) concluded that use of a single biological reference system for trout stocks generally was problematical because the species is highly polymorphic and exhibits a continuum of life-history strategies according to the environmental conditions at a number of spatial scales. It also identified the shortcomings of data currently available for the purpose of establishing biological reference points, specifically that data on rod catches of freshwater resident trout are largely lacking due to the current lack of a national catch-return system for non-migratory trout. Rod effort data for sea-trout are currently only available as 'rod licence' days for salmon and sea trout combined. Age data collected during routine juvenile surveys are limited in many areas. Freshwater age structure of trout is likely to be a key factor in understanding the causes and distribution of anadromy within individual catchments. Hence it is clear from Thornton's work that the current task faces formidable challenges.

Overall production of *Salmo trutta* in rivers can be estimated from the results of electric fishing surveys of the nursery habitat areas in each catchment, and by some assessment of the total stream length, or wetted area, of this habitat type in catchments. However as resident brown trout and sea trout are the same species and cannot currently be distinguished in the freshwater juvenile stages, these data give little clue as to sea trout output of any catchment or sub-catchment. Adult sea and brown trout are not quantitatively assessed in a consistent manner, though there are data on adult brown trout from multi-species fisheries surveys undertaken by for instance the Environment Agency on the middle and lower reaches of river. A small number of rivers have fish traps and counters where returning adult salmonids and in some cases emigrating smolts can be enumerated.

It is therefore difficult to obtain a direct estimate of the total numbers and/or proportion of juvenile *S. trutta* that become anadromous, emigrating as smolts and returning as adults after varying periods at sea.

For the vast majority of rivers the only "yardstick" of the propensity of trout to become sea trout is from recorded angling catch of returning adult sea trout. Some justification for this approach is provided by use of rod catch statistics for assessing salmon stocks (Milner et al. 2002), however the difficulty in assessing juvenile stocks of true sea trout means these methods may not be directly transferable. Nevertheless Elliot (1992) considers that rod catches of sea trout can reflect true stock levels.

6.5 Objectives

The overall objective of Task 6 was:

- to prepare a GIS-based database on the abundance and distribution of sea trout, the quantity and quality of sea trout rearing areas in rivers, the presence of key sympatric species in sea trout production zones, and barriers to migration, in rivers around the Irish Sea; and To explore the potential for developing a common (around Irish Sea) model for estimating sea trout production based on catchment habitat features

6.5.1 Principal Deliverables

Deliverables for Task 6 were:

- A report (new knowledge and advice) describing the spatial variation of juvenile trout production in rivers around the Irish Sea, the potential and actual production of sea trout and the influence of freshwater habitat factors; and

- A database and inventory of sea trout production and habitat in river systems around the Celtic Sea Region.

6.6 Methods

6.6.1 Study Areas

Table 6.6.1 provides information on the rivers in the Celtic Sea Region which were nominated as being significant sea trout rivers for the purposes of the production modelling studies.

Table 6.6.1 Rivers in the CSTP nominated as key sea trout rivers for modelling analysis (number is as coded in Fig. 6.6.1).

North West England			
23. Calder	27. Duddon	21. Derwent	30. Lune
24. Ehen and Keekle	19. Eden	18. Esk (Scottish Border)	29. Kent
20. Ellen	28. Leven	33. Dee	25. Esk
26. Irt	31. Wyre	32. Ribble	
Wales			
55. Nevern & associated tribs	60. Gwendraeth Fawr	Ystwth	51. Dyfi
53. Aeron	44. Dwyfor	47. Artro	49. Mawddacch
50. Dysynni	61. Loughor	52. Rheidol	36. Conway
62. Tawe	38. Seiont	59. Tywi	34. Clwyd
58. Western Cleddau	45. Glaslyn	66. Taf	46. Dwyryd
65. Llyfni	37. Ogwen/Ddu	54. Teifi	39. Gwyfai
Solway Coast (Scotland)			
17. Annan	15. Urr	13. Fleet	11. Bladnoch
16. Nith	14. Dee	12. Cree	10. Luce
South of Ireland			
2. Argideen	8. Castletown	Dargle (not shown)	7. Glyde
3. Bandon	4. Colligan	7. Dee	5. Slaney
6. Boyne	1. Currane/Waterville system		
Northern Ireland			
9. Shimna			

In early 2011 it was acknowledged that in order to model sea trout production in relation to catchment environmental features there was a need to include rivers with lower sea trout abundance to include a wider range of catchment environmental types and be able to compare contributing factors. Accordingly a number of additional rivers in the central CSTP region for which some sea trout rod catch data were available were brought into the database. These additional rivers arepresented in Table 6.6.2. The locations of the final selection of all rivers in the CSTP is presented in Figure 6.6.1

Table 6.6.2 Rivers with lower sea trout abundance included in modelling.

North West England		
25. Annas	28. Black Beck	
Bela	Keer	
Wales		
69. Wye	Erch	Rhymney
68. Usk	Ogmore	Ely
70. Severn	Gwaun	Cefni
Neath	66. Taff	Ysgethin (Barmouth)
Aber	Cegin (Menai)	Wygyr (Anglesea)
Afan	Ebbw	Coron Lake (Anglesea)
Arth	Leri	
57. Eastern Cleddau	35. Dulas (Colwyn Bay)	

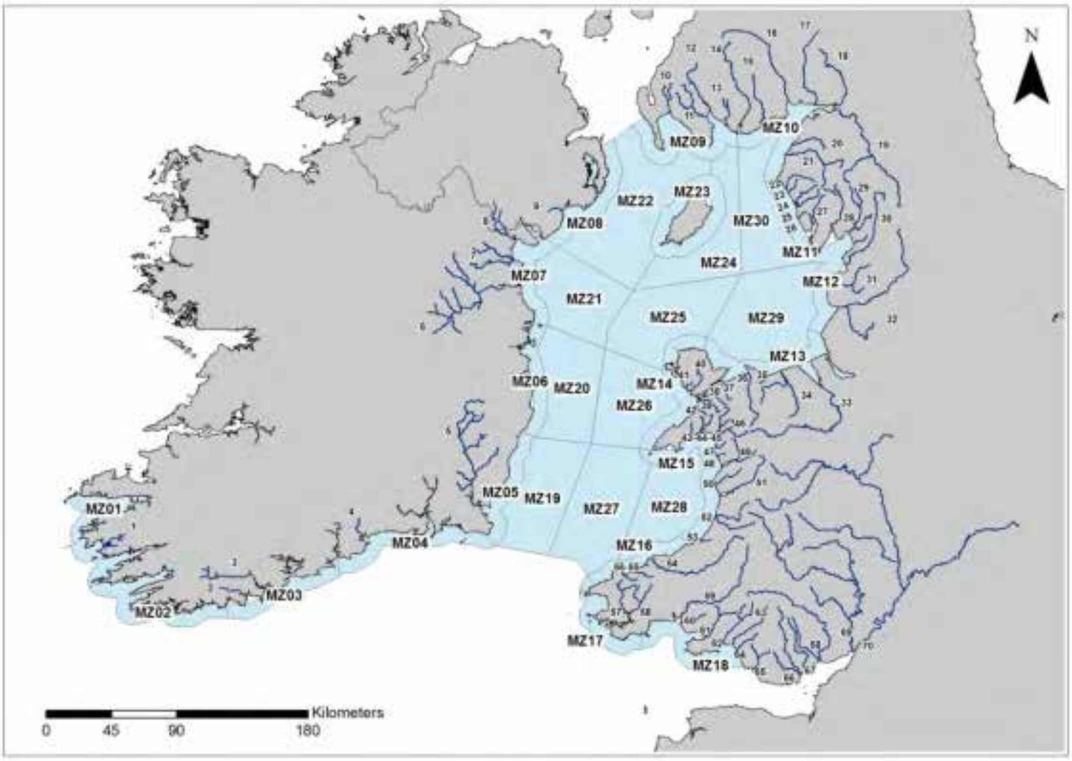

Figure 6.6.1 River Catchments included in Task 6 (river key shown in Tables 6.6.1 & 6.6.2)

6.6.2 Adult sea trout rod catch data.

Rod catch and effort data for England and Wales for the period for the period 2000-2010 were obtained from the statutory migratory salmonid rod catch return system operated by the Environment Agency. Rod catch data only for the Solway rivers were obtained from The Galloway Fisheries Trust, Nith District Salmon Fishery Board and Annan District Salmon Fishery Board. Rod catch data from Ireland (North and Republic) included only sea trout larger than 40 cm forklength, although some estimates of total sea trout rod catch from district fisheries officers were made available (William Roche, pers. com). No angling effort data were available for the Scottish or Irish rivers and therefore these rivers could not be included in the initial analyses and modelling exercise. A decision was taken early on to press forward with developing models for the group of catchments for which we had the most complete data set including rod catch and effort data. In practice this meant that the initial model was developed for North West England and Welsh rivers only. The intention was that once a robust model is developed for England and Wales, the model would be trialled on Scottish and Irish rivers using available information on environmental characteristics.

Mean total annual catch, mean annual total effort in days fished, and mean annual catch per licence-day were all examined in relation to environmental data. Fishing effort data were generally only available as total days spent fishing for migratory salmonids (salmon and sea trout) and it was not possible to make robust estimates of proportion of that time spent fishing for sea trout, hence the assumption has been made that all migratory salmonid fishing effort was theoretically capable of catching sea trout. Some estimates of effort apportionment were made for some rivers in two years (Evans 2006), however there are problems with extrapolation from these observations to other rivers and other years. For some rivers we can be reasonably certain that little effort is specifically directed at sea trout (though is still capable of catching them). Evan's study shows that on some rivers with relatively small salmon runs, a disproportionate amount of angling effort appears to be targeted at salmon. In some cases, sea trout are only in the river in numbers during a relatively short period and fishing effort outside those months could be assumed to be targeted at salmon, however the present annual catch return system does not record fishing effort on a monthly basis and so it is still not generally possible to estimate sea-trout fishing effort.

6.6.3 Catchment scale environmental data

Data on a wide variety of catchment environmental variables were gathered. For all rivers in the study the river catchment was defined as the total land area draining into the river upstream of the head of tide. The full list of environmental variables for which we attempted to obtain data at the catchment level is shown in Table 6.6.3.

For England and Wales these data were obtained from a digital elevation model (Nextmap DEM - a 50 metre resolution elevation model) and from the Land Cover Map 2000 whilst flow statistics for the river at head of tide were derived from the Low Flows Enterprise Model (Wallingford Hydrosolutions 2008). Geological data were derived from British Geological Society 1:625000 maps adapted for development of Water Framework Directive river and lake typologies. For Republic of Eire these were obtained from the outputs of the Wetted Area model (McGinnity et al. 2012), whilst land use data for Ireland were from the CORINE project (Environmental Protection Agency 2000). For the Scottish Solway rivers, data were not available for all variables initially requested but some was obtained from a combination of WFD river Basin plans published by SEPA, from the respective Fisheries Boards and Trusts, and from specific data requests to SEPA via the Boards and Trusts.

Table 6.6.3 List of catchment-scale environmental variables used to model adult sea trout rod catch

Abbreviation	Explanation
Easting	Easting of the head of tide of the catchment
Alkalinity mean	Mean alkalinity of river and tributaries
AVELEVU	Average elevation of catchment (land and water) upstream of the head of tide
CATCHMENT_AREA KM2	This is the land surface area of the catchment upstream of the head of tide
Mean sea trout rod-catch per licence-day 2000-2010 inclusive	Mean adult sea trout rod catch per licence-day, 2000 - 2010 (total catch with effort / total days fished)
DISTSOURCE	Distance to source in metres along main river from the head of tide
GEO_CAL_%_	Percentage of catchment land area upstream of head of tide underlain by calcareous geology
GEO_PEA	Percentage of catchment land area upstream of head of tide underlain by peat geology
GEO_SAL	Percentage of catchment land area upstream of head of tide underlain by saline geology
GEO_SIL	Percentage of catchment land area upstream of head of tide underlain by siliceous geology
Mean >0+salmon parr density per m2	Mean density of salmon older than 0+ derived from all sites and all sampling occasions in the catchment
Mean >0+trout density per m2	Mean density of trout older than 0+ derived from all sites and all sampling occasions in the catchment
Mean 0+ salmon parr density per m2	Mean density of 0+ salmon derived from all sites and all sampling occasions in the catchment
Mean 0+ trout density per m2	Mean density of 0+ trout derived from all sites and all sampling occasions in the catchment
Mean annual no. days fished 2000-2010	Mean annual reported number of days fished 2000 - 2010 inclusive
Mean annual total rod catch 2000-2010 inclusive	Mean annual total rod catch (with effort) 2000-2010 inclusive
Mean daily flow (naturalised) (head of tide)	Mean daily flow at head of tide (discounting abstractions and discharges) from Low Flows Enterprise
Mean daily flow actual	Mean actual daily flow at head of tide after abstraction and discharge - from Low Flows Enterprise
Mean monthly temperatures. Jan-Dec.	Mean monthly air temperatures derived from closest Met Office weather stations for all river segments and averaged
Northing	Northing of the head of tide of the catchment
Q95 (at tidal limit)	95 percentile of actual flow (flow value exceeeded 95% of time)
Qn95 (at tidal limit)	95 percentile of naturalised flow (flow value exceeded 95% of time)
SHREVE	Shreve stream order at the head of tide
STRAHLER	Strahler stream order at the head of tide
Total catchment stream length (m) (from 1:250k)* differs from DRN-derived	Total catchment stream length (m) (from 1:250k)
Total Catchment wetted area	Total Catchment wetted area(from 1:250k)
Total Hardness mean as caco3	Mean total hardness (expressed as $CaCO_3$) of river and tributaries
Total number of barriers	Total number of barriers in the catchment upstream of head of tide
TRUE RIVER GRADIENT M/KM	River Gradient from modelled river network E&W
USACIDG	Percentage of catchment land area upstream of head of tide occupied by acid grassland
USARABL	Percentage of catchment land area upstream of head of tide occupied by arable land
USBLWOO	Percentage of catchment land area upstream of head of tide occupied by broadleaved woodland
USBOG12	Percentage of catchment land area upstream of head of tide occupied by bog
USBRACK	Percentage of catchment land area upstream of head of tide occupied by bracken
USCALCG	Percentage of catchment land area upstream of head of tide occupied by calcareous grassland
USCONWO	Percentage of catchment land area upstream of head of tide occupied by coniferous woodland
USHEATH	Percentage of catchment land area upstream of head of tide occupied by heath
USIMPGR	Percentage of catchment land area upstream of head of tide occupied by permanent grassland
USNEUTG	Percentage of catchment land area upstream of head of tide occupied by neutral grassland
USSALT2	Percentage of catchment land area upstream of head of tide occupied by saltmarsh
USSETGR	Percentage of catchment land area upstream of head of tide occupied by set grassland
USSUBUR	Percentage of catchment land area upstream of head of tide occupied by suburban development
USURBAN	Percentage of catchment land area upstream of head of tide occupied by urban development

6.6.4. The GIS database

Data on the known sea trout and brown trout presence in England and Wales were based upon data gathered as part of the Environment Agency R&D report W2-062 "National Inventory of Trout Fisheries" (Gray and Mee, 2002). Data on estimated locations and numbers of potential barriers to sea trout migration in catchments were obtained from the Environment Agency's Obstructions Database. Sea and brown trout distribution and locations and numbers of significant and impassable barriers identified in these databases were then validated by interviews with knowledgeable local Fisheries and Biodiversity staff, and known sea trout spawning areas were identified. For Scotland and Ireland, information on sea trout presence and locations of impassable barriers was supplied direct from project group members on the basis of local knowledge and application of various migration barrier assessment tools including the protocol outlined in WFD111 (SNIFFER 2010).

6.6.5 Reach scale environmental data

For English and Welsh rivers data on mean gradient, elevation, width, distance from head of tide, monthly mean air temperature, alkalinity and calcium hardness in each river reach (between nodes in the Detailed River Network (DRN): derived from Ordnance Survey Mastermap approximately 1:10 000 scale) were obtained. (Table 6.6.4). The results were exported to an Access database so that numbers and total length of river reaches possessing certain combinations of attributes could be queried and compared between catchments. Data at this scale of resolution were not available for the Scottish or Irish rivers.

Table 6.6.4 List of reach scale environmental and fish population variabales used in analyses of juvenile salmonid abundance

Abbreviation	Explanation
Alkalinity	Alkalinity mg/l in reach containing survey site site- by interpolation from Digital River Network
Altitude	Mean altitude of reach containing site (m AOD)
Area	Site area, m^2
DistMouth	Distance to river mouth of reach midpoint
DistTL	Distance to head of tide of reach midpoint
Easting	Easting reference of site
Gradient	Gradient of river reach containing the site, m/km
Hardness	Total Hardness as $CaCO_3$ in reach containing site
LengthSurv	Duration of survey period in months
MonthSurv	Month in which site surveyed
Northing	Northing reference of site
Salmon>0+	Density of salmon older than 0+ at site
Salmon0+	Density of salmon 0+ at site
Shreve	Shreve order of stream at the site
Strahler	Strahler order of stream at the site
SurvCount	Number of occasions on which the site was surveyed 2000 - 2010
TempApr	Mean April air temperature in the reach containing site (from Met Office)
TempAug	ditto August
TempDec	ditto December
TempFeb	ditto February
TempJan	ditto January
TempJul	ditto July
TempMar	ditto March
TempMay	ditto May
TempNov	ditto November
TempOct	ditto October
TempSep	ditto September
TotSurv	Number of occasions on which the site was surveyed 2000 - 2010
US accum.	Total wetted stream length upstream of the site
Width	Site width, m.

6.6.6. Juvenile Salmonid Data

For England and Wales, electric fishing survey results from the National Juvenile Salmonid Monitoring Programme were obtained and re-formatted to display results for a single sampling occasion at a site on a single row. Juvenile salmonid monitoring data from Ireland and Scotland, where available, were presented as mean values for the catchment.

6.6.7 Analytical approaches

6.6.1.1 Individual catchment-based variables

The values of individual environmental characteristics were examined across the range of catchments in the study (England and Wales only) in order to see whether there were marked discontinuities within the study region, or expressed another way, to check whether catchments fell into distinct groups with regard to particular characteristics, or whether the study catchments could be grouped into distinct river types.

Simple linear regressions of values for mean sea trout catch per licence day for each catchment were run against each of the environmental variables separately as a first step to check for the presence of strong correlations which would inform subsequent more complex analyses.

6.6.1.2 Generalised Linear Modelling

The data on sea trout catch and catchment environmental variables

(Table 6.6.3 and Appendix 6.1) were subjected to a Generalised Linear Modelling process in the statistical package R (R Development Core Team, 2012) in order to elucidate the catchment-scale environmental characteristics that might be driving variation in sea trout rod catch and to generate a predictive model. Further details of the statistical procedure can be found in Appendix 6.2.

6.6.1.3 "Random Forest" Analysis.

Some preliminary exploration of the influence of catchment-scale environmental variables was also analysed using the Random Forest statistical package with sea trout catch per licence day as the dependent variable. Further analyses were run with mean annual total sea trout catch as the dependent variable. Random forests are able to better examine the contribution and behaviour that each predictor has, even when one predictor's effect would usually be overshadowed by more significant competitors in simpler models (e.g., simple or mixed effect regression models) (Strobl et al. 2009b).

6.6.1.4 Juvenile salmonid abundance and reach -scale variables.

Site-specific juvenile salmon and trout data for all English and Welsh rivers in the project were obtained from the Environment Agency National Fish Population Database (NFPD). The data were reformatted so that each sampling occasion at a site was represented by a single row of data. Mean densities of 0+, 1+ and greater than 1+ trout and salmon for each catchment were considered in relation to the full range of catchment environmental variables; site specific abundances for juvenile salmonids were also considered in relation to reach-specific environmental data, obtained from the data for nodes in the DRN. Data available for each reach are shown in Table 6.6.4.

These data (dependant variables [trout abundances] and independent variables [salmon abundance and GIS]) were combined and the relationships investigated using tree based regression models (regression trees and Random Forest in R).

Regression trees are often more realistic when compared with linear regression, which apply a single model to the entire dataset. Regression trees break the data up into "chunks", hierarchically partitioning the dataset, and reapply the model at each successive partition stage. This is known as recursive partitioning. This was deemed the best approach as the large size of the data set suggested that recursive partitioning would provide a more realistic description of the data, as opposed to linear regression which would apply a single model to the entire dataset (i.e. a global model).

The Random Forest method runs multiple regression trees (500 trees used here) to identify the most likely partitions and provides an output which demonstrates the strength of each variable as a descriptive element in the variance of the final output. This final output was presented as dotcharts.

Regression trees were output using rpart (R Development Core Team, 2012)

The regressions trees provided visually demonstrate the partitions in the dataset which best explain variation in trout abundances. Information contained within the diagrammatic outputs shown in the results section below presents the partitioning variable and the value at which the partition occurs (> or < xi), and the number of sites which are contained within each split and the predicted abundance of the dependant variable at each node (point at which the tree splits) and at the terminal nodes. This allows identification of the most productive groups, and as they exist at the lowest possible partition, it is the values for this output at the terminal nodes which are most important.

6.6.1.5 Relationships between juvenile salmonid abundance and sea trout rod catch and catch effort

In order to gain an understanding not just of the productivity of catchments in terms of adult sea trout catch but of the factors driving anadromy, sea trout production should ideally be expressed in terms of returning adult sea trout per unit of S.trutta 0+ parr production. Two catchments of similar size may produce similar numbers of returning adult sea trout but one has a small trout population most of whom smolt and migrate to sea whereas the other has a very prolific headwater system with high overall juvenile production but only a small percentage smoltify and return as adults.

Accordingly an index of mean annual S.trutta parr production for each catchment was estimated using juvenile salmonid monitoring data and the total stream length in which it could be reasonably assumed that juvenile trout production could take place. This approach has a number of shortcomings. Firstly, the distribution of juvenile salmonid sampling sites throughout a catchment was neither random nor stratified and hence is not totally representative of the potential trout production zone of a catchment. Specifically, very small streams less than perhaps 2m wide have not usually been sampled, conversely significant juvenile trout production probably takes place in larger tributaries and the main stem which are generally not surveyed for salmonids. Secondly, it is not possible to readily define from map-based data what the downstream limits of trout nursery areas actually are; even if a yardstick of the limits of trout production (for instance between certain altitude boundaries) were possible, these limits will vary between catchments. For instance it is believed that on the Tywi in South Wales, sea-trout spawning and juvenile production takes place almost down to the head of tide (D. Mee, pers. comm.), whereas in other rivers such as the Dee and Eden the main stems and larger tributaries are dominated by salmon or coarse fish, and trout juveniles are confined to headwaters and smaller tributaries.

Earlier work by Milner et al (2006), & Milner et al. (1993) suggests that in many rivers the bulk of juvenile trout production took place in small streams. Hence an index of total trout parr production (a catchment production metric, CPM) was obtained from the total area of stream width less than 5 m wide and the mean density of 0+ trout parr in catchments determined by electric fishing surveys during the period 2000 – 2010 inclusive. Similar estimates were made using total stream area < 10 m wide and < 20 m wide respectively to take account of production in wider river reaches.

The relationship between these production metrics and adult sea trout rod catch per unit effort was examined using simple linear regression in order to establish whether sea trout rod catch depends on total juvenile production in the catchment. Similarly the relationship between adult rod catch per unit effort and mean density of young trout at sites was also examined.

6.6.1.6 Relationships between juvenile salmonid abundance (catchment production metric) and catchment-scale variables

The production metrics for juvenile trout (0+ and greater than 0+) based on area of stream < 5 m wide, < 10 m wide and < 20m wide were subject to regression analysis with catchment-scale variables as co-variates, in order to check whether juvenile trout abundance was related to broad-scale catchment characteristics.

6.7 Results

6.7.1 Individual Catchment-Scale Variables: Ranking Exercises and Individual Regressions Against Sea Trout Rod Catch Per Licence-Day

This ranking exercise showed firstly that, in respect of most variables, there was a continuum of values rather than clustering into discrete groups of rivers. There were exceptions to this: for variables strongly related to catchment size, for instance catchment land area or river length, the Severn and Wye were markedly different from the rest (Figure 6.7.1).

Simple regression of adult sea trout rod catch per unit effort against individual variables showed very few strong trends other than variables that reflected overall catchment size. For example, total length of main stem river (Figure 6.7.2). Even when the Wye and the Severn – large rivers with low sea trout catch per unit effort – are excluded, the negative relationship between CPLD and river size is still apparent.

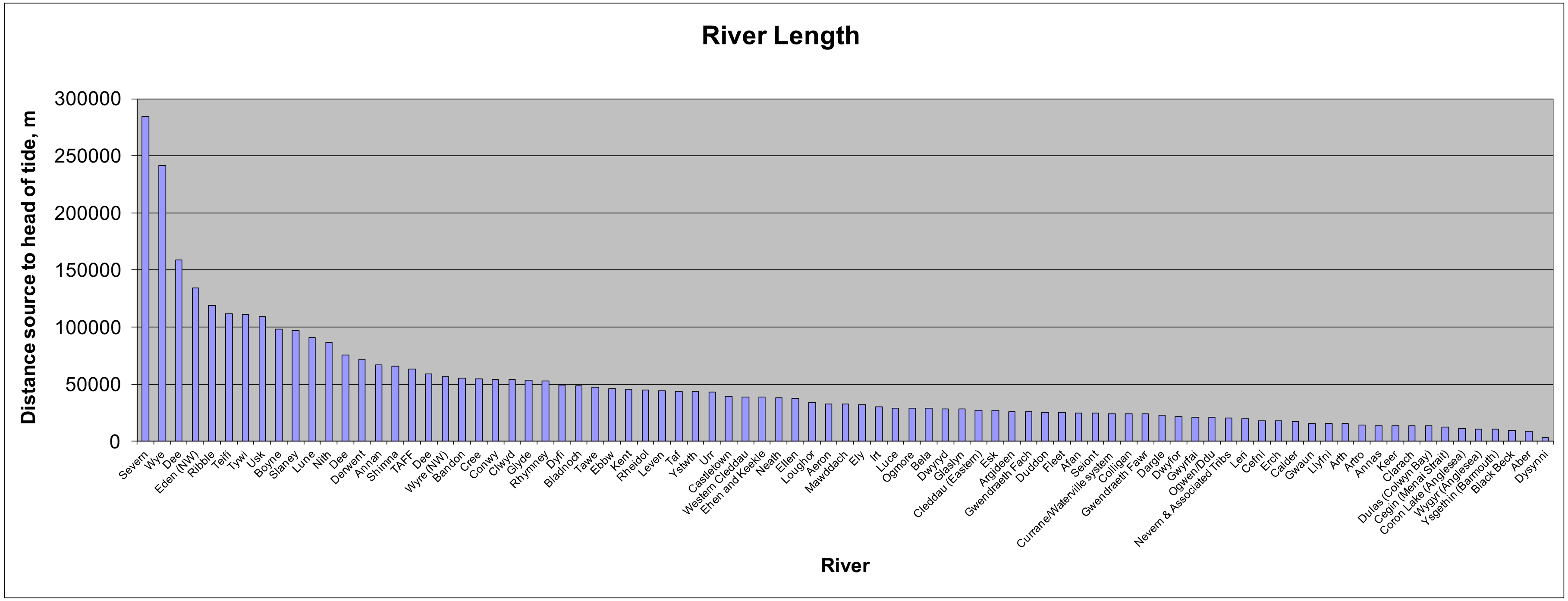

Figure 6.7.1 CSTP river catchments ranked by catchment river length (source to head of tide, main stem)

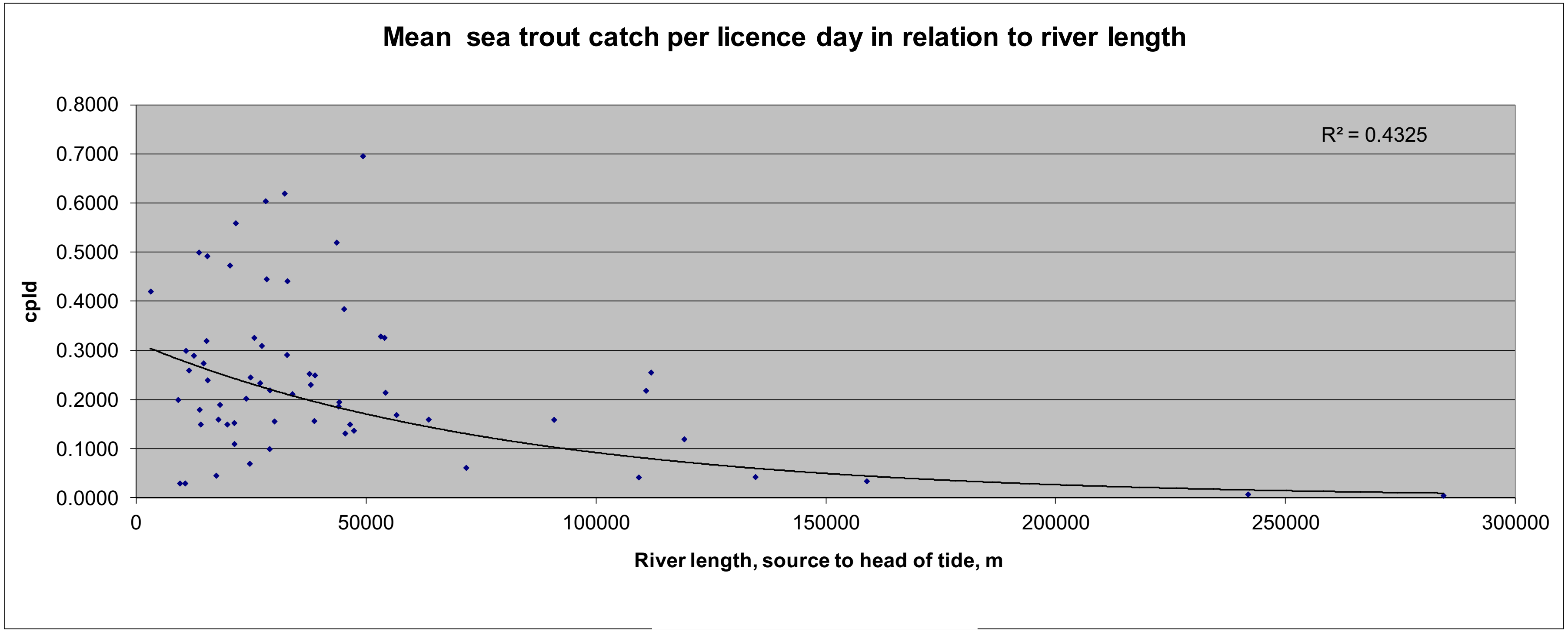

Figure 6.7.2 Simple regression of sea trout catch per licence day in relation to river length (source to head of tide, main stem)

6.7.2 Generalised Linear Modelling: Sea Trout Rod Catch and Effort Using Catchment-Scale Environmental Variables

The dataset initially presented a number of challenges to high quality statistical handling. These included a high degree of multicollinearity, a large number of independent variables measured across a variety of numerical scales and relatively few observations (river catchments) in relation to the number of independent variables available. The initial analysis was performed only using variables for which we had values for all catchments.

The key issues were addressed as follows:

- The explanatory variables were all standardised by subtracting their mean and dividing by their standard deviation to account for their measurements being across wide ranging scales.
- A tree model was used to provide an early indication of the most explanatory variables.
- The tree model was also used, along with scatter plots and correlations between explanatory variables, to establish which variables should be removed from the dataset to avoid the issue of multi-co linearity.

The final iteration of the analyses produced the following model (version March 2013)

- *Ln CPLD = -1.727 +0.306 BLW + 0.235CW + 0.332 IG -0.210 ALK - 0.560 CSL*
- Where CPLD is mean adult sea trout rod catch per licence –day
- BLW - % land cover broadleaved woodland
- CW - % Coniferous Woodland
- IG – Improved Grassland
- ALK – alkalinity
- CSL- catchment stream length

Significance levels and errors of the predictors are shown in Table 6.7.1.

Table 6.7.1 Outputs from General Linear Model of relating sea trout rod catch to catchment variables

Coefficients	Estimate	St. Error	t value	Pr(>t)	Significance
Intercept	-1.72748	0.07845	-22.019	< 2e-16	***
Broadleaved	0.30566	0.08335	3.667	0.000534	***
Coniferous	0.23542	0.08501	2.769	0.007528	**
Improved grassland	0.33188	0.09012	3.682	0.000509	***
Alkalinity	-0.21007	0.09083	-2.313	0.024305	*
Catchment stream length	-0.55904	0.08484	-6.589	1.43e-08	***

Significant codes 0 * 0.001 ** 0.01 * 0.05**

Residual Standard Error: 0.6276 on 58 degrees of freedom (adjusted R squared = 59%)

The model indicates that land cover variables have considerable influence on sea trout catch, whilst geology and catchment size are also important. A small catchment with good broadleaved and coniferous woodland cover mixed with improved grassland with underlying geology dominated by non-calcareous rocks would be expected to produce good sea trout rod catch per unit effort. It should be noted that this can only be applied to a whole catchment and not to try and predict sea trout catch in any reach or tributary because the stream length term would inflate the estimate of sea trout production.

Figure 6.7.3 shows the observed ln (CPLD) on the y-axis versus the fitted ln (CPLD) on the x-axis, based on the final model. The nature of the modelling exercise and the data we are working with makes it inappropriate to attempt to accurately predict sea trout catch, rather, the model can give an indication of the status of the fishery in terms of high, medium or low expected catch per unit effort, in relative terms, together with an expression of uncertainty. Table 6.7.2 shows example predictions using the model.

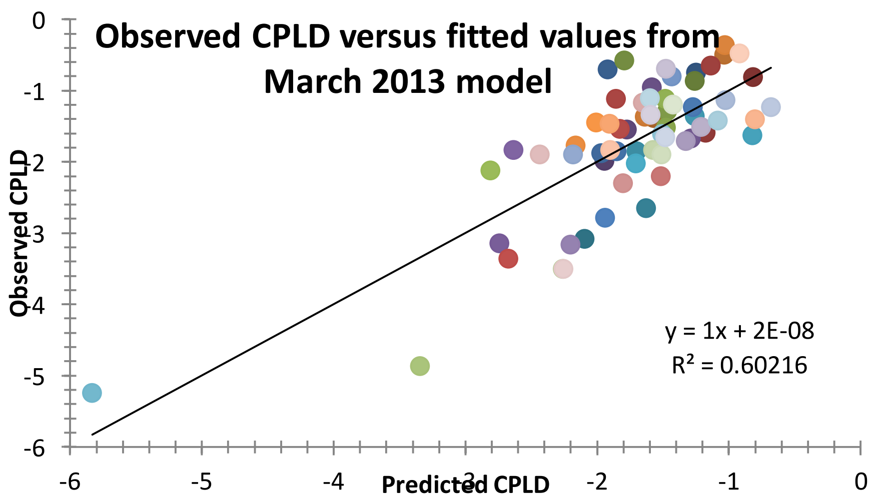

Figure 6.7.3 Comparison of actual mean sea trout catch per licence day with predictions from version 2 of the predictive model

Table 6.7.2 Example predictions from the March 2013 of the model for selected catchments

Catchment	Observed	Observed Class	Predicted	95% CI (lower – upper)	Predicted Class
Nevern*	0.473	High	0.276	0.215 – 0.353	Moderate
Aeron	0.442	Moderate	0.251	0.154 – 0.410	Moderate
Dysynni	0.421	Moderate	0.241	0.186 – 0.312	Moderate
Black Beck	0.030	Low	0.115	0.079 – 0.167	Low
Keer*	0.180	Low	0.294	0.207 – 0.418	Moderate
Aber	0.200	Low	0.220	0.159 – 0.305	Low
Afan	0.246	Moderate	0.469	0.185 – 1.188	Moderate

Class based on equal groupings: Low = (0-0.23), Medium= (0.24-0.46) , High= (0.47-0.7)*different class for observed and predicted

The predictive model based on English and Welsh data could then be applied to Irish rivers as consistent data on key variables in the model were provided, allowing sea trout catch status to be predicted.

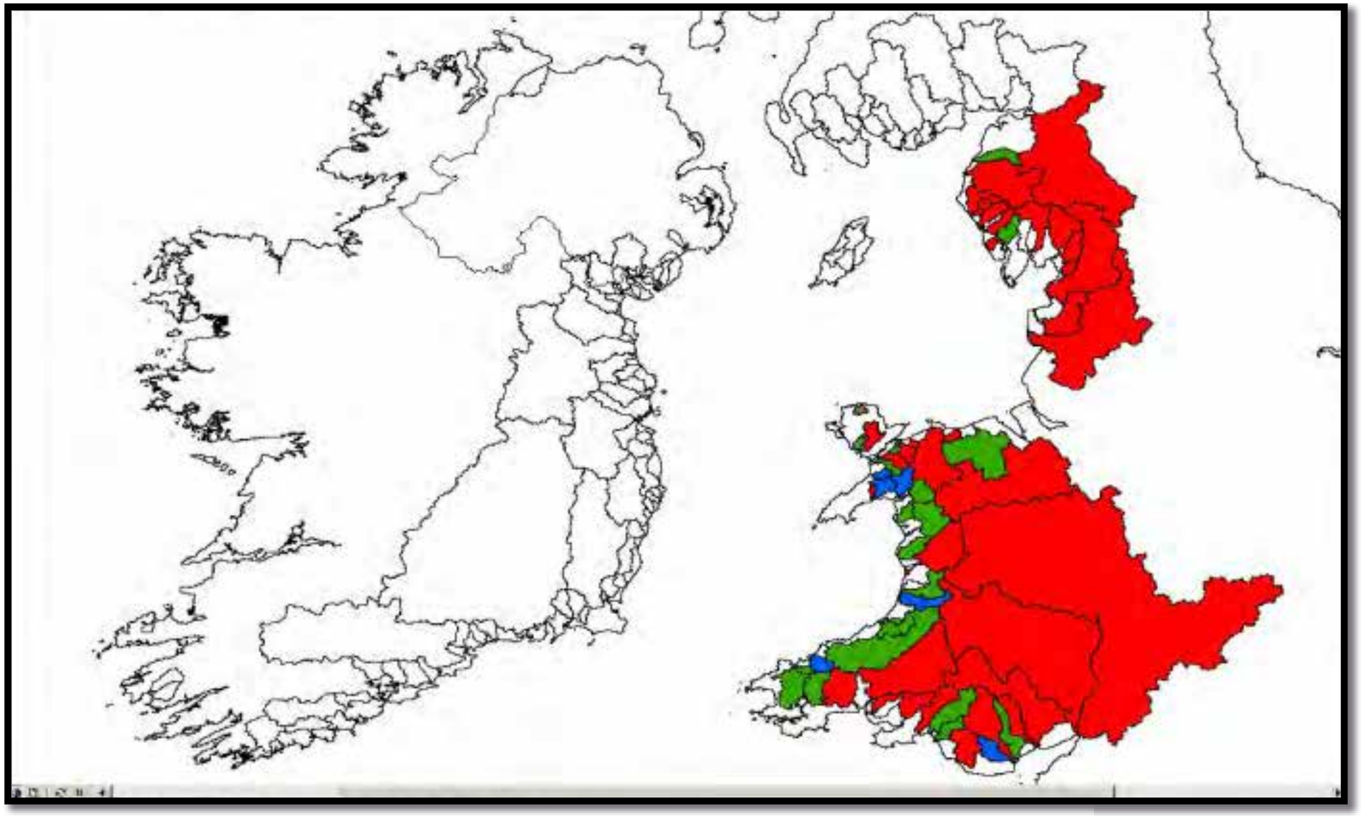

Figure 6.7.4 Actual sea trout stock status based on mean annual rod catch per licence-day, 2000 – 2010. Class based on equal groupings: Low = (0-0.23), Medium= (0.24-0.46) , High= (0.47-0.7).

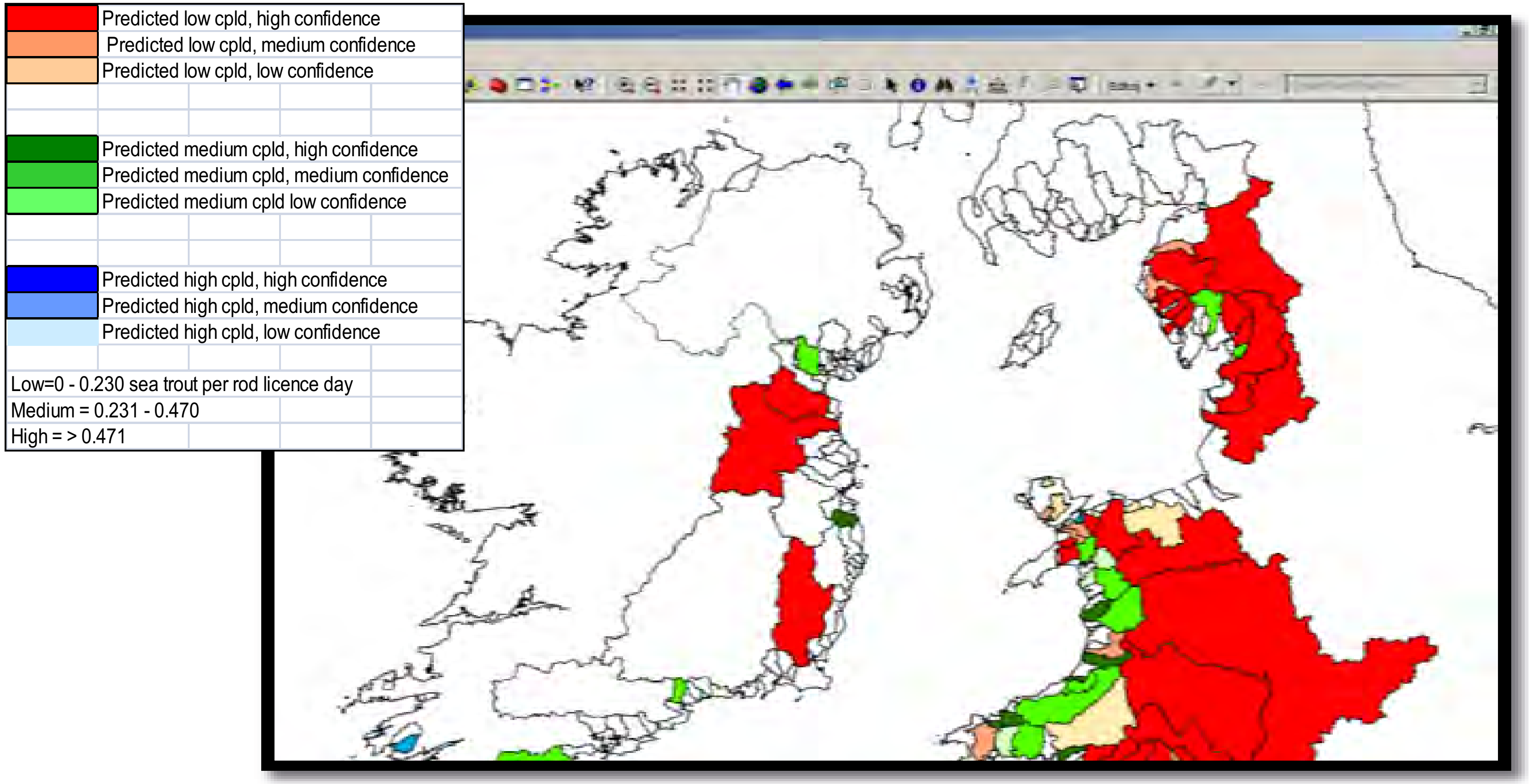

Figure 6.7.5 Predicted sea trout catch status for all CSTP catchments using March 2013 GLM model.

Whilst no catch per unit effort data were available for Ireland, estimates of total rod catch for these rivers by local fisheries officers gave some indication of the status of the rod fishery (Table 6.7.3).

Table 6.7.3 Comparison of predicted sea trout rod catch with fisheries officers' estimates - Ireland

NAME	p.low	p.med	p.high	class	fisheries officer estimated total annual catch - mean 2000-2010	corresponds with FO estimate ?
Argideen	99%	1%	0%	Low	434	√
Bandon	14%	86%	0%	Medium	873	√
Boyne	100%	0%	0%	Low	1973	xxx
Castletown	17%	83%	0%	Medium	1064	√
Colligan	37%	63%	0%	Medium	1764	x
Currane/W	0%	38%	62%	High	2826	√
Dargle	3%	97%	0%	Medium	108	x
Dee	100%	0%	0%	Low	615	x
Glyde	99%	1%	0%	Low	201	√
Slaney	100%	0%	0%	Low	1000	x

Only one river, the Boyne, had a predicted sea trout catch status very different (> 1 class) from the estimated rod catch and it must be stressed that the fisheries officer estimates are for total catch only and do not include effort. The Boyne is a relatively large river with a good salmon fishery and hence lots of rod effort.

6.7.3 "Random Forest" Analysis: Sea Trout Rod Catch and Effort Using Catchment-Scale Environmental Variables

As with the generalised linear modelling, calcareous geology again came out as being of significance, with catchments with lower percentage calcareous geology tending to have higher sea trout catch per unit effort. This initial analysis was performed only using variables for which we had values for all catchments.

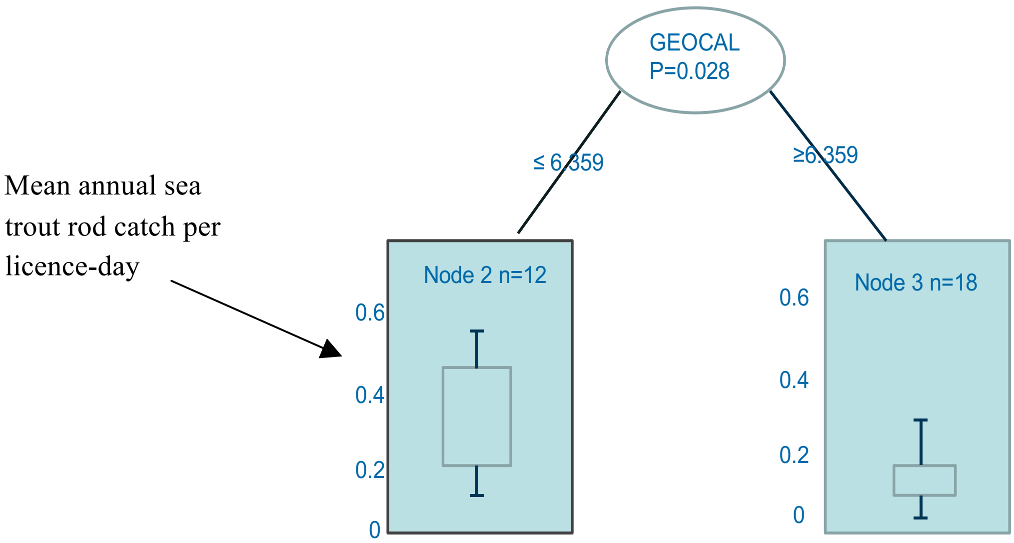

Figure 6.7.6 "Random Forest" regression tree for influence of catchment characteristics on sea trout rod catch per licence-day.

The analysis was re-run using mean annual total sea trout catch as the dependent variable and mean annual rod effort in days as one of the predictor variables (Figure 6.7.7).Fishing effort in days per year emerged as the strongest predictor of mean annual total sea trout rod catch, although calcareous geology and catchment size (expressed by flow and catchment land area) were also important with the very small rivers in base-poor catchments having lower catches than the medium and larger rivers. These indications actually run contrary to those relating catchment characteristics to catch-per-unit-effort. This underlines the limitations of using catch indices to measure stock size – much of the variation we see relates to fishery characteristics.

Mean annual sea trout rod catch

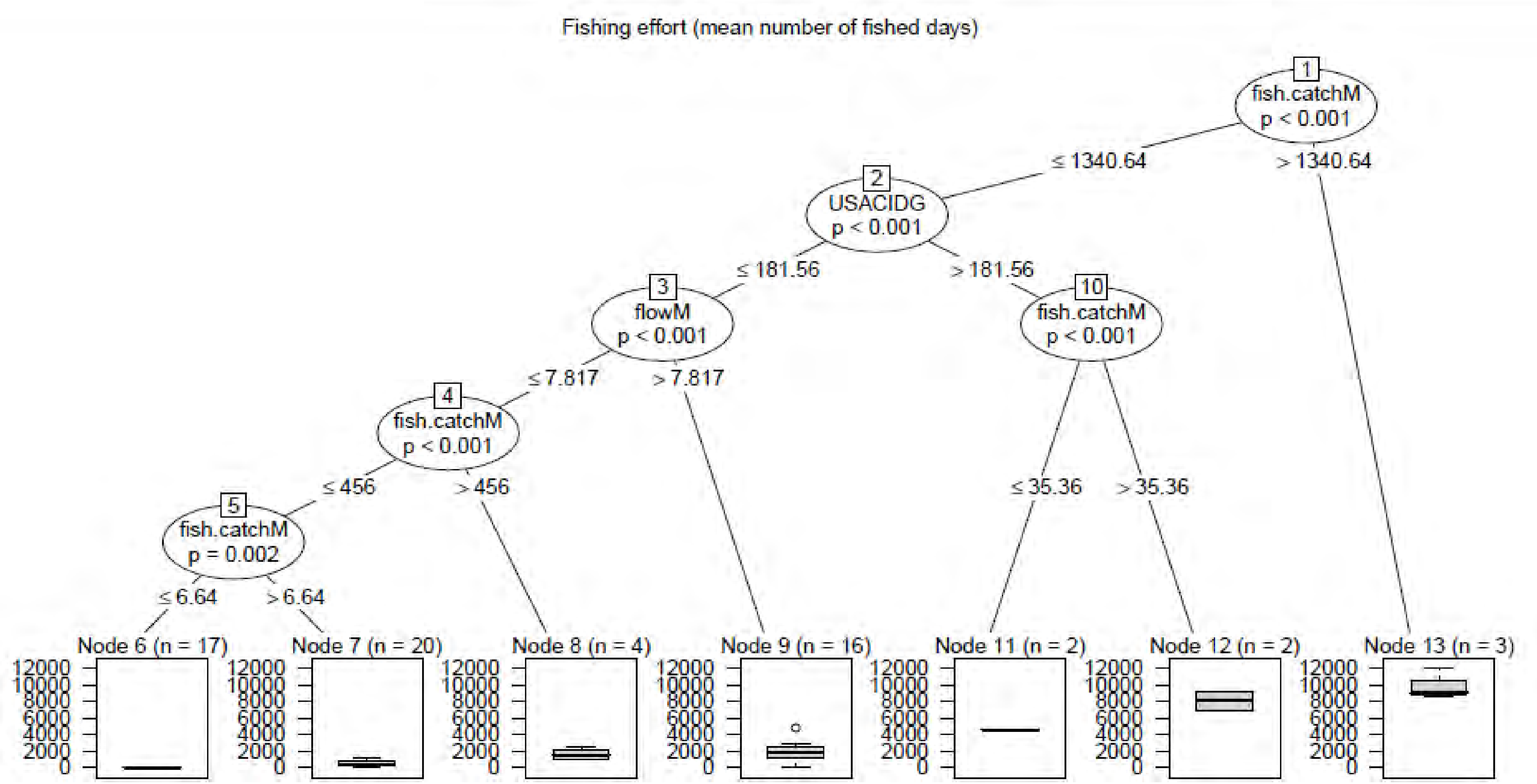

Figure 6.7.7 "Random Forest" regression tree for influence of catchment variables and rod effort on mean total annual sea trout catch

6.7.4 Juvenile Trout Abundance and Reach-Scale Environmental Variables

These data presented challenges both for catchment scale and reach-scale approaches.

Juvenile salmonid sampling sites were not randomly or uniformly distributed within the salmonid nursery zones of catchments and the density of sampling sites varied between catchments. In addition, some sites were sampled throughout the period of study whilst others were sampled only once during the 2000-2010 period making intra-, and perhaps inter-catchment, evaluation problematical (see Figure 6.7.8 and Figure 6.7.9). The distribution of juvenile salmonid survey sites and the mean densities of 0+ salmonids (England, Wales) are shown in the series of maps in Appendix 6.4; summary figures for some Scottish catchments are also shown. It was resolved that analysis would only be performed on data from periods during which the majority of sites were sampled at least once.

In general, the regression trees from random forest highlight the importance of geographical factors in partitioning the data set, illustrated by both regression trees and dotchart, (Figure 6.7.10 to Figure 6.7.13). The analysis also highlighted the role played by geographical location, e.g. easting and northing, in explaining the dataset. It is also apparent that, based on the total variation explained by the random forest model, more variance is explained with the inclusion of abundance of juvenile salmon, however, the increases in percentage variance explained are not major (see Table 6.7.4). Furthermore, whether the presence of salmon is a positive or negative variable cannot be determined from this analysis alone.

Table 6.7.4 Variance in juvenile trout abundance explained by random forest models.

Model	Variance Explained
0+ brown trout abundance v DRN variables	59.5%
>0+ brown trout abundance v DRN variables	51.6%
0+ brown trout abundance v DRN variables with salmon values	61.6%
>0+ brown trout abundance v DRN variables with salmon values	54%

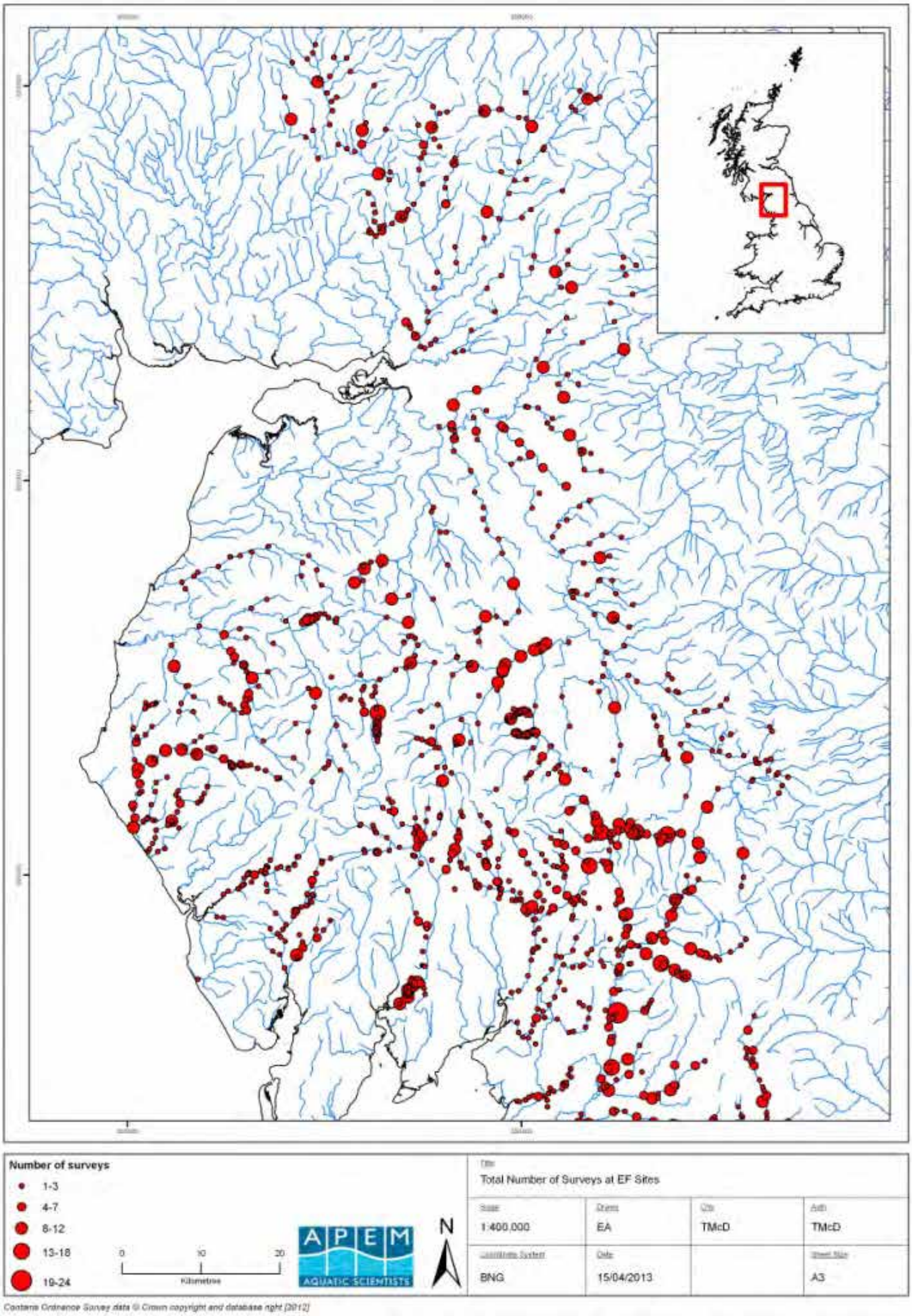

Figure 6.7.8 Total number of survey occasions, Cumbrian rivers, 2000-2010.

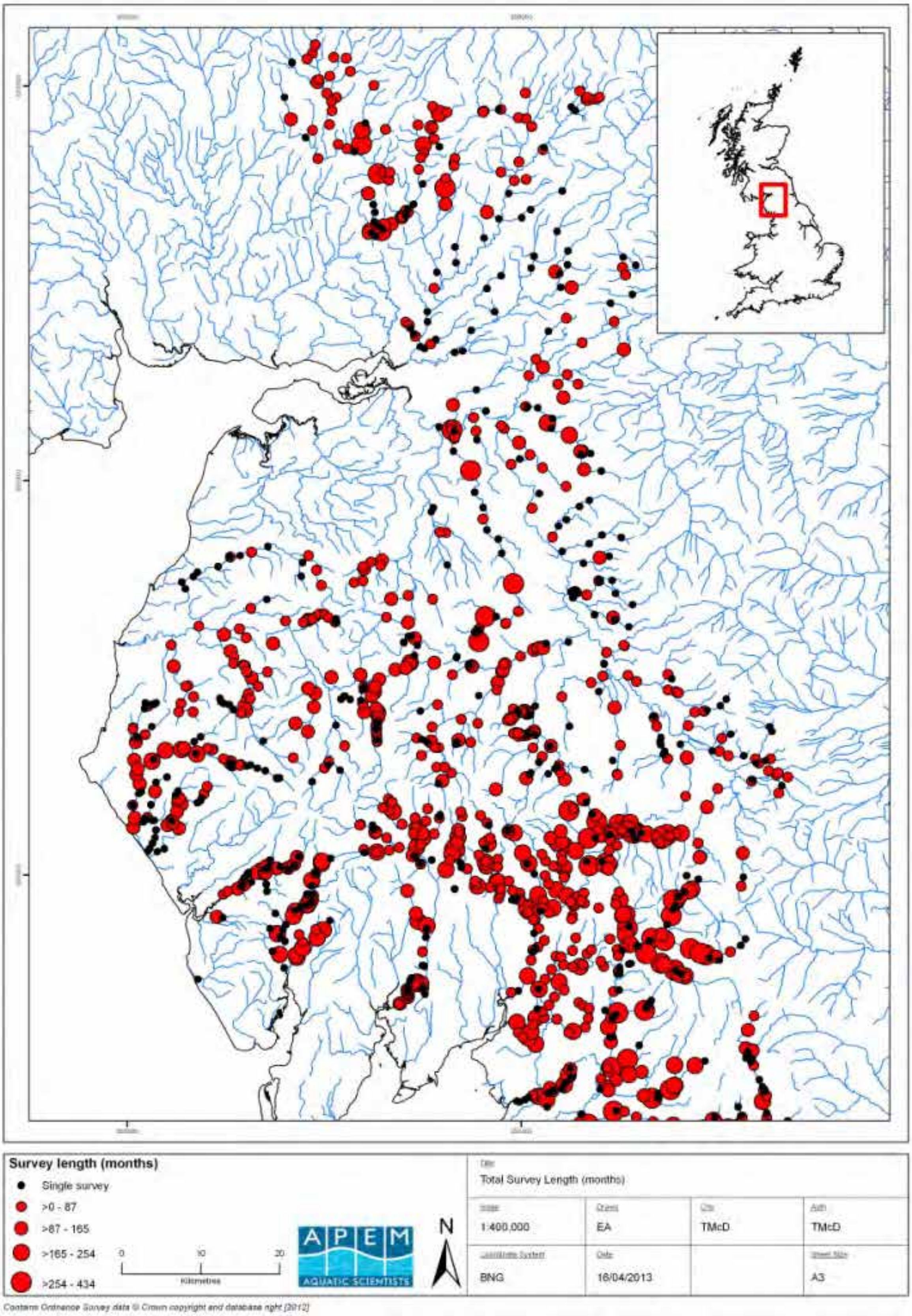

Figure 6.7.9 Total duration of survey in months.

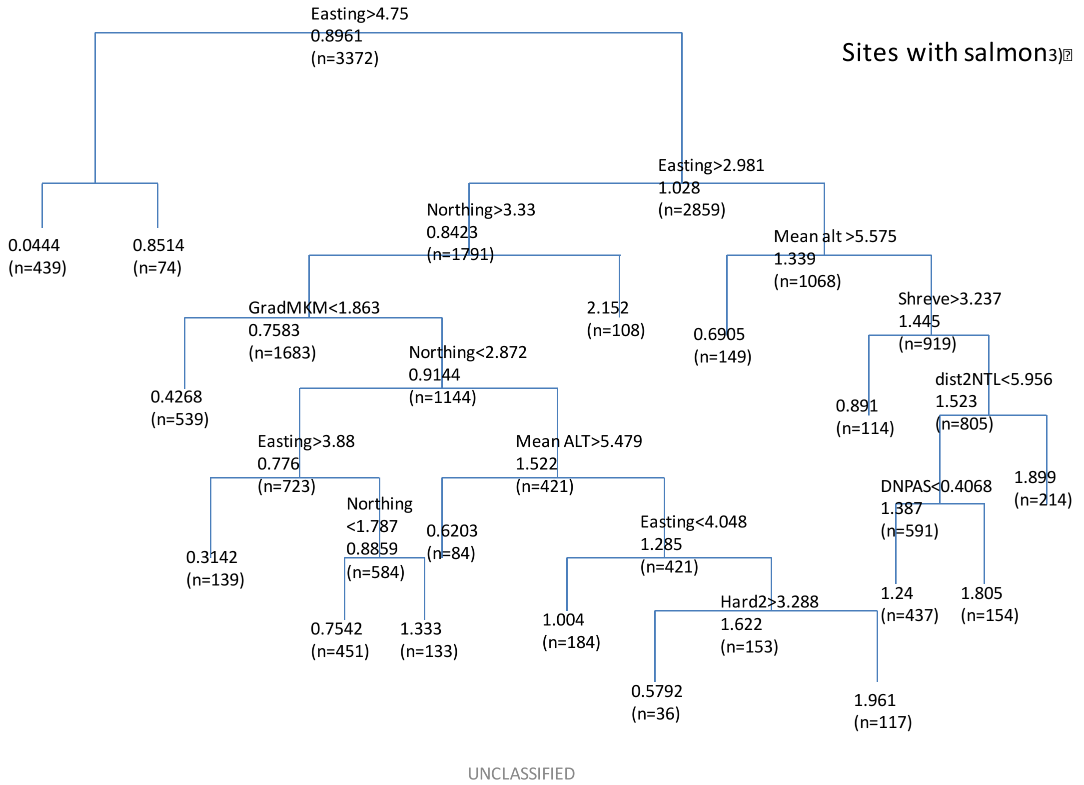

Figure 6.7.10 Random Forest output showing hierarchy of influence of reach-scale environmental variables on 0+ trout abundance (0+ salmon included) at sites

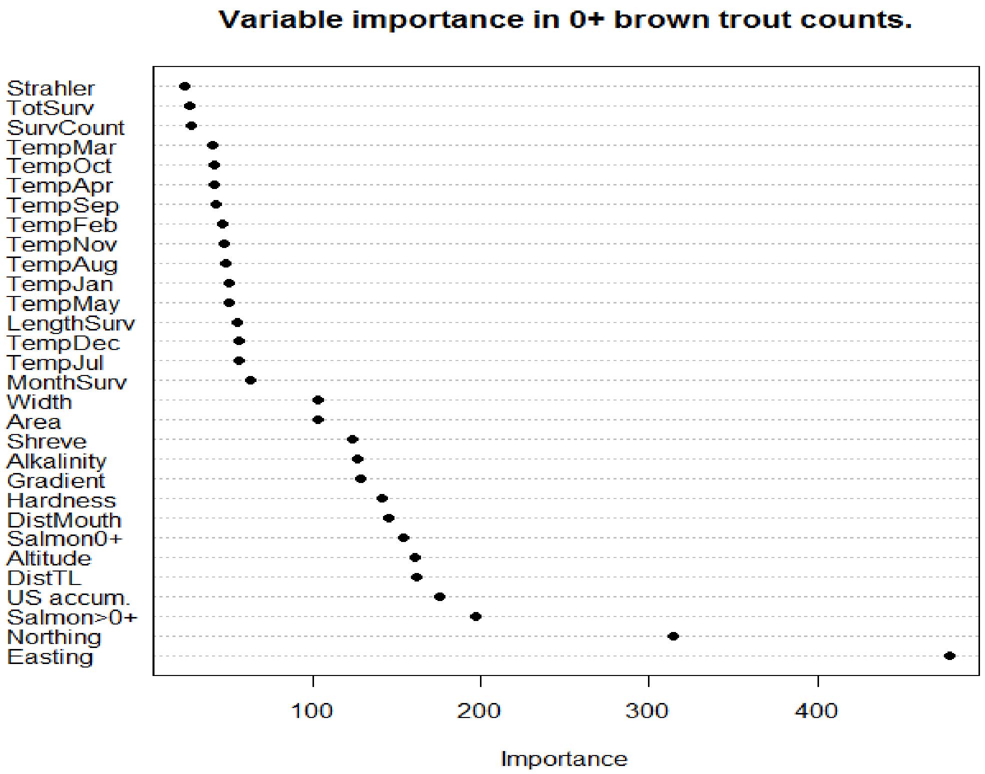

Figure 6.7.11 Dotplot showing relative influence of reach-scale characteristics in 0+ trout site abundance – including juvenile salmon

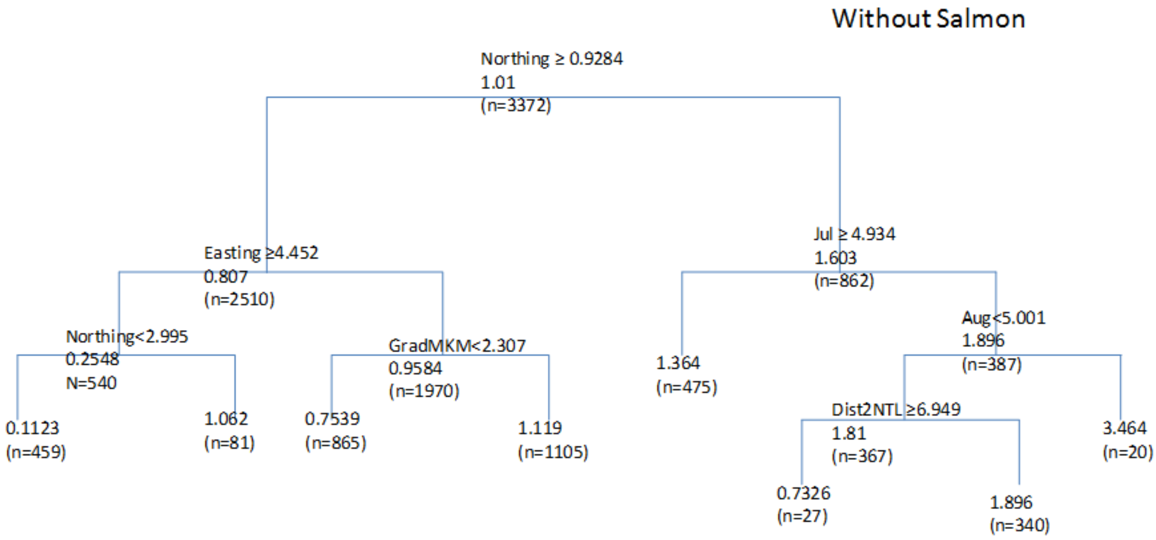

Figure 6.7.12 Random Forest output showing hierarchy of influence of reach-scale environmental variables on 0+ trout abundance at sites (salmon excluded)

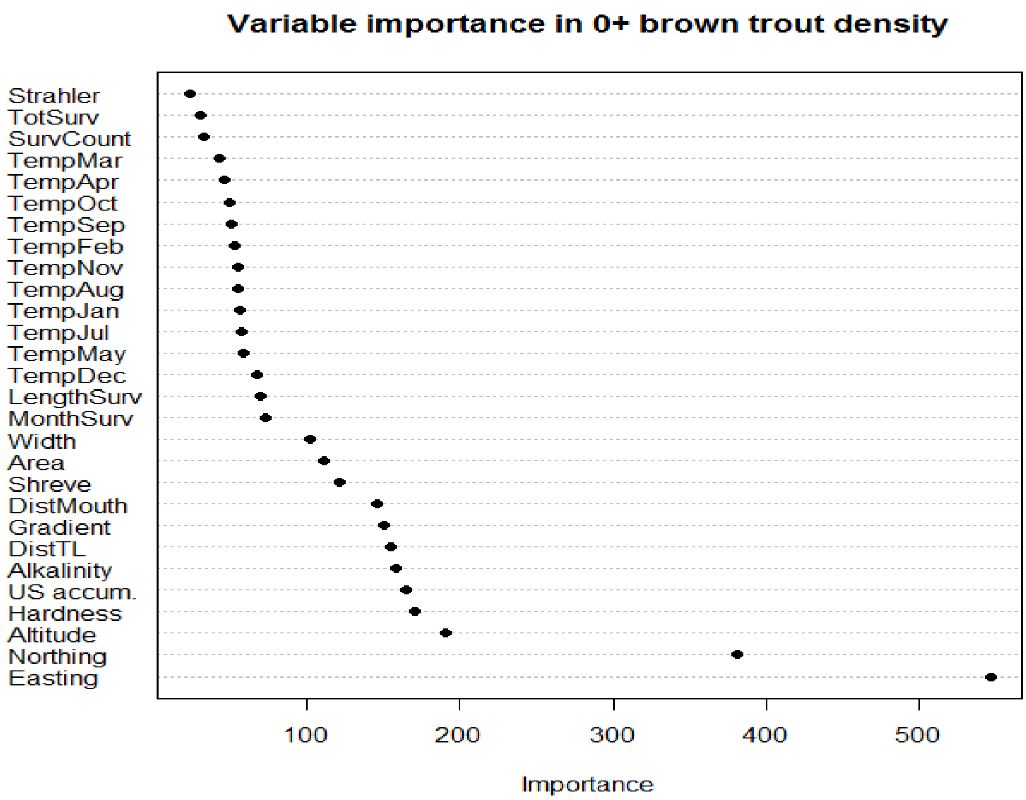

Figure 6.7.13 Dotplot showing relative influence of reach scale environmental variables on 0+ trout abundance at sites (salmon excluded)

6.7.5 Relationships between Juvenile Salmonid Abundance and Sea Trout Rod Catch per Unit Effort

Simple linear regression analysis to develop an understanding of the interrelationship between CPLD and trout and salmon catchment production metrics was undertaken. The results from this analysis are presented in Table 6.7.5.

Table 6.7.5 Regression outputs for influence of juvenile salmonid production on sea trout rod catch per licence-day. (n.s. = non-significant)

Predictor Variable	f-statistic	Degrees of Freedom	t	r^2	p
0+ trout abundance	0.4993	56	-0.707	0.009	0.483
>0+ trout abundance	1.907	56	-1.381	0.016	0.173
0+ salmon abundance	9.85	56	-3.14	0.13	0.002
>0+ salmon abundance	6.87	56	-2.64	0.09	0.01

There is therefore no significant relationship between indices of overall catchment production of juvenile trout and adult sea trout rod catch (cpld).

However there is a small but significant interaction between Atlantic salmon juvenile density and CPLD. Following this, the catchment production metrics for both 0+ and >0+ Atlantic salmon were included as independent variables in a generalised linear regression analysis between the variables identified in Table 6.7.3 and CPLD.

Although there was a significant model constructed from the physical catchment variables presented in

Table 6.6.3 the interaction between CPLD and Atlantic salmon was not retained. This was checked against the variables retained in the original model for catchment variables and sea trout rod catch (Section 6.7.2 and Appendix 6.2) and again the lack of a relationship between juvenile salmon abundance and sea-trout in the presence of the other variables persisted. This suggests that the singular relationship between CPLD and Atlantic salmon CPM is mediated through inter-relationships with physical factors and does not necessarily represent interspecific density dependence interactions manifested through an apparent relationship with final return rates of sea-trout.

6.7.6 Relationships between Juvenile Salmonid Abundance (Catchment Production Metric) and Catchment-Scale Variables

River areas for three categories (channels under 5, 10 and 20m) in each catchment were calculated and used to develop alternative metrics for juvenile trout production. Productivities based on each category were correlated against each other to check for synchronicity, and as correlation coefficients between each area level were quite high (Kendall's Tau > 0.97 for all comparisons), only the density of 5 m channel width area metrics was retained for further analysis. Although a more robust metric could have been derived, this was constrained by the differing approaches historically used to assess salmonid populations.

The catchment production metric for each catchment was analysed in relation to the suite of catchment-based variables (Table 6.3.1 and Appendix 6.1).

Variables were assessed for co-linearity and related variables removed. Kendall's Tau > 0.7 was used as the cut off for retention (following the same procedure as for the GLM of adult sea trout rod catch, Appendix 6.2) and only the variables (n=20) detailed in Table 6.7.6 were taken forward (*see Table 6.7.2 for more detailed explanation of variables*).

Table 6.7.6 Variables retained in analyses of catchment production of juvenile trout and catchment-scale environmental variables.

Variable	Abbreviation
Catch per licence Day	CPLD
Easting	Easting
Northing	Northing
Distance to source	DISTSOURCE_m
Average upstream elevation	AVELEVU
Upstream arable	USARABL
Upstream woodland	USBLWOO
Upstream bog	USBOG12
Upstream bracken	USBRACK
Upstream calcareous grassland	USCALCG
Upstream coniferous woodland	USCONWO
Upstream heathland	USHEATH
Upstream improved grassland	USIMPGR
Upstream neutral grassland	USNEUTG
Upstream saltmarsh	USSALT2
Upstream suburban area	USSUBUR
Upstream urban	USURBAN
Calcareous geology	GEOCAL
Saline Geology	GEOSAL
Siliceous Geology	GEOSIL

Catchment Production Metrics (CPM) for 0+ and > 0+ brown trout for each catchment were regressed against the variables listed in Table 6.4 to develop an understanding between the relationship between catchment scale variables and a singular metric of trout production. The models for both cohorts retained no significant interactions. This process was repeated for those variables previously identified in the GLM model for catchment variables and sea trout rod catch (Section 6.7.2, Table 6.7.1, following the procedure in Appendix 6.2) and again there were no significant interactions, suggesting that, within the dataset examined in the Celtic Sea Trout Project, the overall production of young trout in the catchment cannot be predicted on the basis of catchment characteristics alone.

6.7.7 The GIS Database

Maps of sea trout distribution, location and nature of potential barriers to migration, and known sea trout spawning areas are shown in Appendix 6.3.

The validation of pre-existing information on sea trout distribution and location and status of potential barriers to sea trout migration in England and Wales yielded significant changes to previous iterations. There were some changes in perceived sea trout distribution, mostly between the "sea trout present" and "sea trout possible but presence not confirmed" categories, these however constituted only a small proportion of the total catchment river networks with very little overall change in either category.

The detail of information provided varied between areas; some catchment-based officers had very detailed knowledge of catchments and sea trout presence whereas more senior, area or regionally based staff were more likely to indicate broad agreement with the original 2002 dataset. Even amongst officers with detailed knowledge there was clearly an element of subjectivity in distinguishing between confirmed sea trout presence and sea trout potential presence. In many cases it has clearly been assumed that sea trout are present or theoretically present as far as the downstream-most impassable barrier, this may not always be strictly true.

There was significant new information on potential barriers to migration, including indications of porosity to upstream migrating adult sea trout, and locations of barriers not on the present version of the Obstructions database. Here again however there was subjectivity in the assessment of structures as significant barriers to migration, since in reality this is very difficult to determine: the more formal barrier assessments using WFD 111 methodology undertaken for the Scottish catchments have not yet been done generally in England and Wales.

Information on spawning areas for sea trout was very sporadic, detailed information existed for North Wales and parts of Cumbria, with some more general information for South-West Wales and very little for South East Wales.

For Scotland detailed information was provided on sea-trout presence and spawning only for the Annan, though there was qualitative information on the others.

6.8 Discussion and Conclusions

6.8.1 What Do The Models Mean?

Many studies (see section 6.2.3 and 6.2.4) have examined the factors influencing anadromy in trout species in specific catchments or by comparisons of neighbouring contrasting rivers; however the present study is one of the first to look at this issue over a broad geographic region such as the Irish Sea rim.

Task 6 of the Celtic Sea Trout has produced a model based on catchment features which can explain up to 60% of the variance in mean sea trout catch per licence-day. However it is questionable whether this furthers the understanding of the true drivers of anadromy in *S. trutta*. In reality the models are predicting the performance of sea trout fisheries rather than output from populations. This is because for the less productive sea trout fisheries (on the basis of the small physical size of the river, or its perceived low productivity of sea trout, or the domination of the fishery by other species e.g. salmon) we will inevitably underestimate the true production of sea trout, simply because they are not fished for by significant numbers of anglers. Mean sea trout catch per unit effort is very likely as much a function of the fishery as of the ecosystem. The indications from the analysis of sea trout rod catch and juvenile catchment production nevertheless suggest that total trout production is not a good indicator of adult sea trout abundance and underlying factors influencing the propensity to migrate are more important.

The final general linear model generated (see section 6.7.2) does support the basic theories underlying the drivers for anadromy in *Salmo trutta* outlined in sections 6.2.3 and 6.2.4, although some variables which we might expect to show a strong relationship with sea trout abundance, such as numbers of barriers in catchments, did not emerge as strong drivers of sea trout catch (and by implication, anadromy).

The possibility of more accurate and precise modelling of sea trout production and anadromy in catchments is compromised not only by reliance on rod catch data. There is increasing evidence that anadromy is at least partly under genetic control. Hence, in observing how adult sea trout catches relate to catchment features, we cannot account for adaptive genetic differences between stocks from different rivers which may influence how trout from those populations interact with their environment. In other words we are not dealing with a homogenous stock.

The failure to find relationships between juvenile trout production and catchment-and reach-scale environmental characteristics was surprising given that many authors have found such relationships and produced models and systems to predict and assess trout stocks (Wyatt et al 2008, Milner et al 1993, Heggenes, 1998, Rosenfeld et al, 2000). There are a number of possible reasons for this:

- The rivers studied are broadly similar (i.e. they are all salmonid rivers) and the dataset did not represent a sufficiently large gradient of catchment characteristics to discern the key drivers of trout production.
- The sampling of juvenile salmonids is neither random nor stratified and is mostly targeted on areas where juvenile salmon are found, and is conducted primarily for the purpose of assessing temporal variation in juvenile salmon stock. So again, it is possible that the sites chosen are in river reaches that are generally very similar.
- Sites may not be at carrying capacity and thus not constrained (influenced by) habitat features, and/or are being limited by other factors not considered in this exercise.
- Other aspects of sampling such as number of survey occasions, length of survey programme, and purpose of survey (the dataset may include sites that were monitored for assessment of an impact) may mask real variation in trout production between reaches and sites with differing environmental features.

The emergence of geographical location as the most important driver from the variables examined is also noteworthy and could be integrating other influences, such as distance from the sea, gradient and altitude. In North West England and Wales we are dealing with rivers that are flowing east to west and hence sites and river reaches further east are likely to be smaller, steeper gradient, less productive and at higher altitude and hence support lower densities of juvenile trout. Influence of northings (latitude) appeared weaker probably because the dataset includes some rivers that are flowing almost north-south, such as the South Wales valleys rivers, and others that are south-north, such as the North Wales rivers and the Eden tributaries.

6.8.2 Implications for Management

This study has focussed on identifying the basic environmental characteristics of rivers that influence the tendency of trout population towards anadromy. River managers can have relatively little influence on underlying physical characteristics, however, evidence (from this and earlier studies) does point towards certain courses of action that will foster a viable sea trout population in rivers that are broadly suitable. Conversely, where our understanding suggests that a river is not likely to support significant sea trout runs, managers can focus their attentions on developing fisheries for brown trout, salmon or other species.

Priority areas for river managers for conservation and enhancement of sea trout stocks include:

- Efforts to reduce any anthropogenic enrichment of the catchment which might make the river more biologically productive and thus favour trout residence rather than anadromy; this will include a range of measures to reduce point-source and diffuse nutrient input.

- Maximising quantity and quality of trout spawning nursery streams, via riparian and instream management and reduction of fine sediment input.

- Whilst sheer number of barriers in catchments did not emerge as major drivers of sea trout rod-catch, it is felt that this variable was highly correlated with overall catchment size/stream length which appeared more important. However, at an individual river level, removal or amelioration of barriers to migration has been shown to increase sea trout populations and directly reduce losses of both upstream and downstream migrants. Likewise, screening and other measures at off-takes to reduce entry of downstream-migrating smolts to off-line lakes and dams, as well as more harmful structures such as water abstraction intakes and hydropower turbines, is high priority.

6.8.3 Recommendations and Further Research

6.8.3.1 Sea Trout Rod Catch and Fishing Effort Monitoring

Improved management of sea trout fisheries and continuing research into sea trout population dynamics will only be possible with more detailed and consistently-collected data.

Mandatory systems for recording sea trout rod catch by individual anglers, including details of fish size, location, and date of capture, should be adopted across the Celtic Sea Region to improve data quality.

Sea trout fishing effort should also be recorded since with no measure of angling effort at all it is not really possible to indicate stock size, compare rivers, or assess year to year variation. A large total sea trout catch may indicate high fishing effort on an average sea trout run, or a very prolific run exploited by relatively few successful anglers. Where rod fishing effort is currently recorded (in England and Wales) it should be stipulated that anglers record separately their effort for sea trout and salmon.

6.8.3.2 Further Research into Factors Driving Anadromy

Better management and conservation of sea trout will only be possible with improved understanding based on evidence and research.

Increased understanding of the influence of environmental features on sea trout production will only be gained by undertaking catchment-specific, detailed studies of trout production and movement using a combination of marking and trapping, stable isotope analysis, scale microchemistry and genetics.

In this way the nursery origins in a catchment of sea trout smolts and adults could be identified and more detailed studies undertaken in those areas to elucidate key features. This will enable clearer identification of the key parts of river catchments for sea trout production, and the factors influencing production, in order to target measures to protect and manage sea trout populations.

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7 Marine Ecology, Life Histories and Modelling for Management

7.1 Introduction

7.1.1 Aims and Objectives

The overall aim of Task 7 was to describe marine ecology, life histories and population dynamics of sea trout in the Irish Sea and to model relationships with key environmental features in order to provide management advice. Specific objectives were to:

- Provide a data-base on ecology and life histories for future research.
- Describe and quantify relationships between environmental variables, population life histories and stock features, focussing on adult fish.
- Develop a conceptual model of the relationships in terms of life history optimisation, to develop a theoretical process basis to the population dynamics and modelling.
- Develop preliminary life-history based models of responses to environmental and other pressures that will be of use in fishery management.

Sea trout, the sea-going form of brown trout (*Salmo trutta* L.), are abundant in rivers entering the Irish Sea and support many river rod fisheries and a smaller number of estuarine and coastal commercial fisheries (see Workpackage 2). Sea trout fisheries vary in quality, expressed through catches, fish size distribution, abundance and seasonal run timing. The monitoring and assessment of these features are central preoccupations of fisheries management, which seeks to ensure that fisheries are in acceptable condition and that the stocks reflect good environmental condition (cf Water Framework Directive) in freshwater and marine habitats. The use by sea trout of multiple environments: freshwater, transitional and marine, during their life cycle makes them potentially valuable bio-indicators.

Life histories directly influence the properties of stocks and fisheries by controlling abundance through survival and size distribution, and seasonal run pattern though the age at maturation and return from the sea. Therefore knowledge of life histories and their responses to environmental factors has considerable significance for fisheries and for the maintenance of biodiversity expressed through the variety of trout life histories. In particular, anadromy, the life history strategy of spending the adult stage at sea before return to and breeding in rivers, is what gives rise to sea trout; but it has many variations with fundamental implications for the fisheries.

However, the relationships between trout biology, ecology, life histories and environment, are still poorly described and understood, particularly at sea (e.g. Elliott et al., 1992; Milner et al., 2006). Task 7 aims to describe and analyse these relationships for the Irish Sea in ways that are useful to the fishery managers for managing stocks, or for explaining why variation between fisheries occurs. The Task examines specific issues of sea trout marine ecology and life history variation, but also draws on information from other tasks to assemble understanding and advice that apply across the variety of sea trout stocks around the Irish Sea.

Throughout this account the focus is on the anadromous form, sea trout, because they represent a distinct morph of the brown trout, with fisheries that are managed through different administrative procedures from the resident form. However, it must be emphasised that sea trout are simply one part of the life history range of brown trout and where feasible and appropriate the trout population complexes of accessible (to the sea) rivers in their entirety are considered. In practice often that is not feasible and this dichotomy of life histories, termed partial migration (Chapman et al., 2102), presents significant problems for fisheries assessment and management of trout.

The Task 7 chapter opens with definitions of life history terminology and an explanation of the rationale for the approach to the task. An overview of previous knowledge of life history variation in the Irish Sea is given. The chapter then describes stock status and trends around the Irish Sea, the results of the studies on stock sizes and variation in key life history features, with a focus on growth and survival and explores some effects of climate change. The marine ecology and biotopes section describes feeding at sea and the habitat features of sea trout marine life. Some facets of life history based models of fisheries are outlined and the approach to this on-going work is summarised. Conclusions and recommendations are given.

7.1.2 Trout life History Terminology

There are many stages and variations in trout histories giving rise to a specific terminology and a labelling system that supports age and spawning schedules as revealed through scale reading. The life stage nomenclature used here is based largely part on that proposed by Allan and Ritter (1977).

0+ fry or parr: fish in their first year of post-emergent life. May refer to 0+ fry for the earliest stages (e.g. <1month old) and to 0+ parr, up to the time of their first winter check (normally evident by April/May of their second year.

1+, 2+,…n+ parr: fish in their second and consecutive years of freshwater life.

Residents: broadly, brown trout that do not migrate into coastal waters. There is a continuum of downstream migration in brown trout depending on local circumstances (e.g. feeding opportunities and migration risk); with fish reared in small nursery stream migrating to main stem rivers, to lakes, to estuaries or to the sea. While these are all functionally inter-breeding brown trout, but the fish that migrate to sea are considered separate because of the major environmental and life history shift on moving into open sea zones.

Smolts: young trout having adopted the morphological and physiological adaptations necessary for migration downstream to the sea. There are various classifications of these migrants (see Bagliniére et al., 2013) associated with different adult life history types.

Post-smolts: sea trout at sea after smolting and before their first return to river or first sea winter.

Whitling, Finnock, Juniors, Herling: these are four of many synonyms for the youngest group of post-smolt sea trout that return to rivers in the same year that they smolt, therefore before their first post-smolt winter. They may be mature or not and therefore may or may not contribute to egg deposition. They usually return later in the year (after July), because they typically smolt between March and May.

Maiden fish: adults that have not yet spawned, found in the sea or returning to the river for the first time since leaving the river as smolts (finnock are therefore maidens). The term applies to both sexes.

Kelts: sea trout in rivers that have spawned and are migrating downstream back to sea.

The scale reading terminology follows the conventions set out originally by Nall (1993) and subsequently used by most workers (e.g. Harris, 2000). This is described in the CSTP scale reading manual (CSTP, 2010). As the project developed and some of the characteristics of sea trout marine growth and river return behaviour in the Irish Sea became clearer additional terms were created to reflect the ambiguities, for example Indeterminate Mark (IM) (see Section 3.10). A special section on scale reading and the role that this might play in routine fisheries assessment is included in this report.

However, because scale formulae are used in the text as shorthand for age class, some examples are given below, with their life history meaning. The formula (n.n) has two parts (before the point is freshwater and smolt life, after the point is post smolt, adult reproductive life). The formula conveys:

- age in winters (numerical), based on count of annual “winter” checks
- spawning history (alphabetical, SM) and marine residence
- growth status (denoted by presence of absence of +). Most fish have +, meaning growth (generally termed “plus-growth”) is in progress. Rarely there may be no +, meaning that a winter check has just formed on the edge of the scale. + is also used in multiple returning fish to unambiguously indicate growth between winter or spawning checks. Note that checks are conventionally termed “winter” checks, on the grounds that in most fish growth ceases or slows in winter due to low temperatures; but in practice sea trout can form genuine annual growth checks well into spring or in early autumn and maintain growth during winter months.

7.1.3 Brief Explanation of Sea Trout Scale Formulae (adapted from the CSTP Scale Reading Manual)

The various terms used to describe the life history characteristics of sea trout follow the international Standard Nomenclature proposed by Allan & Ritter (1977). The conventions used to ascribe a numerical formula to describe the pre-smolt and post-smolt life history stages of sea trout are based on those adopted by Nall (1930), Went (1962) and Harris (2000). For example, a two year old smolt having returned to freshwater in the same year as its smolt migration is denoted as 2.0+, the point (.) indicating the separation between river and marine life phases. The initial number in the scale formula after the point records the number of complete post-migration winters spend at sea. In the CSTP, the convention has been adopted of referring to sea growth in first year of marine life as .0+. Although this is not always used in scale formulae of other accounts it provides an unambiguous statement of experience prior to the first spawning mark (SM) in the case of whitling. The + symbol serves two purposes; first it is a representation of the time between maiden sea growth and first spawning, second it represents a period of uncompleted summer growth between one winter and the next. The term maiden refers to a fish that has returned to the river for the first time after migrating to sea and spending a winter at sea as a post-smolt. B type smolt growth is additional growth after the final freshwater winter, associated with in-river growth during the downstream smolt migration, also known as "runout".

Table 7.1.1 Scale formulae meanings and some issues

Scale formula	Interpretation	Issues
1+,2+,3+,4+	Freshwater trout of 1 to 4 years age, with plus growth after the last winter check. Could be smolts. No sign yet of marine (faster, wider circuli) growth	Smolt status determined by behaviours (migrating etc) appearance (e.g. silver), morphometrics (e.g .slimmer, eye enlarges)
1.,2.,3.,4.	Freshwater trout of 1 to 4 years age, with check on edge of scale. Could be smolts.	Freshwater winter check typically coincides with timing of smolt emigration (April-May). An intermediate growth rate, perhaps due to lake or estuarine feeding, is often seen that makes identification of smolt timing problematic, often river specific
1.0+, or 2.0+ or 3.0+ or 4.0+	A maiden Left river as 1/2/3/4yr old smolt, still in post-smolt period, before first winter check. Plus growth is evidently faster that the freshwater growth. If caught in river then it is termed a whitling/finnock etc. If caught at sea or estuary, then its future life history (time of return etc) are unknown.	Might return temporality into any river, leading to a "false check, and possibly false assignment to that river.
n.1/2/3/4 etc	A maiden fish with a marine winter check on the edge of scale	
n.1/2/3/4 etc+	A fish with a marine winter check on the edge of scale	
n.0+SM	Fish that entered freshwater as "whitling and spawned Total post-smolt age = 1	Spawning mark (erosion of scale aged) obscures any formation of annual winter check
n.1+SM+	Fish that spent first post-smolt winter at sea ("marine" check) entered freshwater and spawned Total post-smolt age = 2	
n.1+2SM+	Fish that spent first post-smolt winter at sea ("marine" check) entered freshwater and spawned, returned to sea and returned to spawn a second time Total post-smolt age = 3	Once sea trout start spawning the vast majority return in subsequent years to spawn.
n.1+SM+1+SM+	Fish that spent first post-smolt winter at sea ("marine" check) entered freshwater and spawned, returned to sea and stayed there over third post-smolt winter, but returned to spawn a second time. Total post-smolt age = 4	Extremely rare
n.2+SM+	Fish that spent first two post-smolt winters at sea, entered freshwater and spawned Total post-smolt age = 3	etc

7.1.4 Rationale and Conceptual Model

There is an enormous literature on brown trout ecology and it is not necessary to review it all within this report, but four general accounts cover most of the background: Elliott (1994), Crisp (2000), Bagliniére and Maisse (2000) and Jonsson and Jonsson (2012). Important reviews specifically on sea trout are Elliott *et al*. (1992), which is directed at the British Isles context, Harris and Milner (2006) and Jonsson and Jonsson (2006). In addition, with respect to climate change, readers are referred to Elliott and Elliott (2010) and Jonson and Jonsson (2011).

The key assumption of Task 7 is that the variations in the properties of sea trout fisheries are functions of life history properties, variously: dispersal, survival and fertility; the latter being determined by growth and maturation. The properties of fisheries and life histories therefore can be directly linked (Figure 7.1.1).

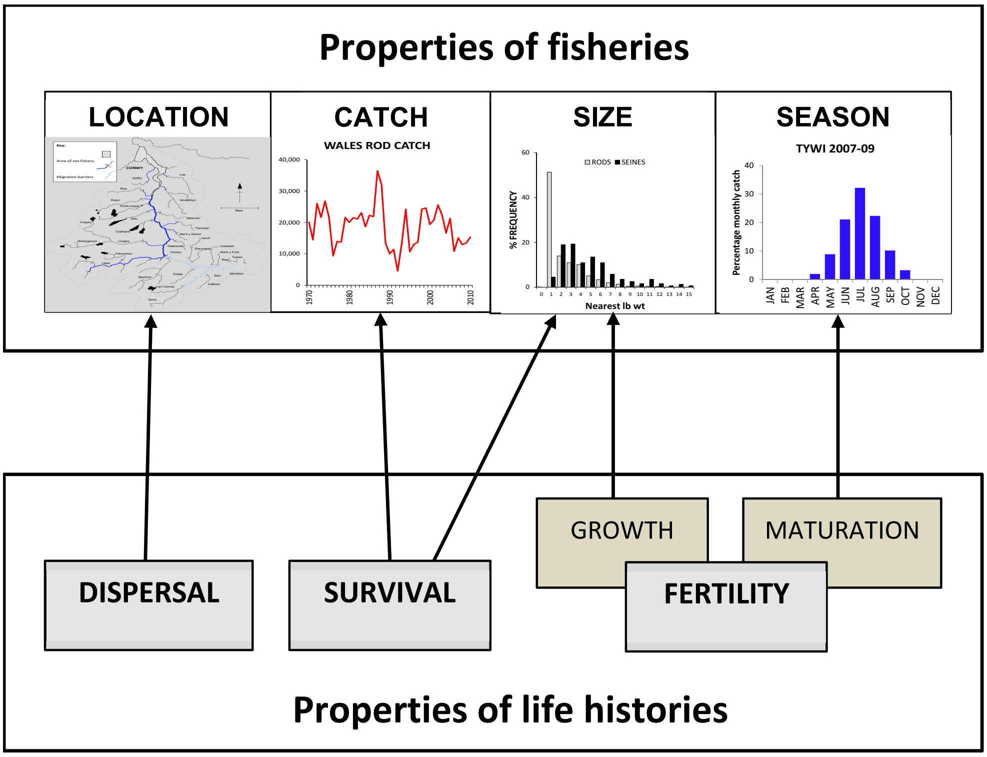


Figure 7.1.1 Links between The properties of sea trout fisheries and life history features

Fisheries have *location*; they may be in different parts of rivers, estuaries or the coastal zone, and they may comprise by-catch in offshore marine fisheries, depending upon how sea trout disperse and where they pass their adult stages. They have *catch levels* which reflect the annual survival of fish and their fluctuations reflect between year variability in survival, including fishing mortality. They have *size distributions*, determined by a combination of survival, growth and selective exploitation. Finally, they have *seasonal timing* which is determined by the time of return from the sea which is influenced by time of maturation and by the timing of fishing.

The marine migration habit, termed anadromy, is an important life history tactic of brown trout, believed to be a quantitative threshold trait, under genetic and environmental control (Ferguson, 2006) and offering adaptive value to lifetime fitness (Jonsson and Jonsson, 2006). Lifetime fitness is the inherent factor governing population growth and resilience (Fleming, 1996) and is potentially compromised by environmental or other pressures that fisheries and environmental management seek to control.

Migratory and non-migratory (resident) trout often live in sympatry (Jonsson and Jonsson, 1993), with only a part of the population migrating to sea, a phenomenon known as partial migration with the two groups being known as the resident and migratory contingents (Chapman *et al*., 2012). There is a strong between-sex difference in the incidence of anadromy, which is more prevalent in females. Female salmonids achieve breeding success through maximising size, egg numbers and egg survival (Fleming, 1996, 1998). It is hypothesised that anadromy offers benefits by allowing access to better (marine) feeding, increased growth and hence fecundity, thus potentially maximising life-time fitness, expressed for example through lifetime egg deposition. However, such benefits need to be set against increased risks from the higher energy expenditure and predation risks associated with migration over long distances across diverse, contrasting environments. The stimulus for migration by juveniles (smolting) is thought to be related to energetics and growth dynamics in the early parr stages (Okland *et al*., 1993; Thorpe *et al*., 1998; Forseth *et al*. 1999; Wysujack *et al.* 2009).

It has been hypothesised that shifts in environmental conditions in freshwater and/or at sea might lead to adjustments in the benefit tradeoffs between residence and migration, sufficient to change the incidence of anadromy and related life history attributes (Ferguson 2006; Jonsson and Jonsson 2006). If this occurs, then these attributes (e.g. growth rates, sizes, maturation timing, repeat spawning) might be reflected in the composition of catches of adults returning to their natal rivers. However, while the theory of changing traits in response to environment is intuitively attractive, clear evidence and demonstrations of it affecting catch composition are still rare (but see Davidson and Cove 2006).

Environmental factors are thought to control anadromy by determining the growth trajectory in the early juvenile stage, possibly through feeding opportunity. This somehow triggers a response by which fish with higher metabolic rate and growth capacity that is not met by the energy supply of its freshwater environment tend to migrate (Cucherousset *et al*., 2005; Olsson *et al.*, 2006; Wysujack *et al*., 2009; Dodson *et al*., 2013; Davidsen *et al* submitted). Lipid metabolic status appears to be an important part of this mechanism, with demonstrable differences in lipid reserves of anadromous and resident juveniles (Boel *et al*. in press).

The presumption from classical life history theory is that migration to sea offers greater reproductive fitness benefits to female trout through the increased fecundity that arises from faster growth on the high lipid/protein diet potentially available in the sea (e.g. sand eel or sprat). However this is only advantageous if the benefits (in terms of life time fitness, e.g. R_0, net reproductive rate) outweigh the costs of enhanced mortality caused by migration to varied environments (e.g. through predation, energy demands, hypo-hypertonic environment shift). The anadromous/resident life history "choice" is therefore based on a risks-benefits trade-off and the factors affecting these are probably some combination of genes and environmental factors in freshwater and at sea. The former (freshwater) being factors to which juveniles would be exposed and therefore might be responsive through reaction norms (e.g. competition, temperature, productivity, flow variation etc), and the latter (those acting at sea) being factors that previous generations will have experienced (e.g. migration distance and energy demands, predation risk, marine productivity and feeding opportunity) (Jonsson and Jonsson, 2006). The freshwater factors appear to involve a combination of continuous variation in liability (i.e. the propensity to migrate) coupled with a threshold for liability, exceedance of which determines if fish migrate or not. Age-specific growth rate appears to be a convenient surrogate for liability which may comprise a range of metabolic and hormonal changes (Dodson *et al*., 2013).

After the first migration from freshwater, further life history choices are made at sea; the principal one being the time to mature for the first time and return to fresh water, which might occur in first post-smolt year, or after 1 or 2 sea winters. This has an effect on total life time egg deposition through survival/fertility schedules (fitness, e.g. R_0) (Hutchings and Jones, 1998; Hutchings, 2002) and also on the size distribution of fisheries; therefore it is important for both population dynamics (rate of increase and stability) and for fisheries performance (catch and value). Maturation and the river return decisions may be related to growth in the first post-smolt year and possibly to freshwater growth.

One (age-structured) life history analytical approach is shown as a conceptual model in Figure 7.1.2. The variables are analysed through life history tables (e.g. Stearns, 1992; Gotelli 2008) to derive net reproductive rate (R_0) and instantaneous rate of population increase (*r*) and then taken into matrix projection models (Caswell, 2001) that enable prediction of the population structure and response to differing environmental factors, comparison of populations and their potential resilience to pressures.

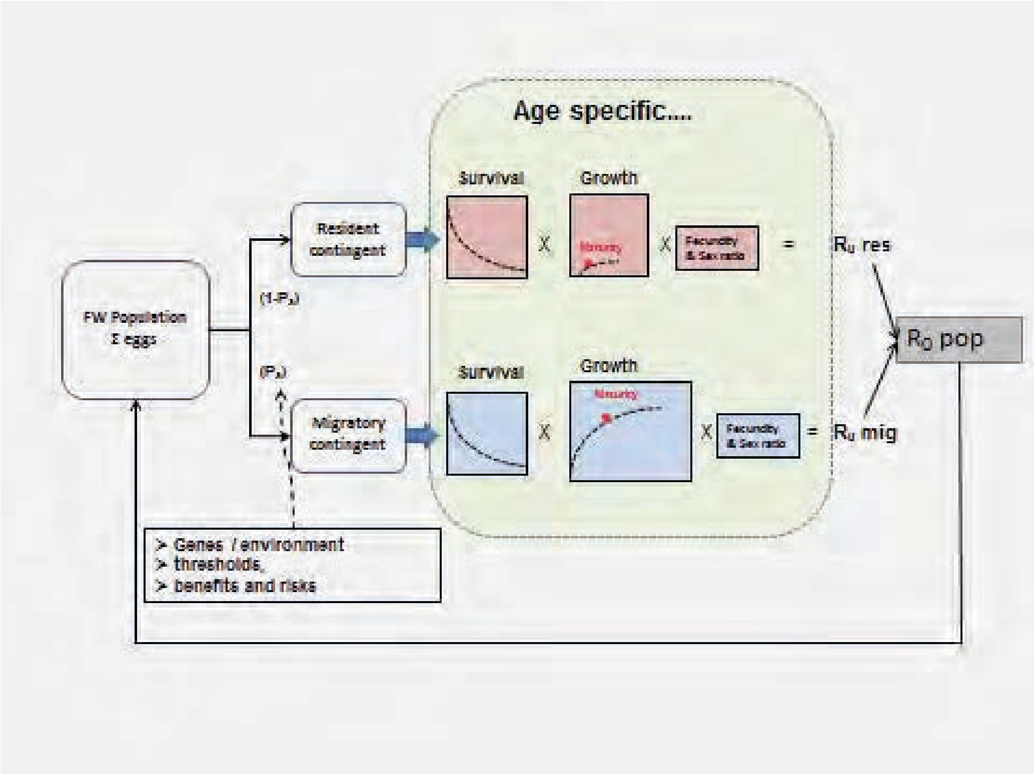


Figure 7.1.2 Outline conceptual model of age-specific life table analysis in partially migrating trout population with resident and anadromous contingents. P_a, the probability of becoming anadromous, is hypothesied to be related to genetics and environmental factors (e.g. temp, growth, productivity) and to site features (physical carrying capacity, distance from sea, gradient and accessibility), which variously influence juvenile metabolism and growth energetics, and migration risks through energy demands and predation. R_0 is the net reproductive rate the mean number of female offspring produced per female over her lifetime, derived from the life table.

Life table approaches have rarely been applied in fishery stock assessment (Pitcher and Hart, 1993; Hilborn and Walters, 1992) even though the value in their use has been recognised (Hutchings and Jones, 1998, Marschall *et al*. 1998). Recently, age-specific matrix models have been used to study salmon population responses to long-term environmental change (Aprahamian *et al*., 2008) and anthropogenic impacts (e.g. Ferguson *et al*., 2008, Lundqvist *et al*., 2008). However, Ferguson *et al* (2008) concluded that age-specific models for sea trout were too difficult to use for their study on hydroelectric power impacts because of the complexity of the life cycle which renders difficult the parameterisation of age- or stage-specific models and the incorporation of regulatory processes. Of particular importance are density-dependent controls of survival and growth, and the complex interactions amongst freshwater growth and maturation determining anadromy. Matrix models, while demanding of data, offer explicit solutions to hypothetical questions about the effects of changing various life table parameters, relevant to climate and other environmental factors or fishing, and therefore can inform fisheries management decisions. Thériault *et al*. (2008) and Ostergren *et al*. (in prep) have used eco-genetic models (Frank *et al.* 2011) to simulate the effects of fishing on life history traits. Life history tactics underpin population dynamics and hence the structure and performance of the fisheries; they are fundamental features that are crucial for science-based management and exploration of the possibilities given the data available for sea trout is likely to be instructive. At the very least, a description of life history variation is an essential starting point for any fisheries management. In this CSTP account a novel approach that combines stage and age-specific life categories is developed.

7.1.5 Outline Review of Previous Work on Sea Trout Stocks and Life Histories in the Irish Sea

Jonsson and Jonsson (2006) review the life history and polymorphism of anadromous trout throughout the limits of its natural range. Only Fahy (1978) has attempted to describe sea trout stock characteristics around the full CSTP area. More geographically restricted accounts have been given for Solway and Cumberland rivers (Nall, 1930, Nall and Fell, 1935), the English and Welsh coast rivers (Solomon, 1995; Harris 2002, 2006). A brief overview of these and several river-specific studies follows.

In Ireland, published accounts from workers like Nall (1931), Went (1944, 1949, 1956, 1957 & 1973), Went and Barker (1943), Fahy (1979, 1980, 1981, 1984 & 1985 b), Fahy and Rudd (1988) and Byrne (1998), have described different individual stocks from around the coast. Some of these workers have compared aspects of the life histories of several stocks (Nall, 1931; Went, 1962; Fahy, 1978 and 1985, and Byrne 1998). The collapse of sea trout stocks in many fisheries in the west of Ireland in the late 1980s led to an increase in investigations of marine survival in this part of Ireland to identify and quantify the extent of the collapse (Gargan et al., 2006 a & b; Poole et al, 1996).

The earliest work on sea trout in Ireland dealt with broad life history characterisation. Focussing on ten west coast systems Nall's (1931) study was the first substantive review on sea trout in Ireland. The review by Went (1962) was more extensive including systems from the west, south and west coasts while Fahy (op. cit.) incorporated Nall's and Went's results with new data from investigations he carried out independently. Fahy (1981) described stocks from several fisheries discharging into the Irish Sea and one commercial net fishery off the Irish Sea coast. Eleven east coast sea trout stocks were investigated by Byrne (1998).

Nall (1931) examined over 2200 sets of scales from mainly rod caught fish taken from ten systems on the west coast of Ireland extending from the Lough Currane fishery in the south west to the Owenea in the north-west. He found that these systems produced short-lived sea trout with a high proportion spawning as finnock and concluded that this parentage produced 'small, slow growing trout.' Three year old smolts dominated in many of these systems which he linked to moderate growth rate due to excessive fish numbers in freshwater.

A major review of Irish sea trout by Went (1962) incorporated stocks investigated by Nall (1931) and extended the range of systems to include systems on the south (Argideen and Ilen) and east (Mattock, a tributary of the Boyne) coasts. His analysis was based on sets of scales provided by fishery owners or from commercial net fisheries. Consistent with Nall's (1931) findings three year old smolts dominated most stocks along the western seaboard whereas two year old smolts dominated stocks in the Mattock (east coast), Argideen, Ilen, Waterville and Inny systems (south and south-west coast). Went showed that sea trout in Ireland are characterised by short-lived stocks with high proportions of finnock (range 47-83%),one and two sea winter maidens (with < 10% returning as 2 SW maidens) and previous spawners.

Fahy (1978) examined eight statistics common to sea trout stock investigations in the previous 50 years in Britain and Ireland in his review of biological and life history characteristics of sea trout around these islands. Life expectancy and weight: percentage of previous spawners were the key features he identified which led him to propose two separate growth based groupings for sea trout, a fast growing, well-conditioned 'Irish Sea' stock and a slower growing, poorly conditioned 'Atlantic' stock. The Irish Sea stock is well-conditioned due to better feeding leading to faster growth while the 'Atlantic' stock, is poorly conditioned with relatively poor marine growth.

Having identified a paucity of sea trout stock descriptions for the east coast of Ireland Byrne (1998) investigated stocks on eleven rivers on the east coast extending from the Fane to the Wexford Blackwater, which were sampled over a three year period by electric fishing. This study focussed on five systems, the Fane, Nanny, Dargle, Potter's and Wexford Blackwater systems where samples >100 fish were available. As Went (1962) had observed for the east coast previously two year old smolts dominated but Byrne found that three year old smolts (93%) dominated the Dargle, a system which drains granite geology. Fahy (1981) noted that sea trout age class diversity was low for fish sampled at sea off the Wicklow coast indicating that east coast sea trout are short-lived which contrasts with sea trout from Wales where samples yield high age class diversity indices.

Long-lived sea trout stocks have a large diversity of age classes and associated life history strategies (Fahy, 1984, 1985). Currane sea trout stocks have high age class diversity with up to 37 age classes recorded (Nall, 1931; Fahy, 1985) while the highest recorded diversity on the east coast was 15 age classes for the River Dargle (Byrne, 1998). Currane stocks are exceptional in Ireland in terms of their longevity and Nall (1931) attributes the larger size of adult fish to good feeding in the adjacent shallow littoral coastal areas. Nall (1931), Went (1962), Fahy (1980) and Roche (unpublished data) found that smolts from this system are substantially larger than smolts from any other Irish sea trout system. These characteristics mark Currane sea trout as being unique in an Irish context with longevity being the key factor accounting for the numbers of large sea trout recorded. Data from Irish Specimen Fish Committee (ISFC) annual reports 1956-2013, which record large rod caught fish, show that Lough Currane consistently produces the majority of specimen- sized fish (≥ 2.72kg) fish ratified annually. Nationally over 86% of all specimen-sized trout logged by ISFC from 1956-2010 were greater than 2.72 kg and ≤ 4 kg.

Five smolt age classes have been recorded from Ireland (Went, 1962); one and five year old smolts are uncommon. On the east coast Mean Smolt Age (MSA) typically ranges from 1.95 to 2.15 (Went, 1962; Fahy, 1981; Byrne, 1998). MSA in Ireland and Wales is generally lower compared to Scottish stocks with latitude being an important factor characterised by longer parr life cycles (i.e. higher MSA) in more northerly stocks (Fahy, 1978). Fahy also suggested that populations with lower MSA had a higher proportion of spawning finnock.

Fahy (1978) concluded that smolt length does not influence the length of returning fish Irrespective of differences in smolt length of different stocks at migration, differential marine growth resulted in relative length uniformity at the end of the first sea winter with maiden fish from Ireland and Scotland averaging about 31 cm and Welsh fish about 34cm. Marine growth data for the Mattock (Went, 1962), an Irish Sea stock, and Waterville, an 'Atlantic' stock (Went and Barker, 1943; Went 1944) showed that Mattock smolts, which are substantially smaller than Waterville smolts, almost doubled in length (93% increase) compared to those from Waterville which increased by 40-50%. Byrne (1998) observed similar compensatory marine growth in Dargle sea trout smolts, which are smaller relative to other east coast populations. Fahy (1977) identified 158 sea trout catchments on the island of Ireland. Additional fisheries were listed by McGinnity *et al*. 2003. Stock descriptions are available for some of the better known, high value fisheries, but in terms of cataloguing sea trout biodiversity in Ireland, many remain to be described.

For the Eastern seaboard of the CSTP area Nall gave early accounts of sea trout in Solway rivers (Nall, 1932), Cumberland and Lancashire rivers (Nall, 1938; Nall and Fell, 1935) and Wales (Nall 1930, 1933). Harris (1970) provided a detailed account for several Welsh rivers. Solomon (1995) reviewed life history variation in English and Welsh rivers based on age structure data from scale reading and earlier accounts, providing a very useful baseline for future work; but as he noted the data for many rivers were thought to be inaccurate due to small or selective scale samples. He reported information for 32 Welsh rivers and 13 rivers in the Northwest Irish region. There are numerous internal reports within the Environment Agency (EA) and its predecessors that give scale readings based on occasional samples and fishkills. Also, intermittent reviews of fisheries (notably that of the Welsh Water, 1985; Environment Agency, 2003) have commented on changing features of sea trout stocks and fisheries. Some rivers have had far more detailed observations that others, due to individuals and circumstances, particularly the Dyfi (Harris, 1970), the Dee (Davidson and Cove, 2006) and the Twyi (Evans, 1994).

The most comprehensive recent study, following through a review and recommendations from Solomon (1995), was that of Harris (2002, 2006) who gathered new information on the rivers Esk, Kent, Lune, Ribble, Dee, Clwyd, Dwyfawr, Dyfi, Teifi and Tywi in Eastern Irish Sea as part of a larger study on 16 sea trout rivers around England and Wales. Harris demonstrated variation in stock characteristics, based on reading scales sampled mostly by angling, and qualitatively classified five stock groupings for England and Wales based on the life history features of mean smolt, age at first return (maiden age), frequency of spawning, growth rates the pattern and timing of runs into rivers. *Group I: short lived / faster growing*, e.g. rivers of NE England (Wear, Coquet); *Group II: shorter lived / slower growing* SW England, e.g. Teign, Camel, Tamar, Axe, Fowey; *Group III: longer lived / faster growing,* rivers of Wales, e.g. Twyi, Dyfi, Dee; and *Group IV: longer lived / slower growing*, rivers of NW England, e.g. Kent, Lune and Ribble.

However the regional groupings were not hard and fast and several stocks fell outside the groups associated with their regions. Thus, of the nominal "Welsh" group (III) the Dyfi and Tywi were considered to produce younger smolts than the others. The Taw (North Devon) was considered more typical of Group III than its neighbours in Group II. The Teifi, Dwyfawr and Clwyd were regarded as more like Group II than III on the basis of spawning frequency and maiden age; whilst the Border Esk was unlike others in Group IV because of its lower spawning frequency. In a more formal classification, based on cluster analysis for three variables, mean smolt age, mean maiden sea age and mean number of spawning years (Figure 7.1.3), the Welsh stocks were grouped with rivers of the northwest England (Harris, 2002) at a second tier level; but widely separated rivers within the Irish Sea (Tywi (south), Dee (middle) and Esk (north) were classified together at the first level.

What this analysis appears to show is that while there might be broad latitudinal influence on stock characteristics within rivers around the Irish Sea, there is also important variation indicative of river-specific factors which could involve the local environment in freshwater and/or genetic differences. In addition to latitudinal trend there is evidence of east-west coast variation with the Irish rivers apparently producing smaller sea trout, or at least having a higher proportion of finnock than rivers at same latitude on the eastern Irish Sea coast. Finally and most importantly, the accuracy of stock descriptions are subject to errors, imposed by the sampling and analytical methods, which all previous authors acknowledge can be high. Therefore, too much should not be read into results from single studies and caution, coupled with statistical rigour, is necessary when identifying wide-scale patterns in life histories.

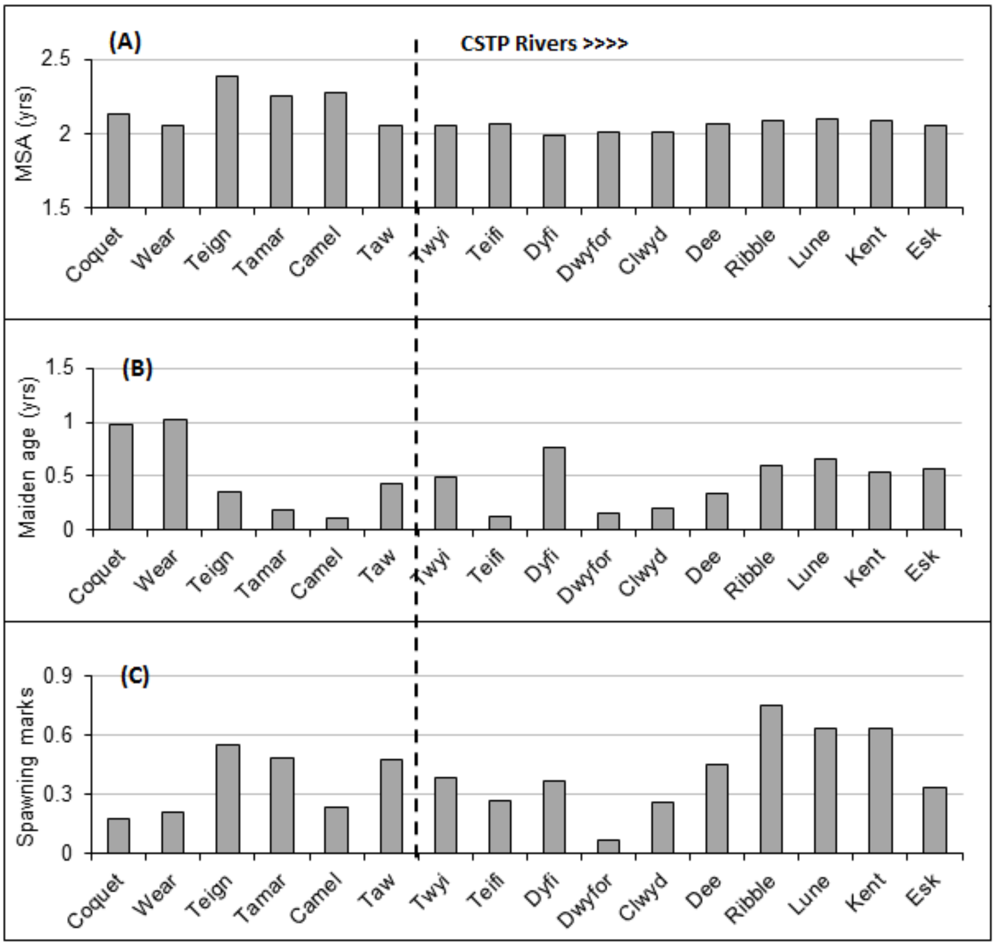


Figure 7.1.3 Some life history features of Welsh and English sea trout 1996-98: A) mean smolt age (MSA), B) mean maiden age and C) mean number of spawning marks. Rivers within the CSTP area are to the right of the dashed line. Adapted from Harris (2002).

Smolt Timing, Age and Size

Sea trout smolts normally leave European rivers between March and May to start their marine growth and maturation phase (Jonsson and Jonsson, 2006). However, there is little direct information on timing for the Irish Sea rivers and what there is comes mostly from opportunistic sampling of smolt runs which has been selective temporally because only part of the run was sampled, or selective spatially because only sub-catchments were sampled. Age and size data also come from these studies (which may have biases as noted above) and also from scale reading and ageing of adults (which have various biases associated with scale reading, for example Lee's phenomenon, selective sampling and mortality. A further issue is the point at which fish are taken to be "smolts". Nall (1930) considered that the end of slow river growth marks the transition from freshwater to marine phases; but fast growth can also arise in main stem rivers, lakes or estuaries where young fish might reside before moving to fully saline waters. Actively migrating, silvered juveniles sampled in rivers can be classified as smolts, but may have some time (days to weeks) to go before they enter the sea. Back-calculation from scales relies on the identification of a check which is taken to mark the transition between slow freshwater growth and faster marine growth. However, this growth change point is often not clearly defined, but it will occur at a later stage, and if feeding continues the fish will be larger, than migrating smolts sampled in-river. The exact correspondence between these two methods (direct measurement or back-calculated estimates) is not well-described, but they are likely to give somewhat differing estimates of smolt size.

Historical Smolt Data

Smolt lengths from various historical sources around the British Isles and one from Normandy (River Bresle) are shown in Figure 7.1.4 (data in Appendix A7.I). The overall mean values for sample mean, minimum and maximum were 187mm, 141mm and 247mm respectively. The minimum and maximum values were on average +33% and -25% respectively of their site means. Unsurprisingly, these averaged values correspond with Fahy's (1978) conclusion that mean sea trout smolt sizes (mean, minimum and maximum) in the British Isles were 195mm, 130mm and 260mm respectively.

The observed variation is due variously to type and location of samples (see above and appendix Table 7.1.1), latitudinal variation and smolt age variation (L'Abee-Lund *et al*., 1989).

The Ceiriog smolts (mean = 126mm, range 95-185mm) were comparatively small, possibly reflecting the location of this nursery tributary on the Welsh Dee, far upstream of the head of tide at Chester. They could be larger by the time they leave the Dee estuary and adopt marine feeding and growth rates. Certainly, average smolt size based on back-calculation on scales of returning sea trout in the Dee is much larger (195mm, range 170-220mm) (Davidson *et al*., 2006); but these values may be biased by selective mortality. Habitat in lower catchments appears to have a big influence on smolt size and in some catchments lakes may be important. For example on the Currane, which produced the largest smolts of the study (Figure 7.1.4), multiple lakes close to the sea are thought to offer a good growing conditions before trout migrate to sea. However, the data sources were considered to be too diverse and lacked consistent age data to warrant more detailed analysis of the effect of lakes.

Smolt size varies with the age of returning fish. Unpublished data from the river Dee indicate that back-calculated 2year-old smolt lengths of .1+ maidens were significantly smaller ($P<0.001$) than those of .0+ maidens (176.8 and 206.0 mm respectively, means over 1991-2007, excl 2002). This suggests that larger 2 year-old smolts tend to return (and presumably mature) earlier than smaller smolts. If smolt size reflects freshwater growth rate this might indicate that freshwater growth rate influences time of maturation and return. Caution is needed because larger smolts may actually be the slower growing group of the juvenile population, being those that do not meet a size threshold for smolting (if indeed there is one) the previous year as age 1+ smolts. To examine this possibility further requires information on freshwater growth, for example size at age 1, which is not available for the Irish Sea rivers. Jonsson and Jonsson (2006) noted that smolt size at age tends to increase with growth rate of parr, and that parr growth increases in more southerly (warmer) latitudes (see also Logez and Pont, 2011) but smolt size appeared to be also related to marine conditions through adaptation with larger smolts at higher latitudes thought to be due to older average smolt age rather than size at age (i.e. freshwater growth-related).

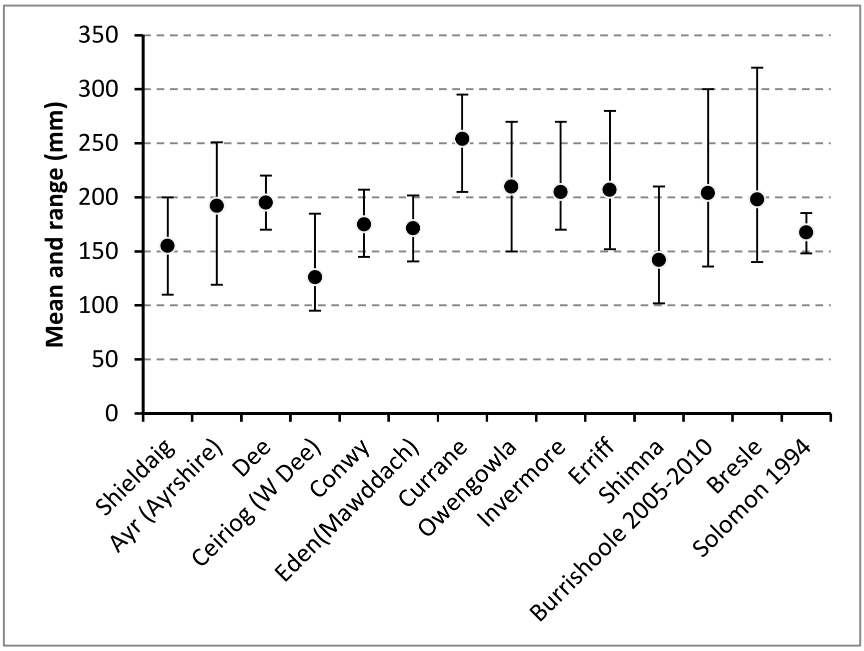


Figure 7.1.4 Smolt sizes (fork lengths, mm), mean and range, based on historical samples of smolt runs in rivers.

Smolt run timing was rarely described in detail over its full duration and in most cases only approximate timings of start, middle and end of runs could be extracted (Appendix Table A7.1). The exception was the long-term monitoring site of Burrishoole, Western Ireland, outside the CSTP area. These indicated that the start, middle and end of smolt migration occurred in respectively: late March, Mid-April and Mid-May. There is seasonal variation in the Burrishoole and peak migration ranged over about a month (2001-2008), probably due to spatial (latitude) annual effects of flow variation and temperature which are determinants of salmonid smolt run timing (Solomon, 1978; McCormick *et al*., 1998). Run timing is an important but missing piece of river- or region-specific information, because it affects the estimation of marine growth based on size at age in adults (see Section 7.4).

7.2 Stock Status and Trends

7.2.1 Introduction

An important part of understanding how populations respond to environmental, fishery or other factors is the description of spatial and temporal variation in abundance. In fishery management terms, stock means an exploited unit of fish comprising one or more populations. In the case of sea trout, each single river stock probably comprises fish from multiple populations located around the catchment. In this account stock is used to mean the aggregated population of a river. The principal and most universally available index of the adult stock is rod catch (e.g. Potts and Malloch, 1991; Shelton, 2001). However, rod catch is normally recorded as the sum of all fish caught in the river irrespective of their sub-catchment origins; therefore catch is a composite index of potentially several different populations. In some Scottish rivers local beat or fishery catches are also recorded, but these are inconsistently available around rivers and may also comprise fish from several populations; they are therefore not used here.

Many factors can bias or confound the relationships between catch, run size and stock, for example recording procedures, fishing effort, angling season, and environmental factors such as river flows (Milner *et al*., 2001), all of which may change over time and between rivers. The resulting errors are more or less problematic depending on the intended application; but a fundamental feature is that no fishing effort means no catch; further and broadly up to some limit, more fishing effort means more catch. In order to get around this confounding effect of effort, catch is often expressed as catch per unit effort (CPUE) to standardise the effect of varying effort. Effort can be expressed for example as licence sales or time spent fishing. A problem for the CSTP was that effort is only recorded for a part of the study area (England and Wales) and only since 1994.

The availability and quality of rod catch data vary greatly amongst the countries and regions of the Irish Sea and these are considered in more detail in Task 2. Task 6 examines the freshwater factors contributing to the spatial variation between rivers. In this section the aim is to describe the variability of catches around the Irish Sea and the extent and scale at which catches, as an index of adult abundance, vary synchronously and may therefore indicate responses to common factors.

7.2.2 Methods

7.2.2.1 Catch Recording

Recording procedures vary amongst the countries around the Irish Sea (Task 2). The main differences are that in England and Wales (E&W) a licence return system for salmon and sea trout run by the EA gives data from each angler on the size (weight) of individual fish caught and capture date for fish >1lb (numbers of sea trout <1lb are pooled per month) and on annual fishing effort; no finer time scale effort data were collected. No effort data were available for the other countries. In Scotland annual catches were recorded on individual beat basis and collated by the local fishery board. In Ireland, annual catches were estimated by local fishery inspectors. The E&W licence return system is known to have changed in its efficiency over years, consequently longer term data are sometimes adjusted for recording accuracy and efficiency (EA, 2003). Where such adjustments are necessary rod catches were adjusted by 1.56, 1.90 and 1.10 for the periods pre 1992, 1992-93 and post 1993 (EA, 2003) respectively. These factors, applied to all rivers, are considered to be minimum values; moreover the true reporting rates may vary between rivers.

7.2.2.2 Effort and Exploitation Rate

Since 1994 and for England and Wales only, rod fishing effort has been recorded as licence sales and as days fished per river, combined for the two common migratory salmonids (Atlantic salmon and sea trout). The days are recorded by anglers on their licence returns, although the effort applied to each species is not distinguished. However, in two years, 1996 and 2006 surveys were conducted to assess the relative effort that anglers spent on the two species indicating that this varies greatly between rivers. For example, the Rivers Dee and Wye have very little effort directed at sea trout compared with traditional sea trout rivers such as the Tywi, Teifi and Conwy, because they are not regarded by anglers as “sea trout rivers”. A few small rivers had no survey data and these were allocated a nominal 100% effort to sea trout (Appendix A7.2). This assumption may have slightly over-estimated sea trout effort, because low salmon catches are returned from those rivers, but the errors are negligible in terms of the others involved. In this section because the spatial variation in catch per unit effort (CPUE, per 100 days) is of interest the adjusted effort on sea trout was used.

Total annual catch (or CPLD) was used as an annual run index, transformed by natural logs where appropriate to standardise variances. Examination of seasonal rod catches showed that catches are not truncated by the ends of the season, indicating that most fish return within the angling season and are sampled by the rod fisheries. While there have been some adjustments to angling season over time (Task 2), the effect of season length was not considered to be major in view of the other sources of variation.

7.2.2.2 Analytical methods

Because the catch data set from England and Wales was of longer duration and better quality the more detailed analysis was necessarily restricted to those rivers. Following an initial description of the Welsh and NW English data, four types of analysis were carried out.

1) A comparison of the temporal variation in catch, effort and CPLD for the Welsh and English data between 1994 and 2010. This was done by partitioning variance into spatial, temporal and error components and taking the temporal component as an index of synchrony (simultaneous change). The analysis was restricted to rivers with annual catch of >100 sea trout and repeated at contrasting geographical scales in order to test if synchrony (NB over this time period) was a function of proximity.
2) A basic statistical description of spatial variation in catch, effort and CPLD (catch per licence day) for the English and Welsh rivers and catch for the Irish, Scottish, IoM and Irish rivers. In order to display the overall variability in catch (as an index of stock size).
3) A basic comparison of temporal trends in catch data for four main regions: Ireland, Wales, NW England and SW Scotland (Galloway coast), in order to identify any broad scale patterns in catch change overt the period 1994 to 2011, for when common data were available
4) A comparison of temporal trends against selected environmental factors that were hypothesised to influence catch, either through effects on putative stock abundance or through fishing effort and its effectiveness. Environmental factors examined were NAO, sea water temperature and rainfall.

Variance Partitioning

This analysis used data for the period 1994 to 2010 (only provisional data for 2010 were available at the time) for 34 English and Welsh rivers that had sea trout rod catches >100. Variance in effort, ln(CwE) and CPLD was analysed by random effects two-way ANOVA (Sokal and Rolfe, 1981) using Excel. There were no missing data or zero catches. The additive model applied to natural log-transformed data, ln(CwE) was:

$$Ln(n_{ij}) = \mu + s_i + y_j + e_{ij}$$

Where n_{ij}= rod catch for river i in year j; s_i = effect due to river i; y_j = effect due to year j; e_{ij} = error, including recording error and interaction between site i and year j.

Variance was partitioned into three components (spatial, temporal and error) at three levels of analysis: first between all 34 rivers; second, within the two EA administration Regions, Wales and North West; third, within each of four geographical regions, North Liverpool Bay, South Liverpool Bay, Cardigan Bay and South Wales. Spatial variance (V_s), temporal variance (V_t) and error variance (V_e) were approximately estimated from:

$$V_s = (MS_s\text{-}MS_e)/m$$
$$V_t = (MS_t\text{-}MS_e)/n$$
$$V_e = MS_e$$
$$\text{and } V_T = V_s + V_t + V_e$$

where V_T = total variance; MS_s = mean square (rivers); MS_t = mean square (years); MS_e = error mean square; m = number of years; n = number of rivers.

7.2.3 Results

7.2.3.1 Comparison of Wales and NW England total rod catch

Data from 32 and 14 rivers were available for Wales and Northwest England (NW) respectively. Long-term trends in total catch were apparent in both regions (Figure 7.2.1), but with a decreasing trend in Wales and an increasing trend in the NW.

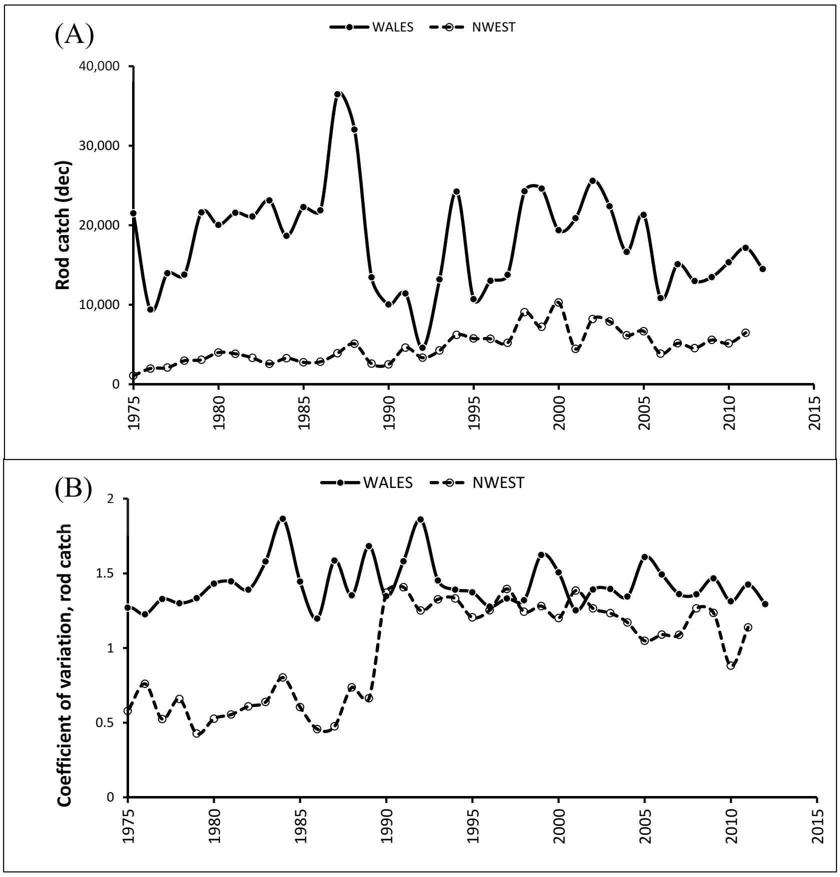


Figure 7.2.1 Long-term trends in declared unadjusted rod catch (A) and coefficient of variation (B) for Wales and NW England (source EA catch statistics), showing the sharp increase in CV in the NW in 1990.

From anecdotal sources it was suspected that the catch recording effectiveness in the NW prior to the late 1980s was less than in Wales. This was examined by comparison of the coefficient of variation (CV) amongst the rivers of each region (Figure 7.2.1). Major variation between the regions was evident with the NW CV before 1990 being very low, but becoming similar to the Welsh data by 1990. The exact reason for this is unclear, but is thought to be a consequence of records being partly fabricated on the basis of previous year's catch values. Consequently, it was not felt appropriate to use the NW data reported before 1990.

A selected set of Welsh rivers was used to examine long-term catch trends. Rivers were omitted if:

- annual catch was less than 100 sea trout,
- they were known to have experienced major environmental change from anthropogenic, river specific factors (e.g. the Taff Barrage)

- they were known to be “poor” sea trout rivers, e.g. Wye, Usk and Dee. The Wye and Usk have low sea trout catches for reasons thought to due to their particular catchment characteristics (see Task 6). The Dee is a special case in that while it has reasonable modern (post 1994) sea trout catches, formerly the sea trout fishery was small and the catch records were believed to be particularly poor.

This selected group of 13 rivers (Ogmore, Tawe, Tywi, Cleddau (combined), Nevern, Teifi, Dyfi, Mawddach, Dwyfawr, Llyfni, Seiont, Conwy, Clwyd) show long-term trends in catch which are partly obscured when shown as arithmetic values (Figure 7.2.2A). However, they become more evident as logged values (Figure 7.2.2B) (because log transformation conveys the multiplicative nature of the variation) and are clearly seen when data are converted to z-scores (z = (annual value - long-term mean)/long-term standard deviation), which show change relative to each river’s long-term standardised to the same scale (Figure 7.2.2C).

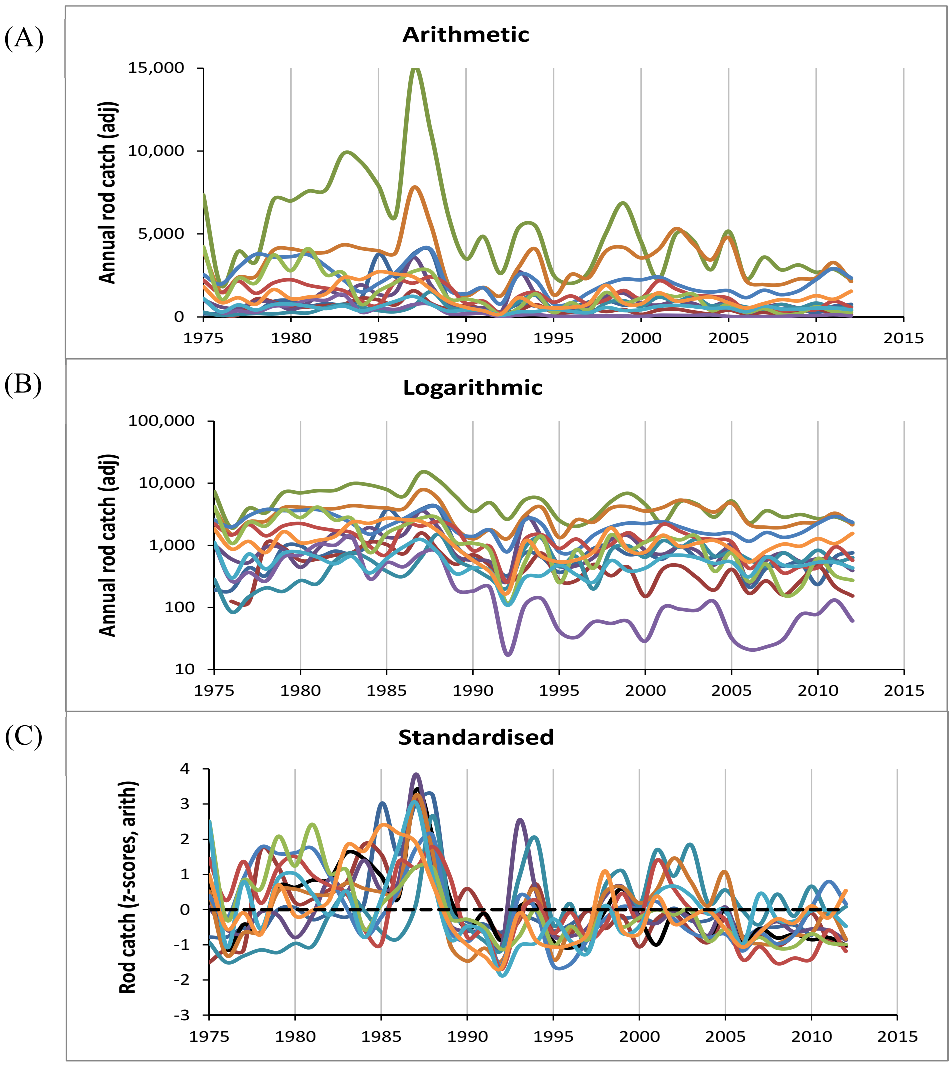


Figure 7.2.2 Extracting pattern from catch data. Long-term trends in annual sea trout catch for 13 Welsh rivers, expressed as (A) arithmetic values, (B) log-transformed and (C) standardised (z-scores), compared to their long-term mean (where Y=0). NB the catch data were adjusted for reporting.

There were river-specific variations and some of the variation is attributable to known external factors such as the lack of a catch return reminder in 1992. However overall, the catch increased from 1975 to a peak in the late 1980s before a sudden decline in 1988/89, then fluctuations with an increase again to a modest peak between 2001 and 2003. Present day catches appeared to have stabilised at a lower state than pre-1990.

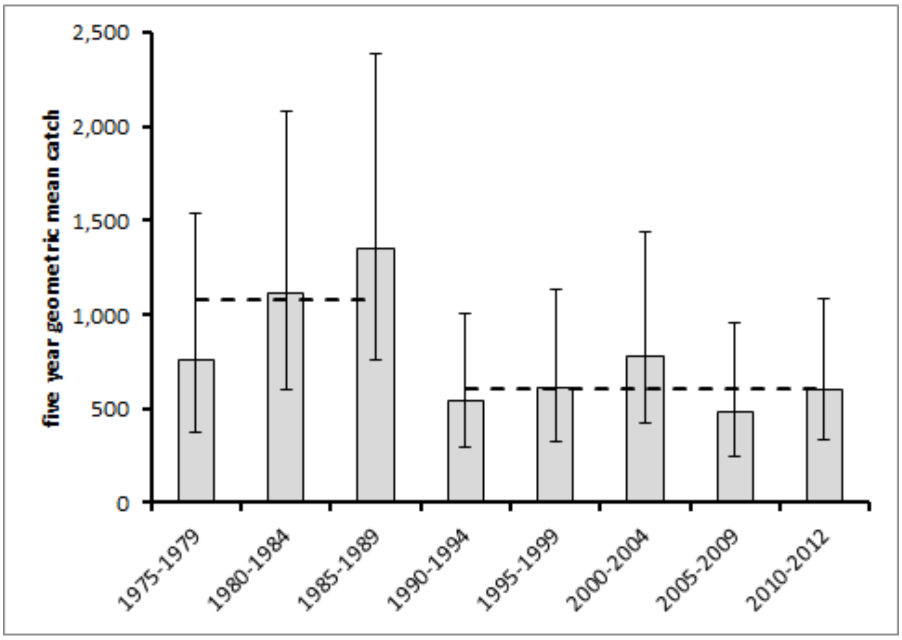


Figure 7.2.3 Five year geometric means and 95% confidence limits for adjusted annual sea trout catch for 13 Welsh rivers. The horizontal bars show period means for the pre- and post-1990 periods.

Five year geometric means better display this comparison (Figure 7.2.3), demonstrating that the post 1990 long-term mean (604 in this set of larger rives) has reduced by 44% from the pre-1990 catch (1,067). It should be noted that this analysis was done on adjusted catch data, by which catches before 1992 were adjusted upwards by x1.56 (see methods). Therefore the conclusion about the relative long-term change makes the assumption that these adjustments were accurate. It is also evident that while reporting of long-term means is a convenience, there have been continual fluctuations of varying periods and that the errors in the data are large.

7.2.2.3 Wales and English Catches Since 1994

Improvements to and standardisation of the catch recording system after 1993 allowed the combination of NW and Welsh data and the incorporation of fishing effort (days/year). Over the period 1994 to 2011 the mean total annual rod catch of all 46 rivers combined was 24,100. Across this group of 46 river means the mean rod catch was 443 (median= 257, range 5-2,719); mean and median effort were 871 and 614 (range, 47-5,932); and CPLD (catch per licence day) were 0.56 and 0.49 (range 0.11 – 1.32) (Appendix A7.3).

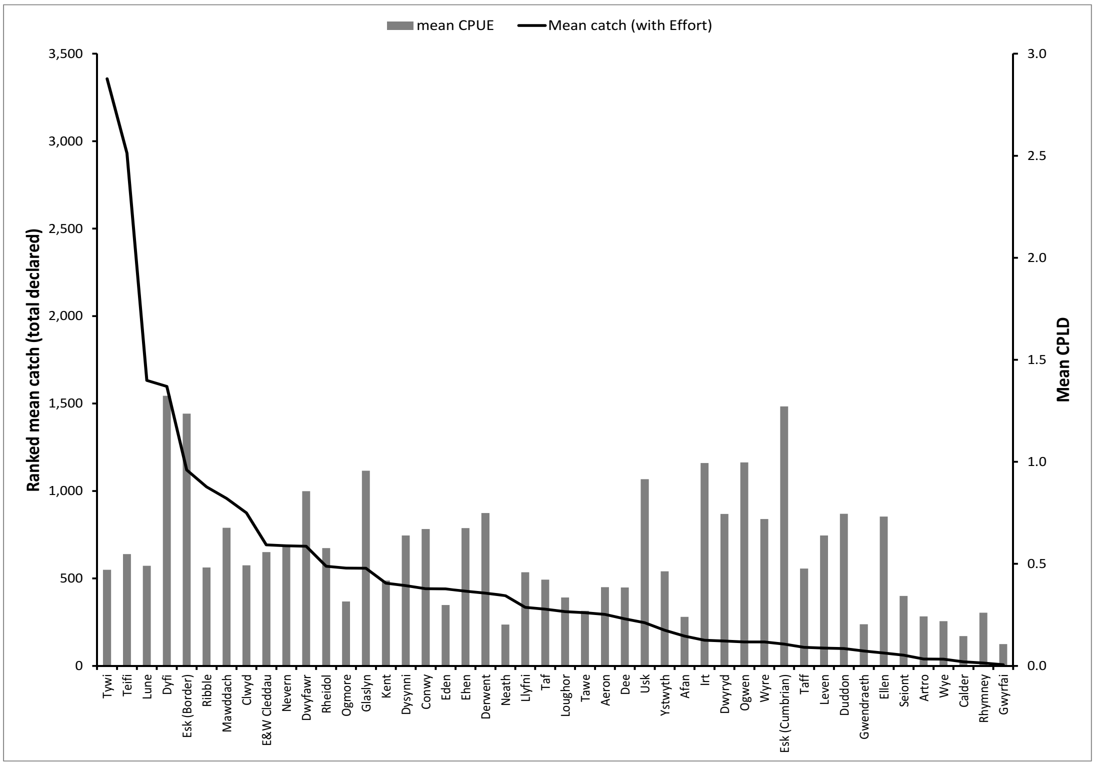


Figure 7.2.4 Ranked mean sea trout rod catch (1994-2011) (solid line) for rivers reported in EA catch statistics for the Wales and NW England. Bars show the catch per licence day.

The ranked catches (Figure 7.2.4) demonstrate the highly skewed distribution, by which 52% of the catch came from the top 7 (15%) rivers. In contrast, CPLD was reasonably uniformly distributed across the rivers. There was some suggestion that rivers with the lowest catches also had low CPLD, but incidence of low CPLD was very variable and not confined to rivers with low catches. More importantly, several rivers with comparatively modest catches had high CPLD (e.g. Usk, Irt, Ogwen and Cumbrian Esk). Factors explaining variation in catch and CLPD are examined in more detail in Task 6; but relationships relevant to interpretation of catches as river stock indices are shown here. First note that CPLD could be derived only for those licence returns on which effort was recorded by the anglers. Thus, for each river there were two sets of catch data: the total declared catch (CDec) (as shown by the solid line in Figure 7.2.4), and the declared catch from licence returns with effort declared (CwE). The two sets were related by CwE = (CDec) x 0.8315 (*a* constrained to zero, n=46, r= 0.996): a slope that was significantly different from 1. Therefore on average the catch records with effort comprised 83.15% of the declared catch for each river. Second, catch was correlated with catchment size; third, catch (CwE) was correlated with fishing effort and fourth, effort was also related to catchment area (Figure 7.2.5A-B).

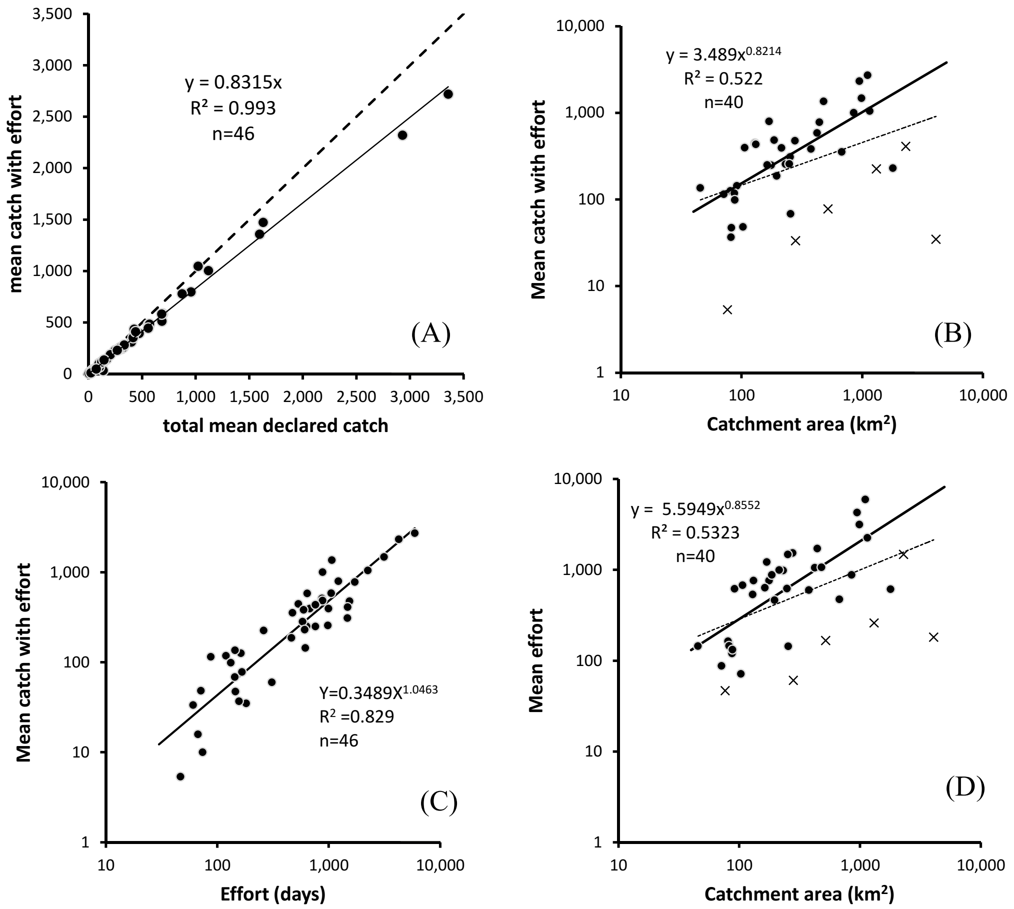


Figure 7.2.5 Relationships for Welsh and English (NW) rivers between (A) sea trout rod catch (catch declared with effort *vs* total declared catch), (B) catch and catchment area, (C) catch and effort and (D) catchment area and effort. Mean data for 1994-2011. In B and D dashed lines refer to all data, the equations given are for the solid lines derived without the six points marked with x which are believed to be unrepresentative of typical sea trout rivers (see text).

The parsimonious expected relationship is that larger catchments should produce more sea trout, i.e. they have larger stocks, all other things (factors affecting sea trout productivity) assumed to be equal: this is seen in Figure 7.2.5B. The rivers contributing to Figure 7.2.5B, include six that were regarded as atypical of sea trout rivers. The Wye, Usk and Dee were removed from the analysis because of their renowned low sea trout catches relative to their size, possibly due to factors to do with their size and overall drainage structure which may not lend themselves to anadromy as a dominant life history of trout in those rivers. The prevalence of Atlantic salmon in these rivers appears inconsistent with this view, but may reflect that species' migration to North Atlantic feeding grounds. The Gwyrfai was removed due to its major catch reduction in recent years. In the NW region the Wyre and Eden were also excluded, but all the data are shown in Figure 7.2.5B and D. Increasing fishing effort is also expected to produce more fish (Figure 7.2.5C) and it is almost axiomatic that larger catchments have more river bank and therefore attract more fishing effort (Figure 7.2.5D). Effort thus confounds the relationship between catchment size and N, because if N was random with respect to catchment size (CA) then increasing CA and effort (E) would be accompanied by reducing CPLD; but this is not the case. In fact CPLD was independent of CA and E (Figure 7.2.6), thus stock size must be positively correlated, on average, with catchment size, although the strength of catch as an index of stock size remains uncertain.

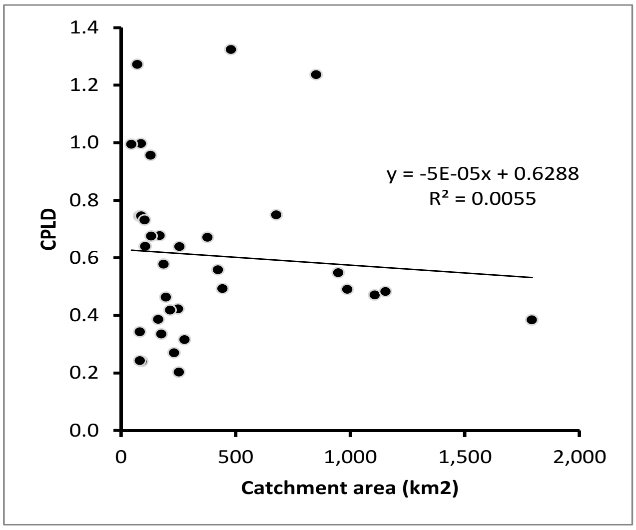


Figure 7.2.6 Relationship between catch per licence day and catchment size, showing no significant association.

There are other factors acting to account for the 10-fold variation seen in average CPLD such as accessibility to the stock, fishing effectiveness and efficiency leading to exploitation rate variation, and in addition there will be productivity variation amongst rivers. These are undoubtedly important and might all affect the CPLD; but there is no evidence that this varies systematically with river size, thus catch is considered to be a reasonable index of overall stock abundance to compare between catchments.

Inspection of trends in effort, catch, and CLPD (Figure 7.2.7) shows the close similarity between Wales and NW England data. Catch showed very similar trends in both regions, with the exception of a big drop in 2001 in the NW (Figure 7.2.7A). Effort (Figure 7.2.7B) declined proportionally the same in both regions and the NW effort decline in 2001 was evidently the cause of the catch change. Consequently, CPLD for the regions were even more closely associated (Figure 7.2.7C). Catch and CPLD tracked each other closely, obviously linked through the common effort change, and are compared in Figure 7.2.7D to show that both metrics give a similar pattern of change with a peak between 1998 and 2002, then a decline followed by a small rise between 2006 and 2011. These common patterns are moderated by effort such that the CPLD was proportionally higher earlier in the time series; but they give confidence that catch data alone gave an index that probably represents stock abundance. The anomaly of 2001 was thought to be due to the effect of the major foot and mouth disease outbreak in that year which affected the accessibility of many fisheries, reduced effort and hence catches; but overall CPLD was not affected apparently.

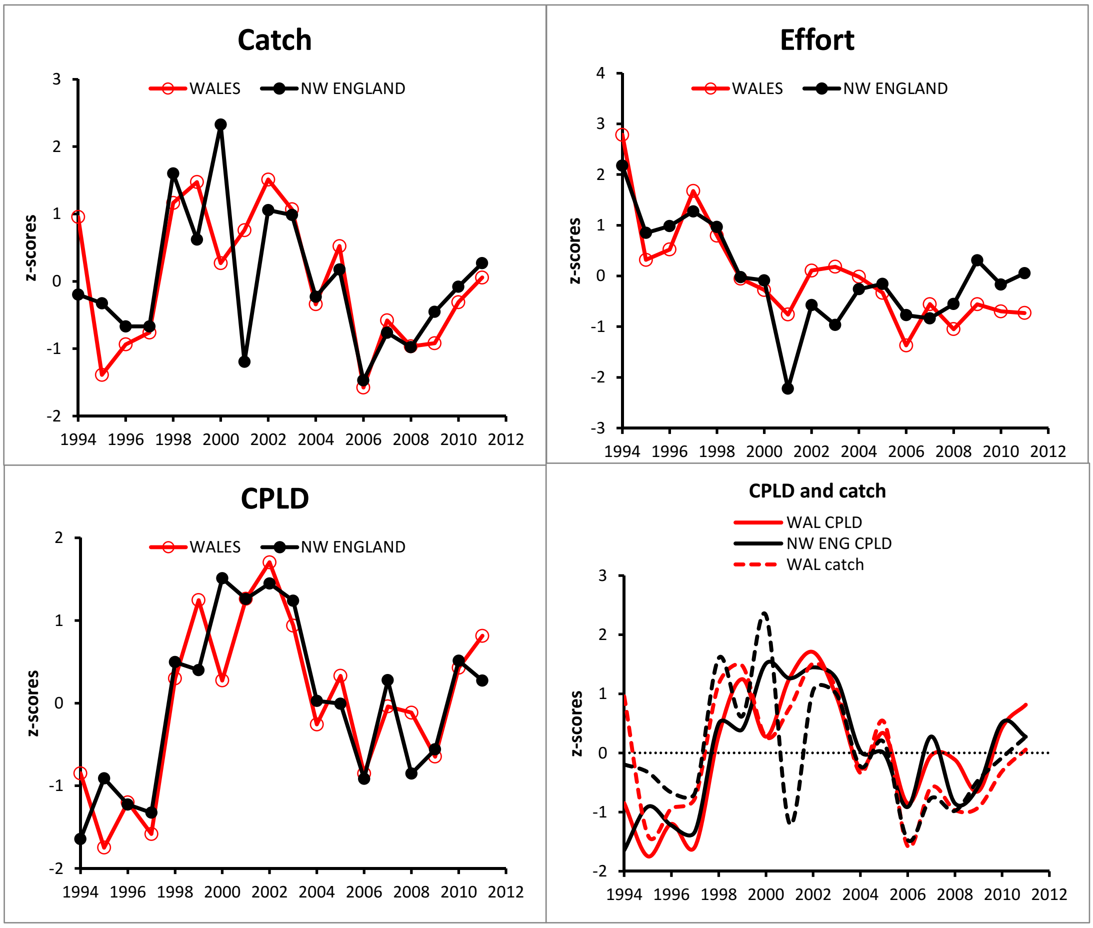


Figure 7.2.7 Variation in (A) catch (i.e. catch declared with effort), (B) effort (adjusted for sea trout), (C) CPLD and (D) comparison of Welsh and English catch and CPLD indices.

Variance Partitioning

The data from Wales and England were further analysed to examine the degree of annual variation between rivers and the extent of coherence or temporal synchrony, which is the degree to which the rivers fluctuated together year on year. This was done by partitioning variance into spatial, temporal and error components. Variance was examined for three metrics: effort, log catch and CPLD. The focus of the discussion is on the CPLD results; because for reasons illustrated above the effort adjustment offers theoretically a better index of stock than catch alone.

Total declared catches (C) were compared with the CwE (catches declared with effort also recorded) and for the period 1994 to 2010. The mean annual % of CwE of C ranged from 73.3% to 96.8%, overall mean was 85.6% (SE =1.6%) The Pearson correlation coefficients (r) for each river's C and CwE ranged from 0.631 to 0.999, overall mean r = 0.955 (SE =0.021). Accordingly, trends and variation in CwE can be regarded as acceptably close to those of the total declared catch.

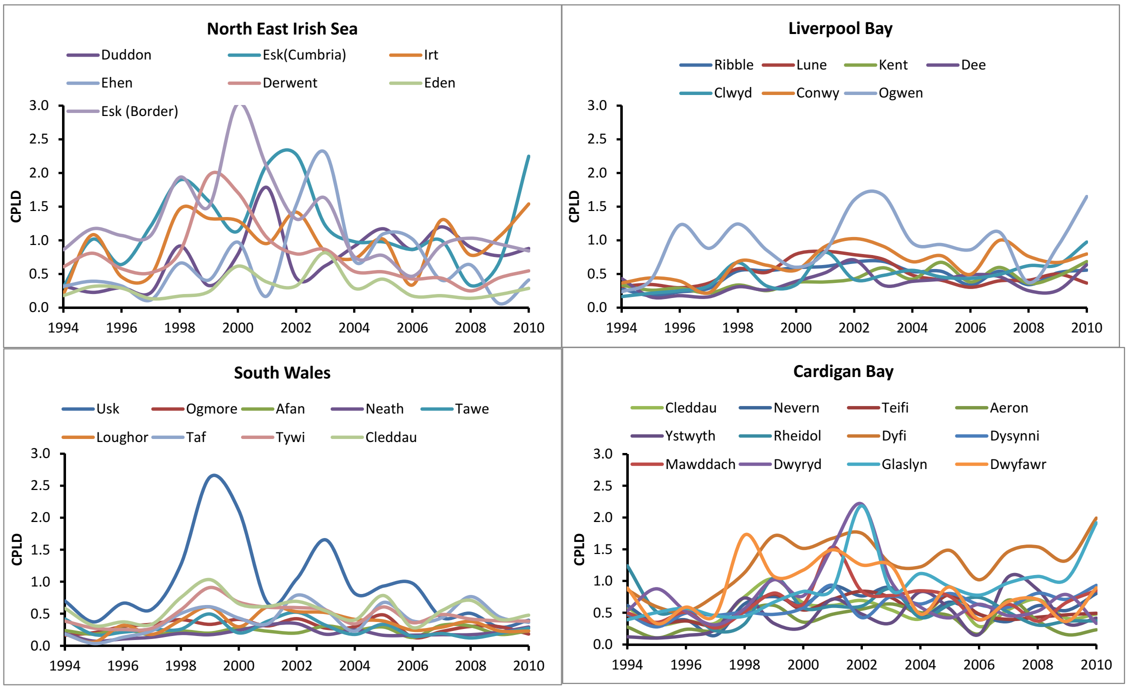


Figure 7.2.8 Comparison of temporal variation in sea trout rod CPLD for rivers in four regions along the Welsh and NW English coast of the Irish Sea.

The degree of synchrony, indexed by Vt, varied between the three response variables (Effort, ln(CwE) and CPLD). Considering all rivers together, Vt was comparatively low for the effort data (3.2% of overall variance), was intermediate for ln(catch) (6.5%) and was highest for CPLD (14.8%) (Table 7.2.1).

Considering the two EA regions, synchrony in CPLD was different, being 6.2% and 14.8% in the NW and Welsh regions respectively. Total variance (CPLD) was also higher in the NW (0.7180) compared to 0.1517 amongst Welsh rivers. Thus CPLD in the NW rivers was more variable and appeared to vary more independently between rivers than in Wales. Inspection of variation for effort (Table 7.2.1) shows that the two region were similar (3.1% and 2.9% respectively); and for ln(CwE) the Welsh rivers were more synchronous (include values from table to back up this statement).

Finer scale geographical partition showed high synchrony in the Liverpool Bay and Cardigan Bay groups (23.9% and 20.6% respectively), intermediate for south Wales (14.7%) and low for the NE Irish Sea (4.6%). The catch variation is shown in Figure 7.2.8 and the standardised form of CPLD (Figure 7.2.9) gives a visual impression of the difference in synchrony, demonstrating the trend for higher variation (lower synchrony) in the more northerly groups, NB Liverpool Bay comprises rivers from north Wales and NW Region. Long-term trends in CPLD were apparent and broadly consistent in all groups, with an increase peaking variously in different rivers between 1998 and 2003. Thus, within groups there were river-specific variations.

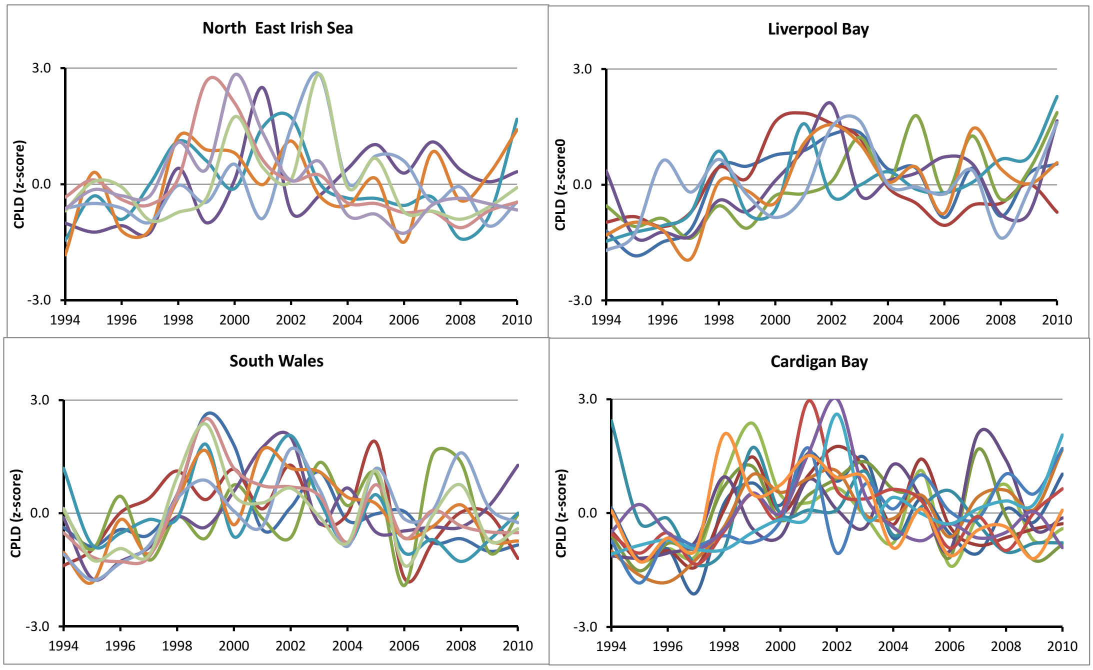


Figure 7.2.9 Comparison of temporal variation in sea trout rod CPLD, standardized to z-scores, for rivers in four regions along the Welsh and NW English coast of the Irish Sea.

Table 7.2.1 Variance partitioning of data on fishing effort, catch declared with effort (CwE) and catch per licence day (CPLD) in 35 rivers at contrasting scales. The rivers in the regional groups are shown below. Only rivers with mean (1994-2010) CwE of >100 were included.

Variance partitioning for sea trout rod catch data 1994 to 2010 (17years), excluding rivers with CwE <100

Level	Group	No of rivers	Effort (Days) Total Variance (VT)	%Spatial (Vs)	%Temporal (Vt)	% Error (Ve)	ln (Catch with effort) Total Variance (VT)	%Spatial (Vs)	%Temporal (Vt)	% Error (Ve)	CPLD (catch per license day) Total Variance (VT)	%Spatial (Vs)	%Temporal (Vt)	% Error (Ve)
All rivers	All rivers	35	1,620,864	88.4	3.2	8.4	1.118	70.2	6.5	23.4	0.1894	41.0	14.8	44.2
EA Region	NW	10	1,793,586	56.3	3.1	40.5	2.060	51.8	3.0	45.2	0.7180	13.8	6.2	80.0
	Wales	25	1,823,372	90.4	2.9	6.7	1.030	69.0	9.2	21.8	0.1517	43.4	14.8	41.7
Geo. region	NE Irish Sea	7	362,492	75.6	3.0	21.4	2.384	80.3	2.3	17.4	1.3456	82.1	4.6	13.4
	Liverpool Bay	7	1,438,150	81.1	7.4	11.5	0.989	85.0	4.4	10.6	0.0944	41.4	23.9	34.7
	Cardigan Bay	11	1,380,940	89.7	4.6	5.7	1.150	68.9	10.5	20.6	0.1692	35.1	20.6	44.3
	South Wales	9	3,237,067	91.9	1.6	6.5	1.042	72.6	10.4	17.0	0.1156	43.0	14.7	42.3

NE Irish Sea	Liverpool Bay	Cardigan Bay	South Wales
Esk (Border)	Kent	Dwyfawr	E&W Cleddau
Eden	Lune	Glaslyn	Taf
Derwent	Ribble	Dwyryd	Tywi
Ehen	Dee	Mawddach	Loughor
Irt	Clwyd	Dysynni	Tawe
Esk (Cumbrian)	Conwy	Dyfi	Neath
Duddon	Ogwen	Rheidol	Afan
		Ystwyth	Ogmore
		Aeron	Usk
		Teifi	
		Nevern	

Modelling Potential

The ability of models to explain variation in catches or CPLD between rivers is limited by the proportion of the explained variance ($V_T - V_e$) that is accounted for by spatial variance (Vs). This was estimated for the CPLD data only (Table 7.2.1) and did not show systematic variation between scales of analysis; being 73.5% for all rivers, 69.2-74.5% for EA Regions and 63-1-94.7% for the geographical regions.

The variance partitioning demonstrated a moderate amount (15-24%) of synchronous variation in CPLD across three of the regions, but low synchronicity (5%) within the NE (Galloway/Solway) region. The cause of this regional difference is unknown. Common factors acting on stocks might be indicated within each of the first three regions and for the overall set (in which 15% of variance was temporal). However, whether the factors were acting on stock or on fishing effectiveness, or both is unclear. However the CPLD varied closely with catch alone Figure 7.2.7) suggesting that fishing effort *per se* was not the cause of the synchronicity.

7.2.3.2 Sea trout rod catch data as indices of stock change

The rod catch data of Ireland and Scotland were less comprehensive than those for Wales and England. The only sets of data common to all countries (there were none for Isle of Man) were for total annual rod catch numbers by river, and these were gathered in different ways (see Methods and Task 2). Nevertheless, they offer the only data that might allow comparison of stock trends around the Irish Sea (data in APPENDIX A7.4). The more detailed analysis for Wales and England above has shown that there were common patterns in CPLD and in catch data (because of the similar trends in effort around these regions) and suggested that these may reflect true stock changes. Therefore the use of catch data from all the countries was considered justified and potentially informative. Data for the period 1994 to 2011 were analysed and in this analysis *total declared* catches for Wales and England were used to offer equivalence to the Scottish and Irish data. Sample sizes (numbers of rivers used) ranged between four and 26, and mean catches ranged between 611 and 743 (Table 7.2.2).

Table 7.2.2 Basic data for sea rod catches used to compared trends between countries (river data in appendix N), SD is standard deviation.

Country	No. rivers	mean catch	min	max	SD
Wales	26	677	88	2,690	796
Ireland	16	743	106	3,357	849
England	10	611	105	1,690	533
Scotland	4	735	136	1,557	664

Example rod catch data for Ireland and Scotland are shown in Figure 7.2.10, in arithmetic, logged and z-score transformations. Equivalent data for Welsh and English rivers were shown in Figure 7.2.8 and Figure 7.2.9. These illustrate that while individual rivers may show specific variation, there is some evidence (in the z-scores) of common patterns.

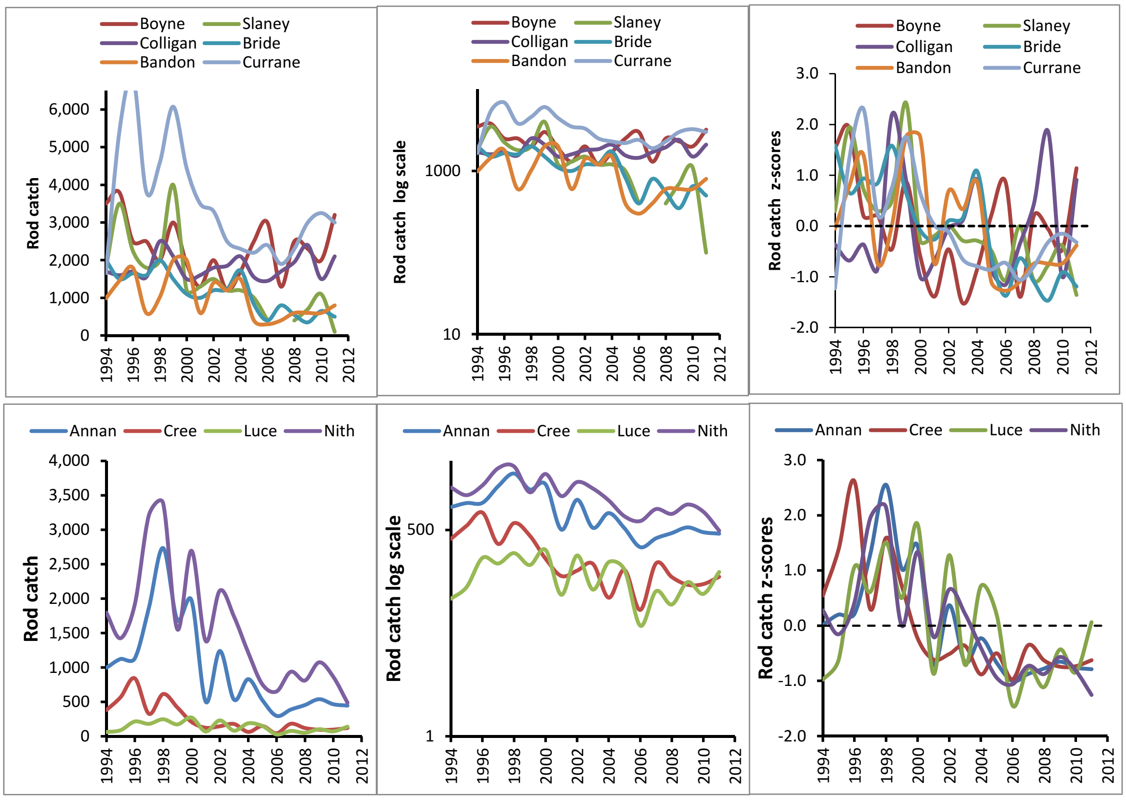


Figure 7.2.10 Temporal variation in sea trout annual rod catches for selected Irish (top panel) and Scottish (lower panel) rivers, expressed as arithmetic, log-scale and z-scores.

Combining arithmetic values and the mean z-scores for the arithmetic values for each region/country gave a visual comparison of the respective trends (Figure 7.2.11). Long term variation showed some common patterns between regions. There appears to have been a peak between 1998 and 2000 (with timing varying slightly between regions), followed by a decline until around 2006, since when there has been a modest upturn in most areas. The pronounced drop in 2001, in Galloway and NW England in particular, can probably be attributed to the foot and moth epidemic which although occurring early in that year is thought to have reduced fishing effort even after the outbreak had ceased and fishing restrictions were lifted. An impression of this is seen in Figure 7.2.11C in which the 2001 values are omitted.

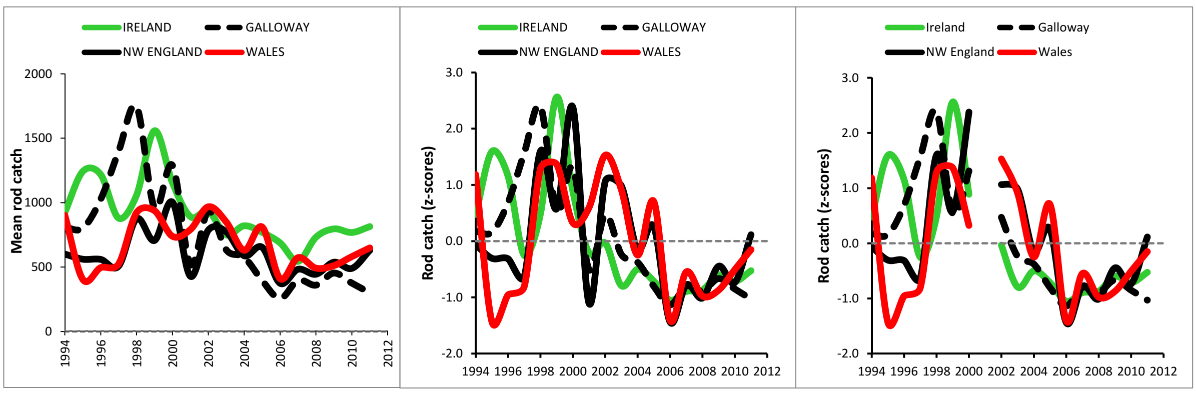


Figure 7.2.11 Temporal variation in sea trout annual rod catches for countries/regions around the Irish Sea: (A) arithmetic means, (B) z-score (of mean catch) including 2001, and (C) z-score excluding 2001 (year of foot and mouth disease – see text).

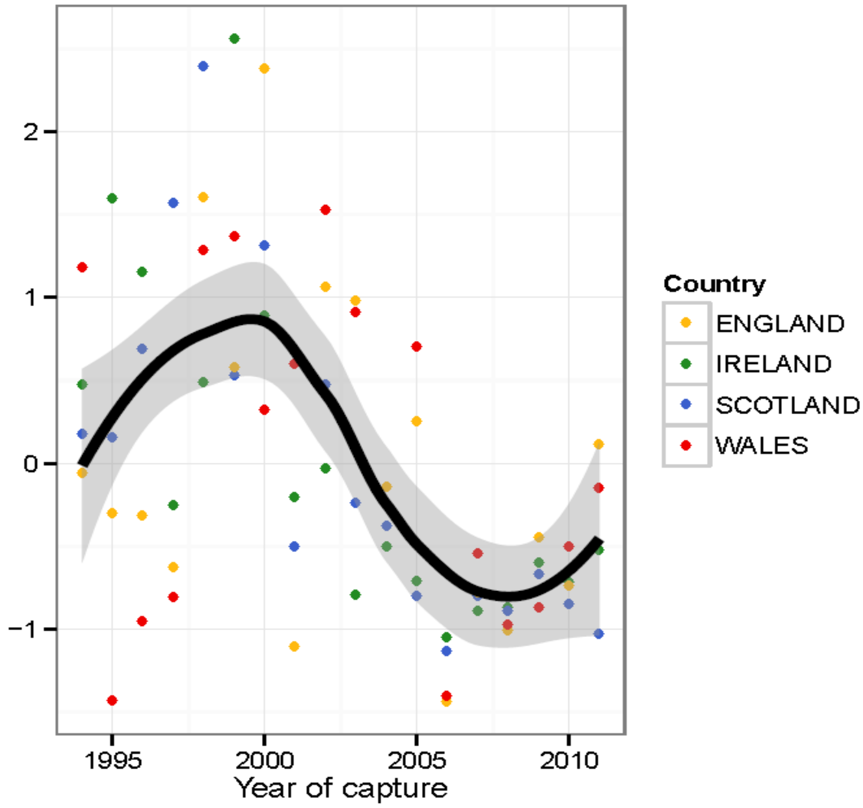


Figure 7.2.12 Combined trend of sea trout stocks, z-scores with a smoothed line based on all catch data and 95% confidence limits (in grey). Individual country/region points are shown.

The combined smoothed data (Figure 7.2.12) indicate a recent cycling pattern peaking around 2000 and a trough around 2007.

Variance partitioning on the same data, using arithmetic and log transformations show that a substantial proportion (34 and 35% for arithmetic and logged data respectively) of the variance in these mean data was attributable to synchronous factors. Spatial variance was low (17 and 8% respectively), but this would be expected because of the selection of rivers with catch >100. It should be noted that the quality of the data was highly variable between regions with least confidence weighting assigned to the Irish data due to their method of collection.

Table 7.2.3 Variance partitioning on the mean values of sea trout rod catches of individual countries/regions used on Figure 7.2.11 and Figure 7.2.12.

	Catch (arithmetic)		Catch (logarithmic)	
	Var	%Var	Var	%Var
Vs	15012.4	16.6	0.0128	8.4
Vt	30547.9	33.8	0.0535	35.2
Ve	44869.6	49.6	0.0859	56.4
Vtotal	90429.9	100.0	0.1522	100.0

7.2.2.4 Provisional Returning Sea Trout Stock Estimate for the Irish Sea

The total number of sea trout in the Irish Sea is of interest because it establishes the species in the hierarchy of free-swimming fish species in the marine ecosystem (Lees and Mackinson, 2007). This section describes a provisional assessment of a major part of the sea trout stock, the returning stock estimate (RSE). RSE refers to those fish that annually enter rivers having spent their recent growth history at sea. There is a further component of adults being those that remain at sea to return as older maiden (predominantly) sea trout; this group is not available to the rod fisheries and cannot be directly estimated from catch data; but other work based on age structure might be suitable to derive an estimate for this group.

Methods

The estimates are based on three sources of information:

1) The relationship between annual declared rod catch and watercourse size derived from Welsh and English rivers.
2) The numbers of rivers draining into the Irish Sea that fall into catchment size categories, derived by GIS.
3) An assumed rod exploitation rate, which can be altered or given a probability distribution.
4) Rod catch data (source: EA catch statistics) were averaged for the period 2007-2011 for 40 rivers in Wales and North West Region of the EA. Catches for this purpose were adjusted for reporting by multiplying declared catches by 1.1 (EA, 2003). Catchment area in km^2 were taken from SALMODEL (Crozier *et al*., 2003), updated by Cefas/EA annual stock assessment reports). Data were log transformed to stabilise variances. The data are given in Appendix A7.5.

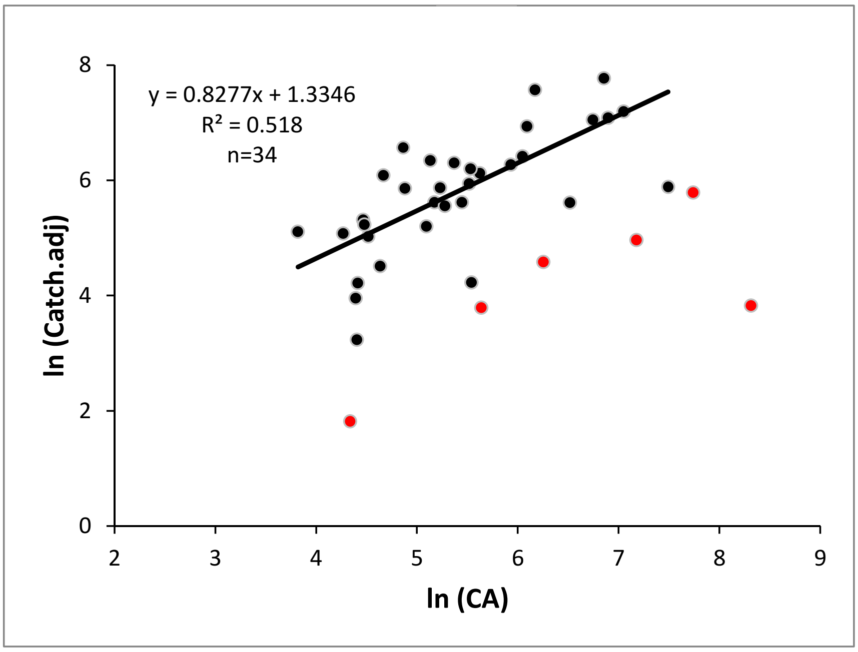


Figure 7.2.13 Relationships between catchment area (CA, Ha) and declared (unadjusted) sea trout rod catch (2007-2011) for Welsh and North West region rivers. The plotted regression line and its equation exclude rivers (red dots) considered to have atypical or rapidly changing (recovering) sea trout catches (see text).

From Figure 7.2.13 the equation used to derive catch (C) from catchment area (CA) was:

$$C = \exp((\ln(CA) \times 0.8277) + 1.3346) \quad \text{(Eqn 1)}$$

The numbers of rivers in different size categories were derived from a digitised 1:500,000 map of catchments draining into the Irish Sea and these areas then used in Equation 1 to estimate rod catch. 554 catchments were initially identified (Figure 7.2.14), of which 8 large rivers were omitted because they were considered to have atypically low sea trout production (Severn, Wye, Usk, Mersey, Eden, Munster Blackwater, Boyne, Barrow). A further 14 drainage areas were omitted because they did not correspond with identifiable water courses, leaving 531 catchments used in the stock estimates.

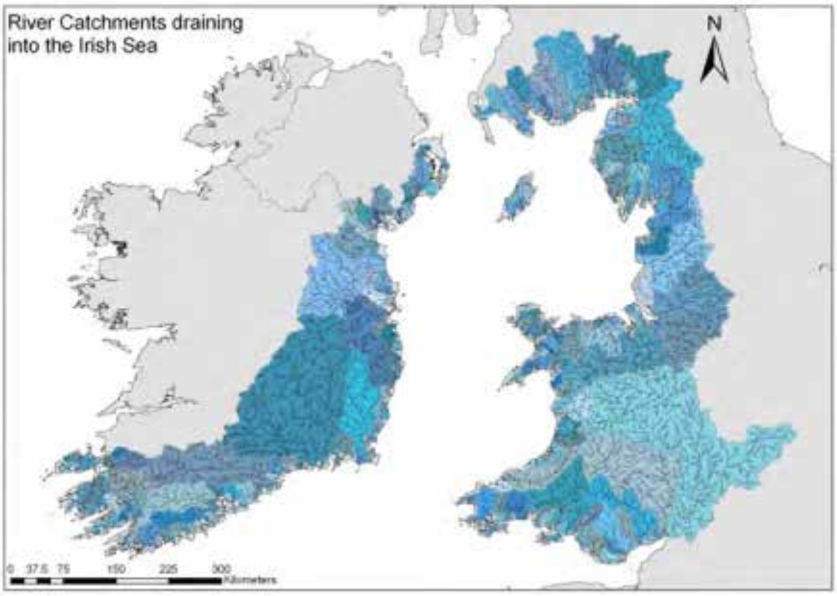


Figure 7.2.14 Map of rivers draining into the Irish Sea. Note the River Severn (the largest catchment, right hand side) was not included in the calculations.

Strahler stream orders of catchments at the points where they enter the Irish Sea were used to classify the river by size between the regions/countries of: Ireland, Northern Ireland, Wales, Galloway, Isle of Man and NW England. Wetted areas (Ha) of channels accessible to sea trout were estimated from catchment area (km2), using a relationship based on 26 rivers in Wales and NW England studied in the SALMODEL project, but not previously reported (Figure 7.2.15).

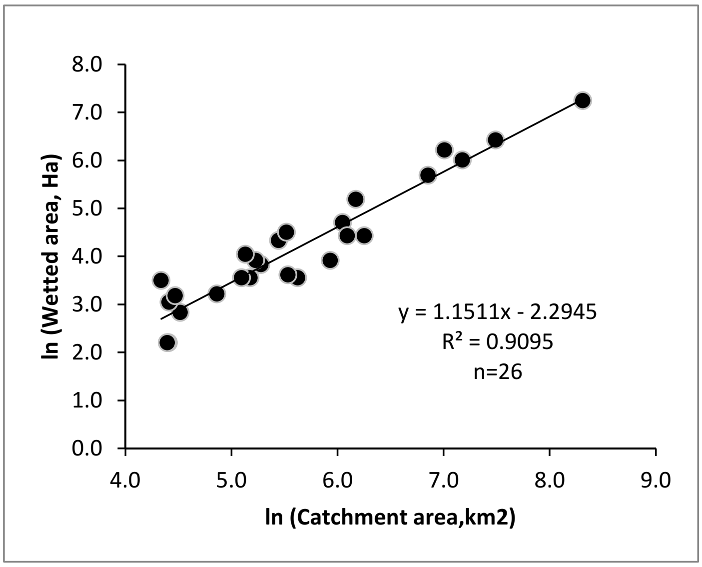


Figure 7.2.15 Relationship between accessible wetted area and catchment area for 26 rivers in Waales and NW England, logged data.

Results

Of the 531 catchments identified, ranging in size from 0.1 to 1,941 km^2, Ireland and Wales contained the largest number with 216 and 164 respectively (Table 7.2.4), corresponding to 26% and 34% of the wetted areas. Naturally most catchments are small, most rivers (54-67%) were within the stream order 1 category, and the frequency/order distributions were similar amongst the countries/regions (Figure 7.2.16). Catchment size (km^2) decreased with stream order (Figure 7.2.17).

Table 7.2.4 Number and wetted areas of 531 rivers used in the catch and returning stock estimates (RSE) by country / region.

Country / Region	Number of catchments	% Number	Wetted Area (Ha)	% wetted area
NW England	56	10.5	18,710	19.6
Ireland	216	40.7	24,733	25.9
Isle of Man	15	2.8	320	0.3
Northern Ireland	33	6.2	947	1.0
Galloway	47	8.9	18,517	19.4
Wales	164	30.9	32,358	33.9
Total	531		95,584	

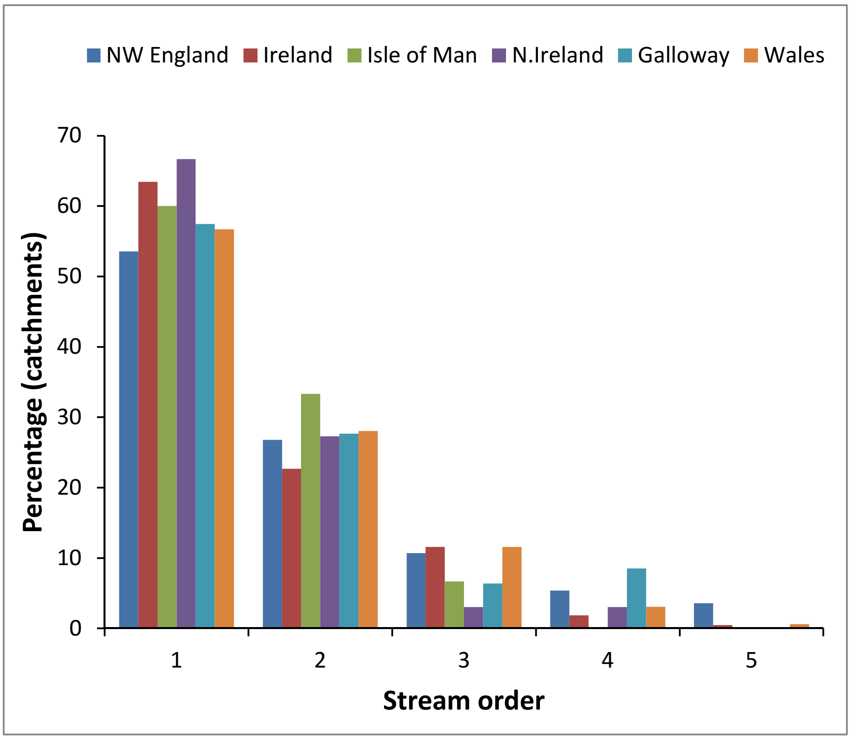


Figure 7.2.16 Distribution of 531 rivers by stream order (Strahler) between countries/regions.

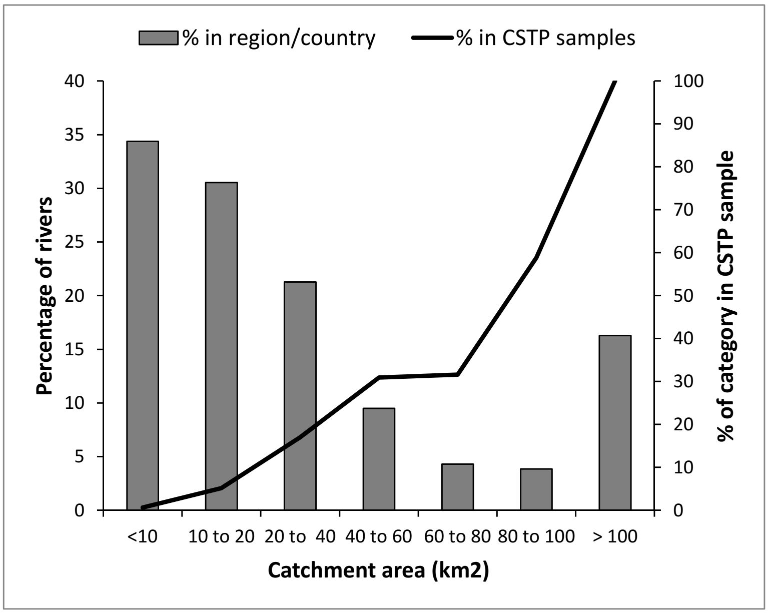


Figure 7.2.17 Comparison of the distribution of catchment size (km^2) in 531 rivers entering the Irish Sea (grey bars) and the percentage of each category represented in the CSTP sampling programme (dashed line).

Average annual rod catches were estimated for each of the 531 catchments using equation (1). Following the numbers of rivers (Table 7.2.4) the largest catch was from Ireland 18,622 followed by Wales, NW England, Galloway, Northern Ireland and Isle of Man (Table 7.2.5).

Table 7.2.5 Summary of catch and returning stock estimates (RSE), as fish numbers and biomass, by country / region, RSE is given for three rod exploitation rate (U).

Country/Region	Estd rod catch	Returning Stock Estimate			Biomass (tonnes)		
		U=0.20	U=0.15	U=0.10	U=0.20	U=0.15	U=0.10
NW England	8,979	44,893	59,857	89,785	32	43	65
Ireland	18,622	93,109	124,145	186,218	67	89	134
Isle of Man	831	4,154	5,539	8,308	3	4	6
Northern Ireland	1,913	9,563	12,751	19,126	7	9	14
Galloway	8,720	43,602	58,136	87,204	31	42	63
Wales	20,278	101,389	135,185	202,777	73	97	146
Total	59,342	296,710	395,613	593,419	214	285	427

RSEs varied in direct proportion to catches, simply being adjusted for putative rod exploitation rates of 20%, 15% and 10%, giving combined estimates for the whole Irish Sea of 297,000, 396,000 and 593,000 fish respectively. Biomass was calculated using a mean fish weight of 0.72kg as used by Lees and Mackinson (2007) based on EA data, to give a middle estimate of 285 tonnes.

Discussion of the RSE estimates

The size distribution of catchments (as catchment area or stream order) draining to the Irish Sea reflects the intrinsic branching pattern of water courses determined by landscape, geomorphological and hydrological processes (Leopold and Maddock, 1953; Downing, *et al*., 2013). The practical issue for the CSTP, apart from any channel or reach selectivity by sea trout (see Task 6), is that the

CSTP has necessarily been highly selective in catchment sizes (because catch data are available only from larger rivers), with a sampling programme that significantly under-represented the smaller catchments (Figure 7.2.17).

These returning stock estimates (RSEs), indicating a central value of 0.3 million sea trout in the Irish Sea, are provisional and based on simplifying assumptions. The named rivers excluded from the RSE calculation represented 52% of the original total wetted area; but their exclusion was justified on the basis that, had they been included their atypically low sea trout production would have grossly distorted the total estimates. Many of the smaller rivers probably actually have no fishery and thus no catch, but the estimates make the assumption that their potential catch might be as projected by Equation 1, which here is used as a simple way to estimate sea trout production.

The relationship between catch and catchment area was based on spate rivers of NW England and Wales and might not be appropriate for the East coast of Ireland and other regions. A full hydro-morphological analysis would be needed to better describe these relationships and their geographical variation; but in any event the catch data were only available in a form suitable for such modelling from England and Wales.

A total sea trout catch estimate has been made before for the Irish Sea. Lees and Mackinson (2007) in their application of the Ecopath model to the Irish Sea estimated an annual catch of 65,626 sea trout for 2002, including net-caught fish. Net-caught fish were excluded for the purposes of this study, because most net fisheries have closed through regulation. Furthermore, Lees and Mackinson did not include the Scottish rivers and assumed equal rod catches for Wales and Ireland (in the absence of Irish catch data). In the present calculation the Irish catch was only 44% of the Welsh catch (Table 7.2.5). The total estimate here of 593,000 includes contributions from many more, but much smaller, rivers. However, it does not include a further population component at sea, being those adult, predominantly maiden, fish remaining at sea; this may be large particularly for those regions with a high proportion of >0SW maidens and previous spawners, which are principally the rivers of the eastern sea board. This might account for the lower estimates reported here.

Rod exploitation rate (U) was another important assumed parameter in the estimates which is known to vary between rivers. Shields *et al*. (2006) reported U for sea trout ranging from 2.7% to 20.9% in five rivers in England and Wales, of which two, the Dee (2.7%) and the Lune (20.9%), lie in the Irish Sea area. The Dee is regarded as a lightly fished river considering the size of its sea trout run (Ian Davidson, pers. comm.). 15% is therefore considered to be a reasonable mid-range value, although Lees and Mackinson (2007) used a value of 10% for rods with an additional 5% for net exploitation.

The RSEs reflect the numbers of sea trout returning to rivers, but a further stock component comprises those fish left at sea (mainly maidens) and estimation of this additional stock will require better description of the life history characteristics of the rivers than presently available. RSE is therefore an underestimate of the true marine standing stock in any year. Contribution to the ecosystem is better expressed in terms of biomass or productivity. Lees and Mackinson used a mean size of 0.72kg and an Irish Sea area of 58,000 km^2 to derive a biomass estimate for the Irish Sea of 0.005 t km-^{2}. The present CSTP estimate is 285/58,000 = 0.004 t km^{-2}. To put this sea trout estimate into context, Lee and Mackinson (2007) estimated the total Irish Sea fish biomass to be 62.512 t km^{-2}; with some key species being: mackerel 34.26 t km^{-2}, adult cod 0.324, sand eel 2.014 t km^{-2} and bass 0.084 t km^{-2}.

7.2.3 Conclusion on Stock Status and Trends

Overall, the trends in rod catch data around the Irish Sea over the last 20 years are consistent with response to some common factors. While the possibility that factors operating through fishing alone cannot be ruled out, the evidence from the Welsh and English data, for which effort and CPLD were available, suggests that changes in catch were driven mainly by true stock variation. Unfortunately, common data for all countries and regions covered only a short period from 1994 to the present. The most reliable long-term set was thought to be the Welsh data from 1975 (Figure 7.2.2) which show a rising trend from 1975 to 1989, followed by a substantial reduction in the late 1980s. Present day stocks are comparatively stable or showing some upturn, however they are substantially lower than pre-1990.

The reduction in the late 1980s in the Welsh fisheries, though much less severe, coincided with the major collapses seen in the west coast Irish and Scottish sea trout fisheries. In those cases the important impact of lice infection through marine salmon farms has been implicated (Gargan *et al*., 2006; Butler and Walker, 2006). However, there are no marine fish farms adjacent to the Welsh rivers and it must be concluded that some additional factor was involved. Indeed this 1989 shift in status was evident in some other components of marine ecosystems, including salmon and might be indicative of some widespread environmental change (Beaugrand and Reid, 2003), although whether this represents a sudden regime shift or more gradual change is still unclear (Spencer et al., 2011).

Estimating overall stock abundance for sea trout in the Irish sea was a tall order given the availability and quality of the data and using rod catches as stock indices always comes with caveats even in the best circumstances. Therefore the estimate of 0.3 million sea trout (= 0.004 tonnes km^{-2}) has to be taken with caution, but is similar to a previous estimate and is believed adequate to place the species within the wider marine ecosystem context.

7.3 Stock Structure and Life History Variation 2009-2012

This section summarises the key life history features of the CSTP data set. The variety of sampling methods, seasonal effort and sample sizes across the rivers meant that life history descriptions were often biased.

7.3.1 Scale Reading (Methods), Age and Life History Data

Scale reading was a significant element of the CSTP project. Sampling of sea trout (see Section 3.5) was an important bridge with anglers who supplied most of the samples from rivers. The scale reading and interpretation involved substantial joint training, setting of consistent protocols and data sharing between project team members in Ireland and Wales.

Scale reading methodology used for this project is described in the CSTP scale reading manual (CSTP, 2010) which was produced for CSTP by Dr Russell Poole following a scale reading workshop for CSTP team members and sea trout scale reading experts held in 2010. The trout life history nomenclature and scale reading terminology used here is presented in Sections 7.1.2 and 7.1.3 of this report.

The majority of sea trout aged from different systems presented commonly observed life history patterns where freshwater and marine stages on scales were distinguishable and determination/measurement of scale landmarks was feasible. Fresh water winter marks can usually be distinguished from sea winter and spawning marks. However, over the course of the project it was evident that the distinction between the latter two marks was sometimes ambiguous. Spawning activity is characterised by extensive marginal erosion on scales but the extent of erosion led to difficulties in interpreting life histories for some sea trout. Limited scale erosion or erosion on the shoulders of the scales only were the primary features of this interpretational issue. The project team regulary discussed interpretation of these scale features, and several observed life events were identified that could explain such incomplete erosion including erosion at sea, partial migration to estuary, migration to river without spawning, and actual spawning. Aiming to manage such ambiguity marks of uncertain origin (sea winter/spawning) were classified as indeterminate marks (IM). This term was used together with the standard scale reading terminology.

The central issue which led to the development of the IM classification was the inconsistency in interpretation of the first post-smolt annual check which were taken to represent:

- checks in winter growth of fish which remain at sea over their first sea winter, or which return to their natal river or its estuary, but do not spawn
- OR genuine spawning marks of fish that have entered the river and spawned

Termed “finnock marks” because they were often evident in fish that were returning to the rivers as finnock (aka whitling) these marks also occured in older sea trout and were characterised by a mild degree of erosion and the loss of only a few (e.g. <10) circuli. The number of circuli lost was variable and this led to interpretation inconsistency. This did not affect the ageing because, irrespective of the cause, all were regarded as annual checks. Nevertheless, the distinction was important because the timing of maturation and first spawning was a key variable in determining a population’s growth rate and “fitness”, and was crucial for life history analysis and life cycle modelling. Equally the selection of maiden fish was a prerequisite to back-calculation of size at age for growth studies.

It was hypothesised, but not unequivocally demonstrated, that the first spawning check of any sea trout was the least distinct of its lifetime, because the degree of erosion was less than in the spawning marks of older fish, which characteristically are very distinctive. The degree of erosion in the older (larger) fish may be greater because:

- they tend to return to the river earlier in the year and therefore experience a longer period of fasting and living in the freshwater hypotonic environment
- they experience a relatively greater gonadal development (compared to young, small fish)
- the process of scale formation and its relation to metabolic/catabolic processes may vary systematically with age

However, further studies are required to investigate the relationship between fasting, maturation and scale resorption in sea trout to characterise scale erosion.

For this project and to formalise discrimination between annual checks and spawning marks a decision matrix (Table 7.3.1) was developed to ensure rules-based decisions and consistency among readers.

Table 7.3.1 First post-smolt scale check identification and characterisation. Nomenclature and approach adopted for CSTP scale reading

Period	Problem	Characterised by	Decision
Freshwater, up to smolt stage (actual check)	To identify genuine annual checks	Narrowing of circuli, contrasting with the wider circuli of putative summer growth	Label as age 1,2,3 or x (if uncertain)
Freshwater, up to smolt stage (smolt stage)	To recognise the point of smolting, in order to back-calculate size at that point.	May be very distinctive, may merge gradually into faster marine growth (end of FW phase not distinguishable), or may display an identifiable phase of intermediate growth (termed B growth or runout).	Label measurements as SM (measurement to clear smolt point, before B growth), B (measurement to end of B growth), SI (smolt size indeterminate)
Marine phase, 1st post smolt mark ("finnock" mark) (SW or SM)	To identify apparent checks which show continuum of erosion and circuli loss that can be interpreted as either Sea Winter (SW), Indeterminate Mark (IM) or Spawning Mark (SM)	Typical sea winter (SW) check (narrowing of circuli, taken as winter growth, no loss of circuli) OR Indeterminate Mark (IM), where some circuli loss apparent (up to10) but not extensive lateral or posterior erosion OR Typical Spawning Mark (SM), where substantial erosion (>10 circuli lost) is evident on both laterals and often around posterior margin.	Label as SW, IM or SM.
Marine phase, 1st post smolt mark ("finnock" mark) (SW end point)	To identify clear SW end point	Well defined SWs may show unclear start/end points, but have an extended phase of narrower or disturbed, erratic circuli where identification of a point for back-calculating 1st yr marine growth is difficult	Identify and label measurements to start and end of best estimated winter check, then each value or an average can be used subsequently for back-calculation

A scale sampling programme on such large scale was ambitious and the data extraction proved difficult. The main limiting factors were:

- Bias in the sampling times (years and season) between rivers. This will lead to bias in apparent life history structures.
- Variation in scale interpretation between readers (in spite of joint training)
- The sheer difficulty in reading some scales arising through genuine variation in scale formation between rivers. This might have reflected topographical differences imposed by the regional coastlines that could influence the migratory behaviour, feeding growth and maturation of fish from different rivers. For example, B growth appeared to be more prevalent in fish from the Irish east coast; and sea trout in the Solway Firth seemed to show less clear demarcation of freshwater and marine growth, possibly reflecting more gradual transition between freshwater and truly marine habitats. Others showed greater incidence of maiden sea trout returning to rivers but not spawning, leading to inconclusive river entry marks obscuring the classic distinction between spawners and maidens. Related to this was the common difficulty in some regions in distinguishing between river/spawning check and sea winter checks (see below), possibly reflecting migrations into estuaries rather than full

freshwater. In order to deal with this the CSTP introduced the term IM, meaning an 'indeterminate mark' where it was uncertain whether an annual check, indicated spawning, river entry without spawning, or a sea-winter. Therefore, IMs were unequivocal regarding age, but uninformative about life history.

- Weak winter checks. It was apparent that some sea trout kept growing (and therefore feeding) through the winter and displayed no or only a weak winter check. This was unexpected and confounds the classic distinction between "winter" and summer growth and the term "winter check" being synonymous with an "annual check" as it tends to be in freshwater. There was evidence of the "annual check" occurring in the summer months after an early spring growth spurt and it is possible that this was indicative of environmental limits on summer growth in some areas.

It should be noted also that some ethical issues arose (relating to constraints on sampling scales from live fish) and logistical issues that in some countries / regions constrained the sampling by anglers. Much time and effort went into liaising with angling groups by giving talks, training and e- mail shots; but even with that there was noticeable variation in readiness of anglers to engage with the project. Some groups were outstandingly helpful; others felt less able to participate. The reasons for this are not clear and it was not appropriate to explore them in this report; but they should not be ignored in any future programme, because they affect the consistency of the scales sample coverage and therefore the options for life history analysis.

Conducting such a geographically wide scale programme may present unresolvable difficulties; and solutions may lie in more intensive projects on fewer rivers. However, further analysis of the data is required to describe these biases fully and to demonstrate the errors that potentially arise. Given the importance attributed to life history variation (although this importance itself requires better characterisation), a more robust and long term protocol for sea trout scale collection and analysis is needed to make the method suitable for scientific assessment. The CSTP collection and the Harris collection are invaluable resources and need careful curating to preserve for this and other projects.

The scale reading produced useable data in spite of these issues; but they point to the need for fuller analysis and great care is needed in using them for some purposes (see Section 7.7). The CSTP sample archive and database is an extremely valuable asset for exploring various questions which could not be addressed in the timescale of the project. Further funding will be sought to pursue this. One area that was briefly touched on (but unreported here) was the joint use of scale patterns and microchemistry and further work is recommended.

7.3.2 Outline Life History Variation

Because of the issues outlined above caution should be exercised in interpreting the data, restricting conclusions to those results which are robust against such errors. The aim was to provide a first baseline description of Irish Sea stocks and to look for patterns in the data. The methods for cleaning up the size data are described in Appendix A7.6. Data on life history structure and size (length and weight) statistics are reported for individual rivers in Appendix A7.7. Examples of these data are shown in Table 7.3.2 for two contrasting rivers: The Dyfi (Wales), a river with widely varying life histories, and the Slaney (Ireland) with much less variety.

The CSTP scale samples were concentrated in comparatively few rivers and monthly distributions of samples showed that most fish were sampled in summer months of May to August, but some exceptional samples were taken in the autumn, for example on the Nith where adult fish were sampled by electrofishing.

Table 7.3.2 Example of summary life history data for two contrasting rivers, the Dyfi (Wales) and the Slaney (Ireland), details for all rivers are in Appendix A7.7.

Country	river	form.list	Scale formula	Number of fish	Freshwater age (yrs)	Total age (yrs)	Sea age (yrs)	Fork length mean (mm)	Length SD (mm)	Fresh weight mean (g)	Weight SD (g)
Wal	Dyfi	1	1.1+	7	1	2	1	495	42	1246	432
Wal	Dyfi	2	1.1+1SM+	3	1	3	2	505	35	1437	235
Wal	Dyfi	3	1.2+	5	1	3	2	459	59	1360	237
Wal	Dyfi	4	2.0+	18	2	2	0	365	62	591	265
Wal	Dyfi	5	2.0+1IM	36	2	3	1	487	50	1326	469
Wal	Dyfi	6	2.0+1IM+1SM+	4	2	4	2	530	50	1955	603
Wal	Dyfi	7	2.0+1IM+3SM+	2	2	6	4	815	35	6290	1683
Wal	Dyfi	8	2.0+1SM+	8	2	3	1	497	71	1346	439
Wal	Dyfi	9	2.0+2IM	1	2	4	2	510		2320	
Wal	Dyfi	10	2.0+2SM+	3	2	4	2	628	98	3043	1311
Wal	Dyfi	11	2.1+	103	2	3	1	496	38	1382	376
Wal	Dyfi	12	2.1+1IM	10	2	4	2	492	66	1450	583
Wal	Dyfi	13	2.1+1SM	2	2	4	2	508	46	1590	240
Wal	Dyfi	14	2.1+1SM+	12	2	4	2	590	54	2464	777
Wal	Dyfi	15	2.1+2SM+	3	2	5	3	660	100	3510	1304
Wal	Dyfi	16	2.1+3SM+	5	2	6	4	708	147	4808	1092
Wal	Dyfi	17	2.1+4SM+	1	2	7	5	813		7260	
Wal	Dyfi	18	2.2+	9	2	4	2	495	49	1500	317
Wal	Dyfi	19	2.2+1IM	1	2	5	3	720		4080	
Wal	Dyfi	20	3.0+	3	3	3	0	411	30	614	275
Wal	Dyfi	21	3.0+1IM	2	3	4	1	558	11	1870	240
Wal	Dyfi	22	3.0+1SM+	1	3	4	1	500		1420	
Wal	Dyfi	23	3.0+3SM+	1	3	6	3	670		3120	
Wal	Dyfi	24	3.1+	4	3	4	1	485	71	1660	824
Wal	Dyfi	25	3.1+1IM	1	3	5	2	540		1930	
Wal	Dyfi	26	3.1+2SM+	1	3	6	3	770		5900	
Wal	Dyfi	27	3.2+	1	3	5	2	546		1590	
Wal	Dyfi	28	x.0+1IM	1	NA	0	NA	530		1930	
Wal	Dyfi	29	x.1+	4	NA	0	NA	513	47	1234	455
Wal	Dyfi	30	x.1+1IM	1	NA	0	NA	406		1360	
Wal	Dyfi	31	x.1+1IM+2SM+	1	NA	0	NA	580		2040	
Wal	Dyfi	32	x.1+1SM+	1	NA	0	NA	648		3260	
Wal	Dyfi	32	x.1+1SM+	1	NA	0	NA	648		3260	
Ire	SLAN	1	2.0+	135	2	2	0	271	36	304	93
Ire	SLAN	2	2.0+1IM	9	2	3	1	325	48	445	175
Ire	SLAN	3	2.0+1IM+1SM+	2	2	4	2	355	21	397	81
Ire	SLAN	4	2.0+1SM+	8	2	3	1	346	36	496	190
Ire	SLAN	5	2.1	1	2	3	1	320			
Ire	SLAN	6	2.1+	5	2	3	1	340	19	518	58
Ire	SLAN	7	3.0+	22	3	3	0	280	25	317	91
Ire	SLAN	8	3.0+1IM	2	3	4	1	300	113	680	
Ire	SLAN	9	3.0+1SM+	2	3	4	1	349	27	553	140
Ire	SLAN	10	x.0+	3	NA	0	NA	270	18	227	57
Ire	SLAN	11	x.0+1IM+1SM+	1	NA	0	NA	394		1130	
Ire	SLAN	12	x.0+1SM+	1	NA	0	NA	457		624	

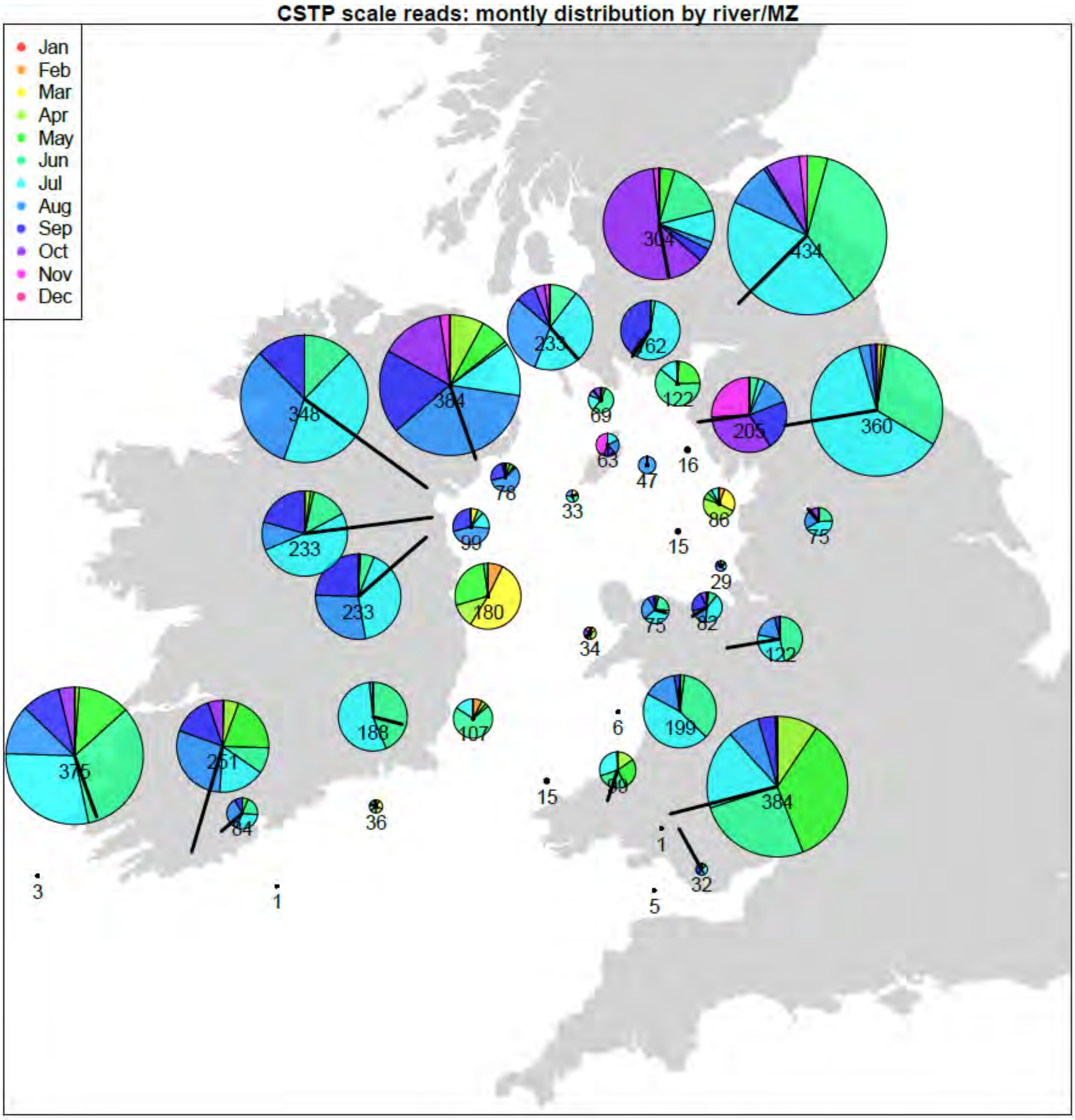


Figure 7.3.1 Monthly distribution of scale samples across marine zones and rivers. The fraction of the total sample collected in each month is presented as sectors colour-coded by month. Circle sizes are proportional to sample sizes (also shown in numbers below circle centre). Detail by month is presented in Table 7.3.3.

Table 7.3.3 Monthly distribution and totals of scale samples across marine zones and rivers

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
CURR	0	0	0	4	46	125	108	44	34	14	0	0	375
ARGI	0	0	1	13	50	23	41	74	36	13	0	0	251
BAND	0	0	0	0	5	17	25	30	7	0	0	0	84
SLAN	0	0	0	0	0	82	103	3	0	0	0	0	188
BOYN	0	1	0	0	1	12	96	66	57	0	0	0	233
DEWR	0	0	0	5	3	32	120	25	48	0	0	0	233
CAST	0	0	0	0	0	43	149	113	43	0	0	0	348
SHIM	0	0	0	30	25	3	47	140	74	56	9	0	384
IOM	0	0	0	0	0	0	11	13	7	4	28	0	63
LUCE	0	0	0	0	0	24	106	71	18	9	5	0	233
FLEE	0	0	0	0	0	4	89	6	63	0	0	0	162
NITH	0	0	0	1	13	50	28	7	12	188	5	0	304
ESKB	0	0	0	0	18	155	182	39	3	30	7	0	434
EHEN	0	0	0	0	0	8	6	25	44	69	53	0	205
LUNE	0	0	4	3	1	113	223	10	5	1	0	0	360
RIBB	0	0	0	0	0	18	32	17	1	7	0	0	75
DEEw	0	0	0	0	0	57	38	22	5	0	0	0	122
CLWY	0	0	0	0	1	8	33	16	18	5	1	0	82
CONW	0	0	0	0	3	16	29	20	6	1	0	0	75
DYFI	0	0	0	0	4	70	91	29	5	0	0	0	199
TEIF	0	0	0	15	27	27	29	1	0	0	0	0	99
TYWI	0	0	0	36	133	100	70	28	15	1	0	1	384
LOUG	0	0	0	0	0	0	1	0	0	0	0	0	1
TAWE	0	0	0	0	0	4	9	6	9	4	0	0	32
MZ01	0	0	0	0	0	1	0	0	0	0	0	2	3
MZ03	0	0	0	0	1	0	0	0	0	0	0	0	1
MZ04	0	3	8	7	5	5	2	4	1	1	0	0	36
MZ05	0	8	0	4	3	75	17	0	0	0	0	0	107
MZ06	0	13	93	21	49	4	0	0	0	0	0	0	180
MZ07	0	0	6	0	0	5	15	44	28	1	0	0	99
MZ08	0	0	1	3	4	1	1	46	19	2	1	0	78
MZ09	0	0	0	1	3	38	14	5	1	7	0	0	69
MZ10	0	0	0	1	29	75	16	1	0	0	0	0	122
MZ11	0	0	1	0	3	5	5	2	0	0	0	0	16
MZ12	0	5	23	41	6	4	7	0	0	0	0	0	86
MZ13	0	0	0	0	4	1	6	11	4	3	0	0	29
MZ14	2	0	4	10	3	0	2	0	2	6	5	0	34
MZ15	0	0	0	0	2	0	2	0	1	1	0	0	6
MZ16	0	0	0	2	0	13	0	0	0	0	0	0	15
MZ18	0	0	0	0	1	4	0	0	0	0	0	0	5
MZ23	0	0	5	2	0	8	10	8	0	0	0	0	33
MZ29	0	0	0	0	0	0	0	15	0	0	0	0	15
MZ30	0	0	0	0	0	0	0	47	0	0	0	0	47

The arbitrary target of 300 fish with age and length over the project was reached in only 7 rivers and only 22 rivers had samples with >40 individuals, considered sufficient to provide informative overall size distributions summed across seasons and years (Figure 7.3.2)

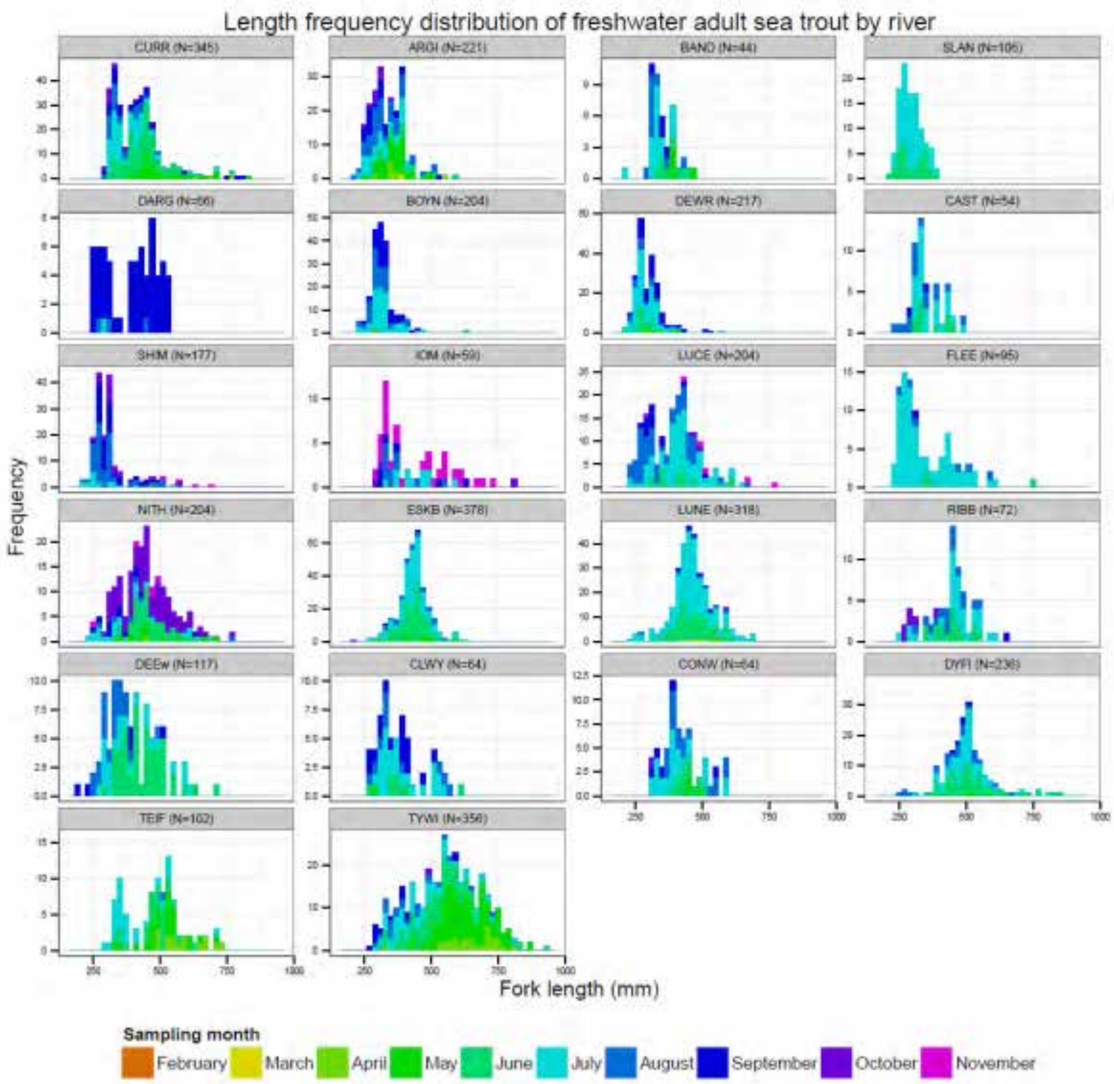


Figure 7.3.2 Length frequency distributions (bin width=20mm) of aged and measured returning adults of 22 rivers with a minimum sample size (N) of 40 individuals. The month of capture date has been colour coded.

Inspection of the size distributions for the 27 rivers showed a characterising difference in the occurrence of small fish (mainly whitling) smaller than around 400mm; although in some rivers this might have been influenced also by sampling bias. The seasonal return patterns were also seen, with larger fish, tending to enter earlier in the season, as is well established for sea trout. Similarly, visual inspection showed a broad scale geographical variation in life histories (Figure 7.3.3) with a proportionally higher abundance of older fish, >1SW sea maidens and previous spawners, being found on the eastern side of the Irish Sea (Galloway down to Wales) compared to the Irish coast.

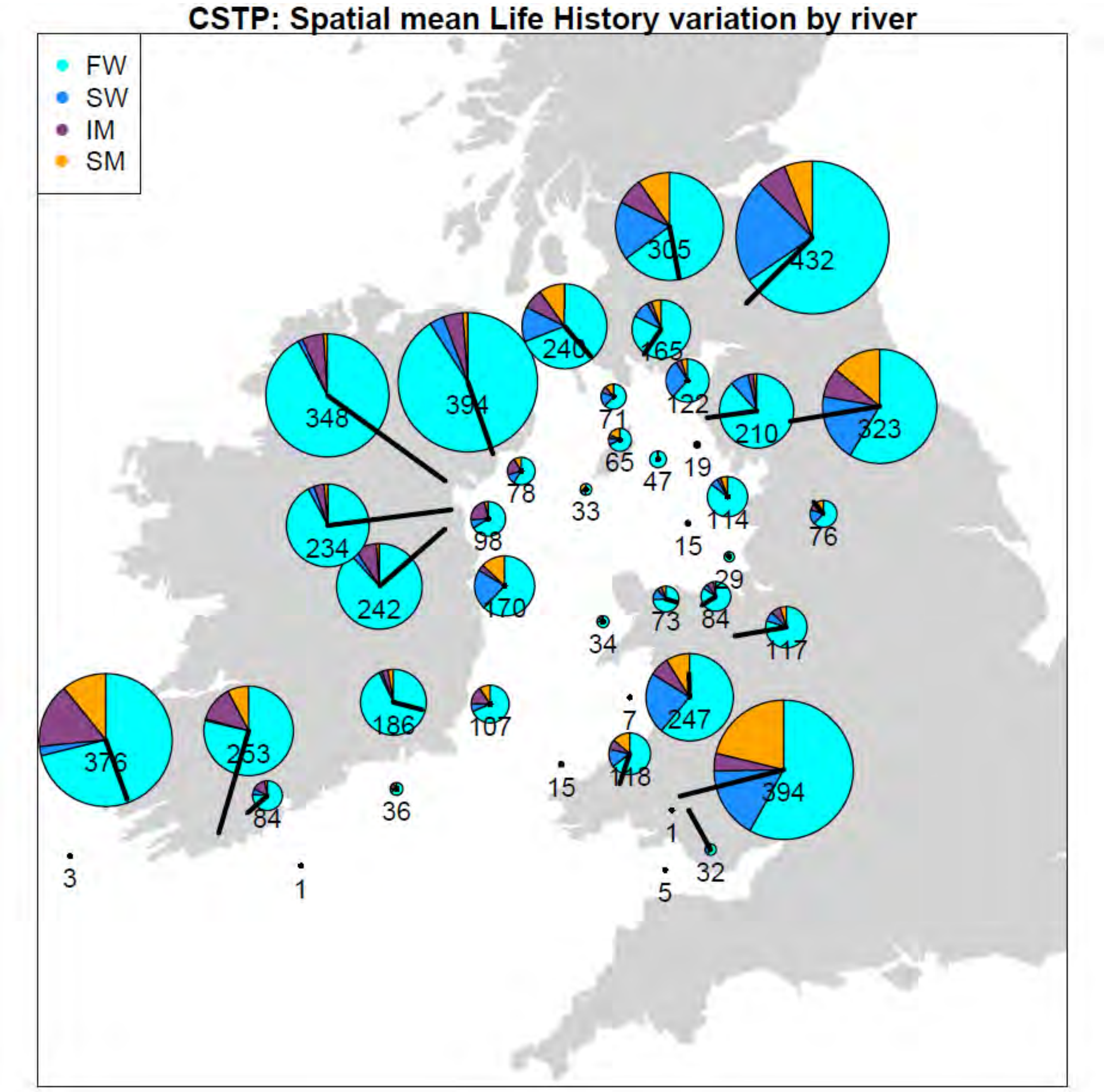
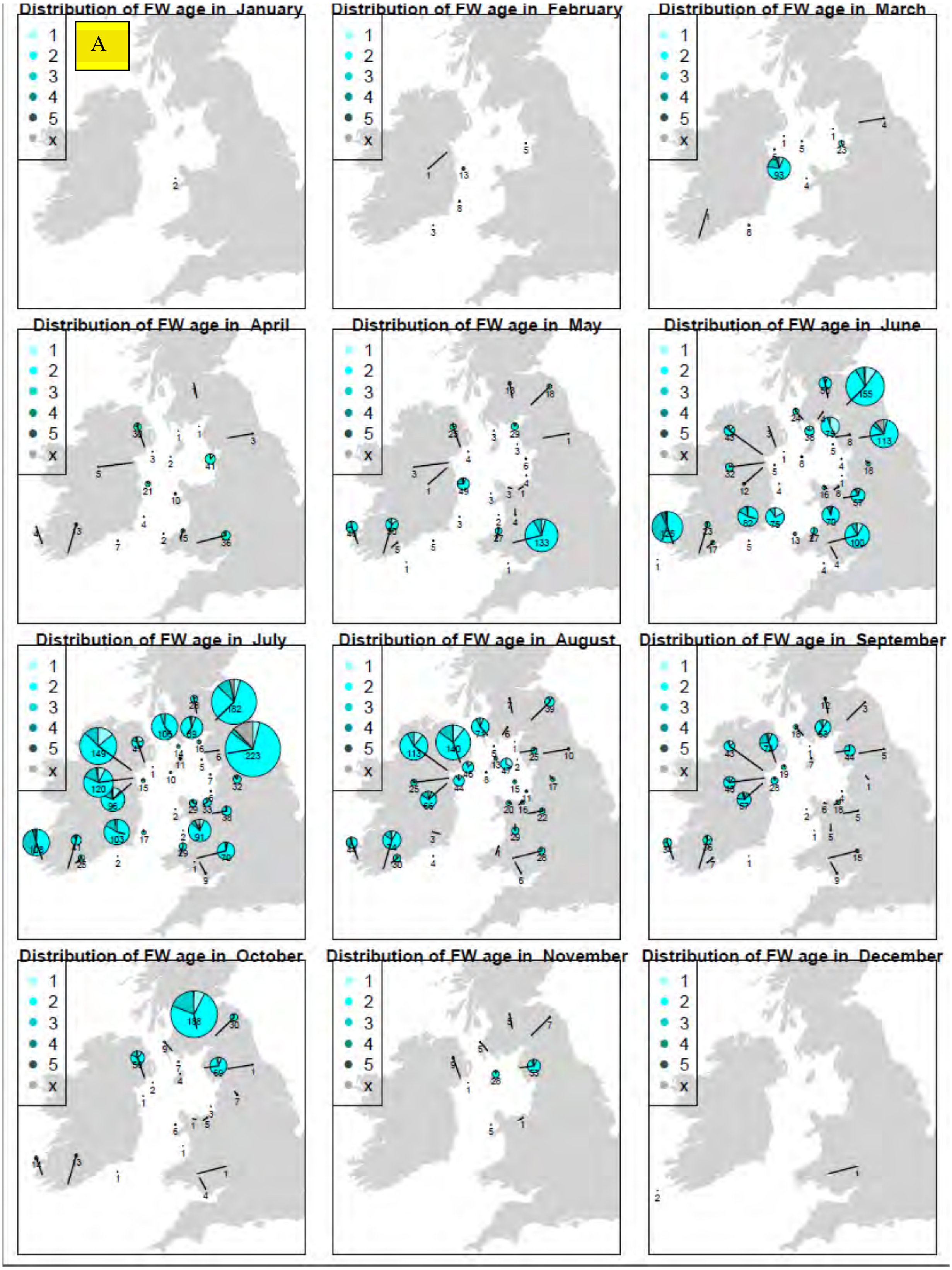


Figure 7.3.3 Mean life history variation among rivers. The mean number of years spent on average on each stage is shown as proportions of pie charts colour-coded by stage: cyan=fresh water (FW), blue=sea winters (SW), purple = indeterminate marks (IM), orange=spawning events (SM).

Most of the samples from Irish rivers were characterised by high proportions of finnock (whitling), with the exception of the Currane at the SW tip of Ireland which had a life history structure more in common with the stocks in larger rivers of Wales and England (Figure 7.3.4). The monthly entry pattern seen in larger fish was also evident in previous spawners which were mainly found in samples taken in January to July (Figure 7.3.4d).


A
Distribution of FW age in January
Distribution of FW age in February
Distribution of FW age in March
Distribution of FW age in April
Distribution of FW age in May
Distribution of FW age in June
Distribution of FW age in July
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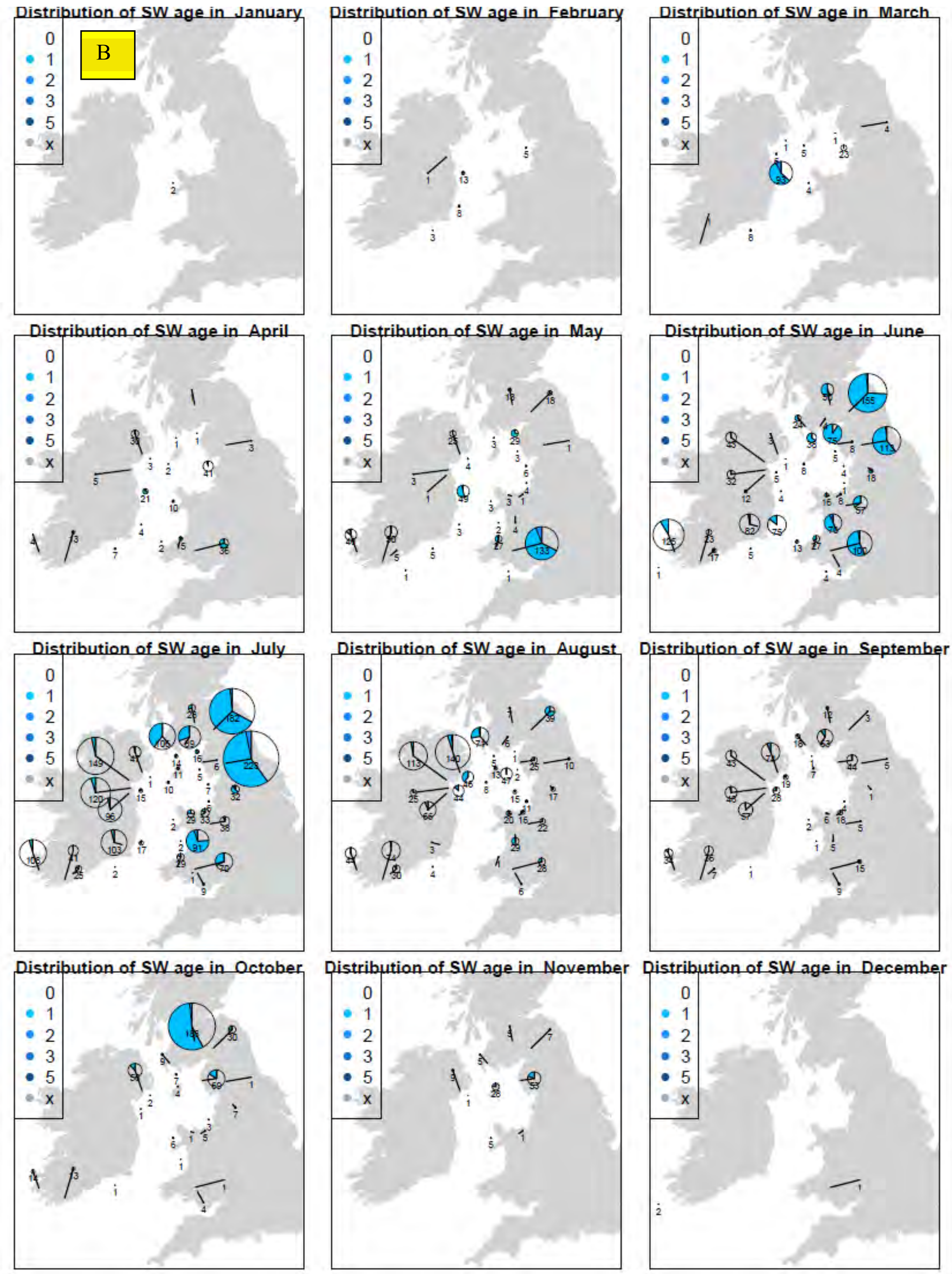
B
Distribution of SW age in January
Distribution of SW age in February
Distribution of SW age in March
Distribution of SW age in April
Distribution of SW age in May
Distribution of SW age in June
Distribution of SW age in July
Distribution of SW age in August
Distribution of SW age in September
Distribution of SW age in October
Distribution of SW age in November
Distribution of SW age in December
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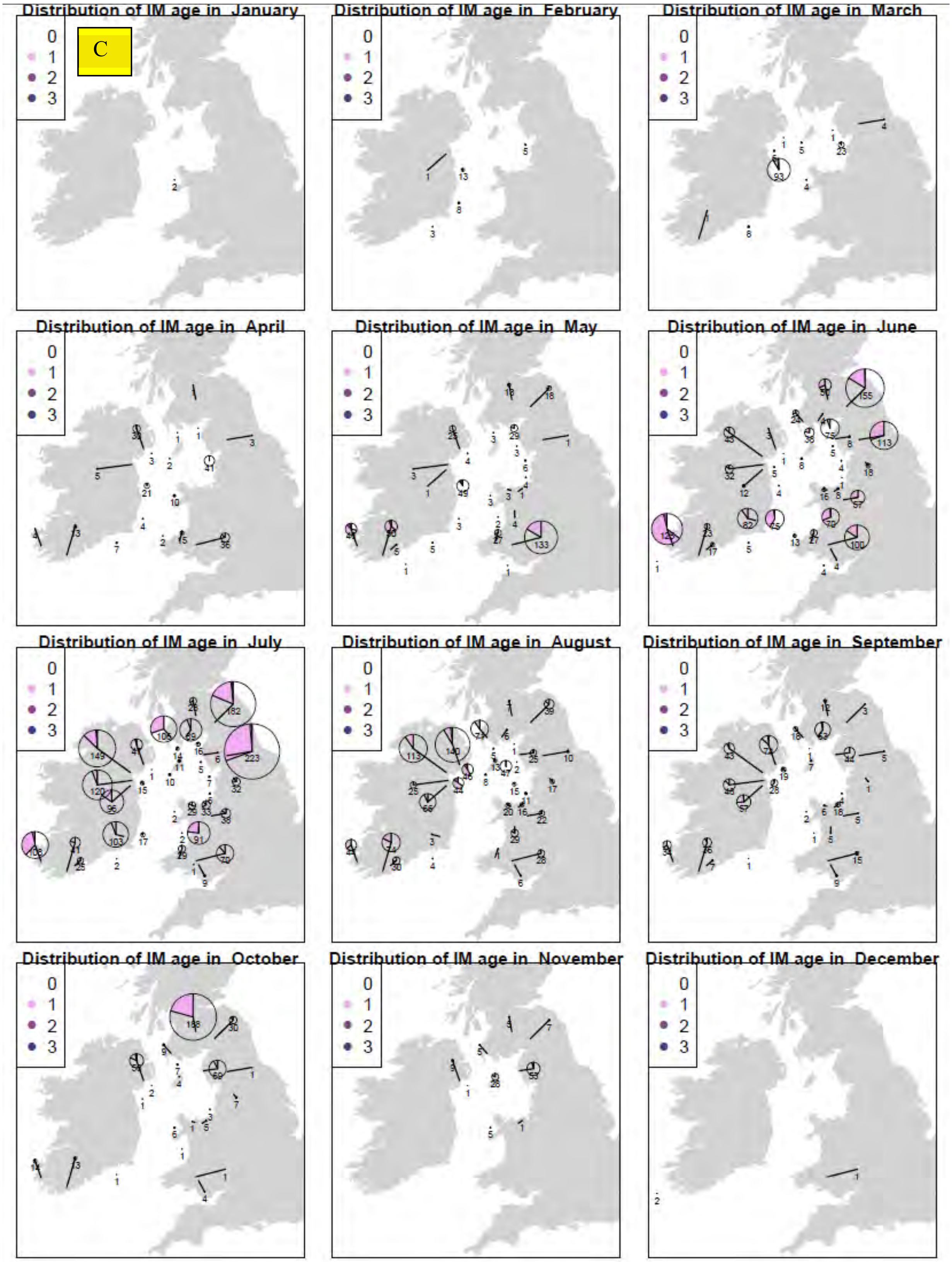
C
Distribution of IM age in January
Distribution of IM age in February
Distribution of IM age in March
Distribution of IM age in April
Distribution of IM age in May
Distribution of IM age in June
Distribution of IM age in July
Distribution of IM age in August
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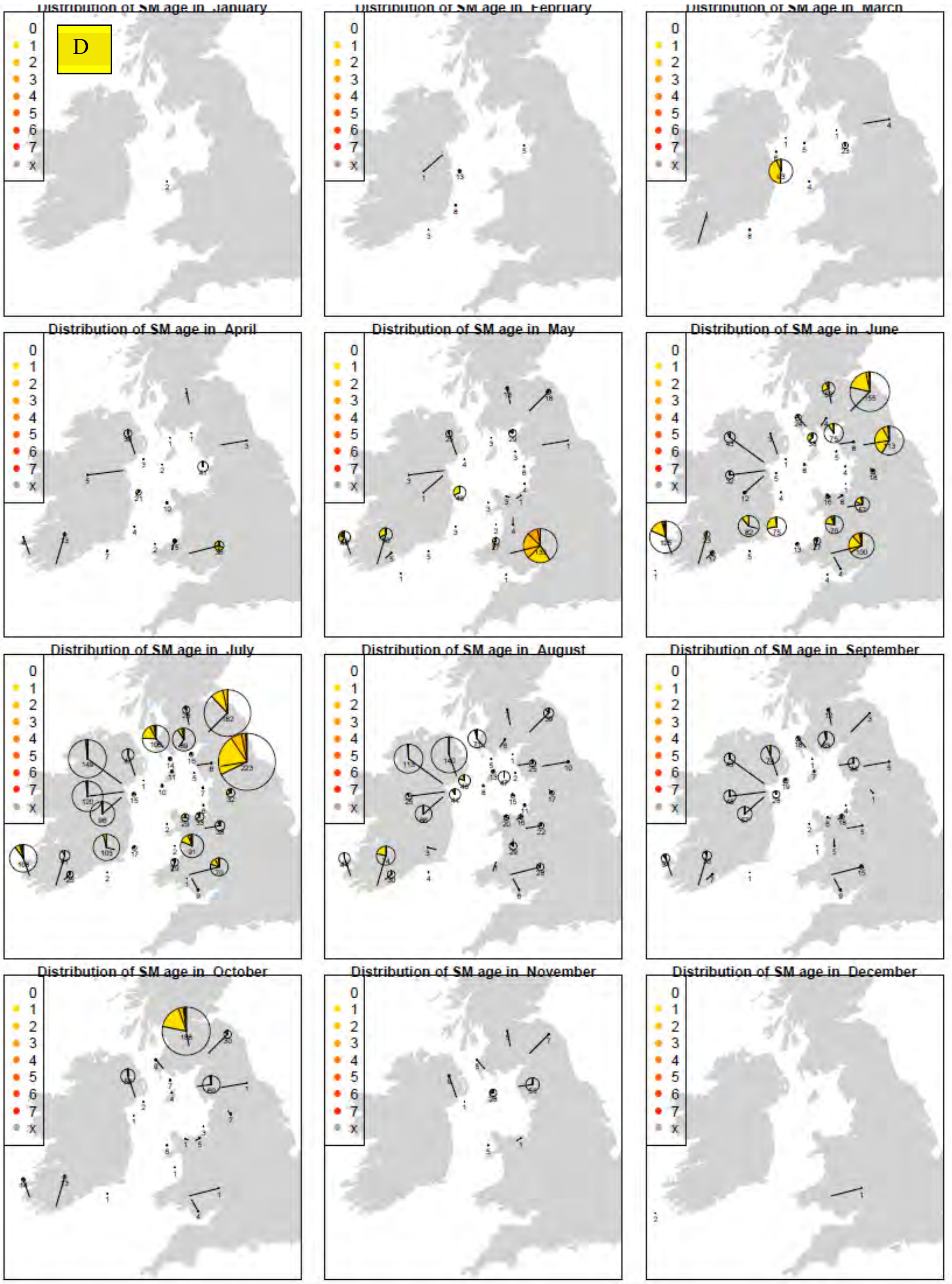


Figure 7.3.4 a-d: Spatial distribution by months of different frequencies of life history stages: Fresh water years (a), sea winters (b), indeterminate marks (c) and spawning marks (d): transparent = 0 years at that stage; increasing intensity indicate higher number of years at a stage: fresh water (FW) = cyan; sea winters (SW) = blue; indeterminate marks (IM) = purple; spawning marks (SM) = yellow to red.

Overall smolt age distributions (Table 7.3.4) were typical for sea trout in the British Isles. Percentage occurrence of 1, 2, 3 and 4yr old smolts was 7.1%, 81.7%,10.8% and 0.4 % respectively. In the contemporary (2010-2012) samples mean smolt (MSA) age varied between 2.43 yrs (Currane) and 1.81yrs (Tawe) and there was no significant relationship between mean smolt age and latitude on either sea board, or in combination. Mean sea age ranged from 0.17 yrs (Slaney) to 1.46yrs (Tywi) with an overall mean of 0.74yrs.

Table 7.3.4 Sea trout smolt age distributions of 23 different Irish Sea rivers, 2009-2012.

		Smolt age							
Country/Region	**River**	**1**	**2**	**3**	**4**	5	**NA**	**Sample**	**MSA(yrs)**
Galloway	B.ESK	6.5	85.9	7.6	0.0	0.0	2.70	444	2.01
	FLEE	7.3	88.5	4.2	0.0	0.0	0.60	166	1.97
	LUCE	3.3	89.6	7.1	0.0	0.0	0.41	241	2.04
	NITH	8.5	77.0	14.4	0.0	0.0	0.33	306	2.06
Isle of man	IoM	1.5	95.4	3.1	0.0	0.0	0.00	65	2.02
Ireland	ARGI	10.3	79.1	10.3	0.4	0.0	1.17	256	2.01
	BAND	21.4	72.6	6.0	0.0	0.0	0.00	84	1.85
	BOYN	9.5	74.8	14.5	1.2	0.0	1.63	246	2.07
	CAST	12.9	77.3	9.8	0.0	0.0	0.85	351	1.97
	CURR	0.3	60.4	35.9	3.2	0.3	1.57	382	2.43
	DEWR	9.4	76.9	13.2	0.4	0.0	0.85	236	2.05
	SLAN	0.0	86.0	14.0	0.0	0.0	2.62	191	2.14
Northern Island	SHIM	10.9	71.8	16.8	0.5	0.0	1.99	402	2.07
NWEngland	EHEN	6.2	88.1	5.7	0.0	0.0	0.47	211	2.00
	LUNE	4.3	91.0	4.6	0.0	0.0	11.02	363	2.00
	RIBB	9.2	89.5	1.3	0.0	0.0	1.30	77	1.92
Wales	CLWY	6.0	89.3	4.8	0.0	0.0	1.18	85	1.99
	CONW	12.3	83.6	4.1	0.0	0.0	2.67	75	1.92
	DEEw	8.5	89.7	1.7	0.0	0.0	4.10	122	1.93
	Dyfi	6.1	88.3	5.7	0.0	0.0	3.52	256	2.00
	TAWE	21.9	75.0	3.1	0.0	0.0	0.00	32	1.81
	TEIFI	3.4	91.5	5.1	0.0	0.0	0.00	118	2.02
	TYWI	4.3	90.1	5.6	0.0	0.0	1.25	399	2.01
Total		**7.1**	**81.7**	**10.8**	**0.4**	**0.0**	**2.15**	**5108**	**2.05**

Life history diversity is regarded as an important attribute conveying stability and resilience to populations (Fleming *et al*., 2014). One expression of life history variation is the observed range of times of first returns (maiden age) and repeat spawning schedules. Table 7.3.2 demonstrates that the same total age or sea age can be achieved with very different life history tactics. In the Dyfi for example, total age 3 fish show four different scale formulae: 1.1+1SM+, 1.2+, 2.1+, 3.0+ (this excludes the IM categories which if they could be determined would be assigned to one of the others) and the possible permutations rapidly increase with age, but in practice this is moderated by mortality.

Excluding the IM categories and fish identified as still in the freshwater phase (1+, 2+, 3+ and 4+), a total of 51 different categories of scale formulae were recorded for migratory trout from 23 rivers (Table 7.3.5).

Table 7.3.5 Scale formulae and their frequencies, ranked by abundance for migratory trout for which full formulae were available and without indeterminate marks, recorded during the CSTP in 23 rivers, combined across all samples.

	Sea Age (yrs)												
Scale formula	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**NA**	**Total**	**%age**	**cum%**
2.0+	1832										1832	46.89	46.89
2.1+		808									808	20.68	67.57
3.0+	333										333	8.52	76.09
2.1+1SM+			191								191	4.89	80.98
2.0+1SM+		144									144	3.69	84.67
1.1+		106									106	2.71	87.38
1.0+	104										104	2.66	90.04
2.1+2SM+				62							62	1.59	91.63
3.1+		48									48	1.23	92.86
2.0+2SM+			41								41	1.05	93.91
2.2+			34								34	0.87	94.78
2.1+3SM+					26						26	0.67	95.44
1.1+1SM+			22								22	0.56	96.01
3.0+1SM+		17									17	0.44	96.44
2.2+1SM+				14							14	0.36	96.80
4.0+	13										13	0.33	97.13
1.2+			12								12	0.31	97.44
2.0+3SM+				12							12	0.31	97.75
2.0+4SM+					8						8	0.20	97.95
3.1+1SM+			7								7	0.18	98.13
1.2+1SM+				6							6	0.15	98.29
3.0+2SM+			6								6	0.15	98.44
1.0+1SM+		5									5	0.13	98.57
2.1+1SM			5								5	0.13	98.69
2.1+4SM+						5					5	0.13	98.82
3.0+3SM+				5							5	0.13	98.95
1.1+2SM+				4							4	0.10	99.05
3.1+3SM+					4						4	0.10	99.16
3.1+2SM+				3							3	0.08	99.23
1.2+2SM+					2						2	0.05	99.28
2.0+1SM		2									2	0.05	99.33
2.0+2SM			2								2	0.05	99.39
2.2+2SM+					2						2	0.05	99.44
2.2+3SM+						2					2	0.05	99.49
3.0+4SM+					2						2	0.05	99.54
3.2+			2								2	0.05	99.59
4.0+1SM+		2									2	0.05	99.64
1.0+1SM		1									1	0.03	99.67
1.0+3SM+				1							1	0.03	99.69
1.1+3SM+					1						1	0.03	99.72
2.0+5SM+						1					1	0.03	99.74
2.0+6SM+							1				1	0.03	99.77
2.0+7SM+								1			1	0.03	99.80
2.1+3SM					1						1	0.03	99.82
2.1+5SM+							1				1	0.03	99.85
2.1+6SM+								1			1	0.03	99.87
2.1+7SM+									1		1	0.03	99.90
3.0+3SM				1							1	0.03	99.92
3.0+6SM+							1				1	0.03	99.95
3.5+						1					1	0.03	99.97
5.0+	1										1	0.03	100.00
Total fish	2283	1133	322	108	46	9	3	2	1	0	3907		
Count of formulae	5	9	10	9	8	4	3	2	1	0	51		

The most prevalent category was 2.0+ (47%) and 90% of the fish fell into the top seven categories (individual river data are shown in Appendix A7.7). The most diverse sea age classes were the 2yr olds, with 10 different scale formulae, but 1 and 3yr olds both had nine. In the absence of other factors, formula diversity should be mainly a function of age (which determines the maximum possible number of combinations) and abundance at age, but increasing mortality reduces abundance of older potentially more diverse ages. The diversity of scale formulae between rivers was described using the Shannon-Weiner diversity index (H), which attempts to combine abundance and prevalence. There was a 3-fold variation in H values, which are shown ranked in Figure 7.3.5. In these samples across the 23 rivers, mean H was related significantly to mean sea age (MSA) by $H = 2.158MSA^{0.3282}$ (r=0.911, p<0.01, df=21). This is only to be expected for reasons outlined above. Diversity indices are difficult to interpret (Southward and Henderson, 2000) and the aim here is simply to illustrate and compare the variation rather than attribute any life history significance to it. However a different life history metric (than simple scale formulae), such as a combination of time of first return and multiple spawning, might offer a more informative analysis and alternative ways to express this variation are examinted in Section 7.6.

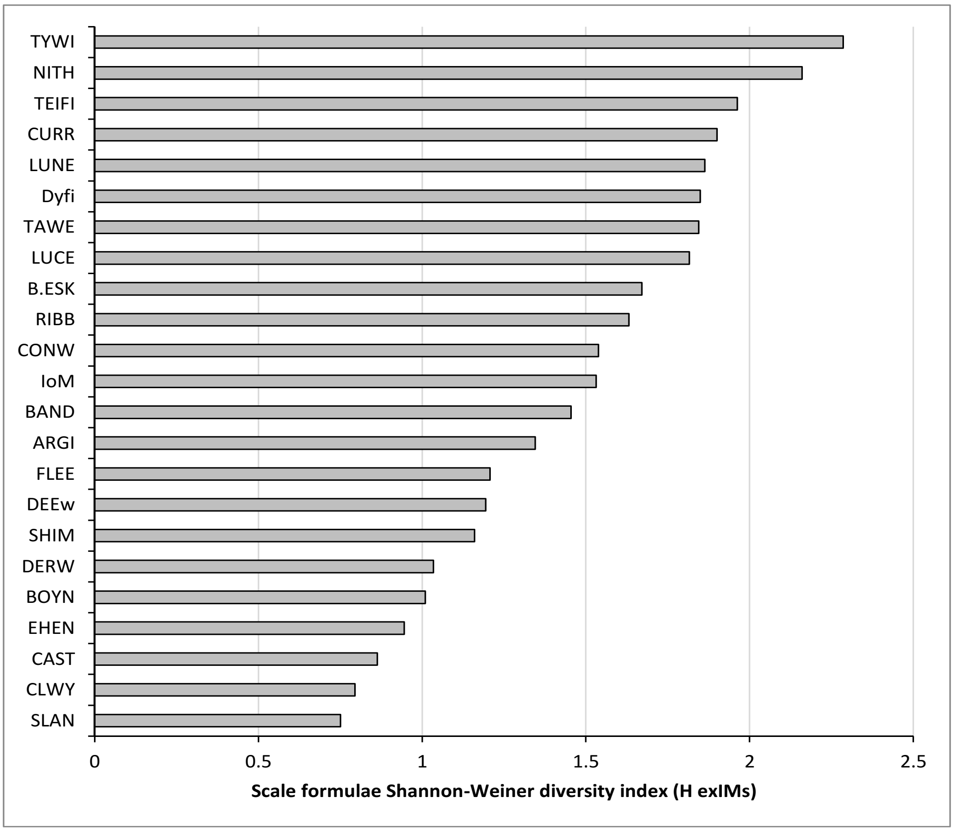


Figure 7.3.5 Scale formulae diversity in various rivers as measured by the Shannon-Weiner index (H).

7.4 Size at Age, Growth Rate and Condition of Adult Sea Trout

7.4.1 Introduction

The growth of fish, their size at age and rate of change in size is controlled by genes and the environment and is the single most important feature of their biology. In life history terms fast growth rate is associated with early maturity and thus time of first return to spawn, because this optimises the lifetime egg production (Hutchings and Jones, 1998). Size is positively correlated with swimming speed, migration capacity (energy reserves that give the ability to deal with distance and difficulty), predator avoidance, prey size range (jaw gape size) and fecundity. Salmonid smolt survival is related to size at smolting (Salminen, 1997; Jonsson and Jonsson, 2014). Sea trout average size increases with river size (Crozier *et al* 2003), possibly due to the advantage that size brings for migration through long catchments (Jonsson and Jonsson, 2006).

Because fish are poikilothermic (cold-blooded) their growth is indeterminate; therefore environmental conditions, principally water temperature and food availability, are expected to affect strongly growth rate and size at age, in addition to the influence of any population (e,g. density) or genetics effects. Consequently, many environmental factors that might influence sea trout population structure and dynamics do so by altering growth. Growth rate in juvenile salmonids including trout has also been reported to vary with population density, although the effect might be most apparent at low densities and other factors can override density (Grant and Imre, 2005). Finally, fisheries may be selective for fish within a particular size range, either through the mode of operation of the gear or as a result of size limits for retention. Growth, as both *size* (e.g. Length, L, and Weight, W) at age and rate of change in size (growth *rate*), is therefore a crucially important variable to describe and understand in sea trout.

An additional metric, Fulton's condition factor ($K \sim W/L^3$), an index of the fatness of fish, is also important, because it is regarded as a simple surrogate for the fish's nutritional status. For example, the incidence of skinny salmon returning to Scottish coasts has been interpreted as indicative of poor feeding conditions at sea possibly related to marine survival (Todd *et al*., 2008). K introduces its own problems however, mainly due to allometric growth (Froese, 2006), and these need to be borne in mind.

Apart from Fahy's (1978) account, sea trout growth variation has not been examined in the Irish Sea in relation to its response to environmental factors and its implications for life history and population dynamics. Questions relevant to the CSTP are:

- What are the geographical variations in growth rate, size-at-age and condition distributions of smolts, adults at sea and adult returnees around the Irish Sea?
- How do environmental variables, particularly related to climate, affect observed variation?
- How might movements around the Irish Sea account (taking fish to different temperature and feeding regimes) for any variation in size and growth patterns?
- What are the consequences of any growth variation for population dynamics, population characteristics and fisheries?

Sea trout sizes at age have previously been described for some of the Irish Sea rivers, but in most cases caution should be applied because of size-selective sampling and measurement errors, particularly where measurements have been made by anglers or netsmen (Harris 2002). Harris (2002) reported the results from a study including ten Irish Sea rivers (Section 7.4.3.1) and compared data from previous studies extending to the 1930s (see Harris for references).

Growth of adult sea trout is difficult to estimate from size distributions of rod catches in rivers because the river run from which catch is taken represents only that part of the total population that has returned to breed or, in the case of some whitling to shelter over the winter (Solomon, 1994, Degerman *et al*., 2012). Thus, size at age for fish older than .0+ can be misleading because the sizes are composites of fish with different life histories and thus growth conditions. The act of return is itself related to maturation in most adults, which in turn is likely to be influenced by marine growth rate; thus even maiden returnees are a biased sample of the extant population.

This section focuses on growth in the marine phase aiming to (a) describe a baseline of size, growth and condition from the rivers, and (b) describe and analyse relationships between growth metrics and explanatory factors of temperature and latitude (a surrogate for temperature and also for other climate variables and day length).The analysis explicitly tests hypotheses that, for adult sea trout in the sea:

- Growth rate does not vary between rivers or with latitude.
- Condition is independent of season and location (latitude).

- It will be seen that in a species like (sea) trout with complex patterns of migration between freshwater and marine habitats, and when as in this case samples are selective and data have biases, measurement of growth is extraordinarily difficult. No one method proves totally satisfactory and the analyses below use four metrics:
- Mean size at age
- Between year annual length increment between .0+ and .1+ maiden groups.
- Between cohort (within single year or pooled years) increments between .0+ and .1+ maiden groups
- Within-year variation in size of a cohort.

7.4.2 Data Sources

Five main sources of size at age data were examined for size and growth variation.

1) Historical data (a). The Harris (2002) set 1996-98. This was in the form of the original raw data files from that study, providing size at capture for fish aged by scale reading. Scales were taken and fish measured mostly by anglers, with some trap data from the Lune and Dee.
2) Historical data (b): various reported values for size at capture (collated from the literature by Fahy, Solomon and others). Some are from the 1930s, but their exact provenance and biases are unknown. These data were used with other sources to examine long term changes in size at age.
3) Contemporary data (a): Dee trap. This is the benchmark data set, scales and measurement taken to refined protocols from the literature and QA since 1991. For the CSTP data were made available from 2010 to 2012.
4) Contemporary data (b): CSTP samples from freshwater (rivers) taken by combination of anglers and some electrofishing *(see Section 3* Sampling),.
5) Contemporary data (c): CSTP samples from marine zones *(see Section 3* Sampling), taken by combination of anglers, scientific surveys and commercial fishing.

There is a major distinction lies between types 1-4 (fish that have returned to freshwater) and type 5 (fish remaining at sea).

7.4.3 Methods

The raw data from the Harris (2002) study were processed to describe size at age and growth rate in maiden fish. Maidens were regarded as less prone to bias because in principle they have not experienced any breaks in growth for spawning migrations. However, as noted above, fish sampled in rivers represent only the returning component of the bigger marine population and the exact location of adult sea trout during their growth cannot be known; for example, some unknown proportion of the .1+ fish might have spent part of their adult life in river as whitling. The parsimonious assumption for this stage of analysis was that they have all grown in the sea within some limited distance of their river of recapture. This was made in order to attribute temperatures to river groups. It was further assumed that when sea trout enter freshwater they stop feeding and growing. In fact there may be some small level of river feeding (Elliott, 1997), but this was not considered to cause significant growth compared with marine feeding. If it can be assumed that fish are caught soon after entry their capture date reflects the end of the growing period in that year. Unfortunately, fish enter rivers over several months and may not be caught immediately. Therefore the date of capture is only an imprecise measure of when they stopped growing. Harris (2002) commented on the large errors arising from measurement of length and weight by anglers and this was apparent in the raw data set. Weight was considered too unreliable as an index of growth rate and all growth analysis here is based on length, considered likely to be more accurately recorded.

Weight (W, g), fork length (L, mm) and condition ($K = W*100000/L^3$) data were examined to identify and exclude values deemed unreasonable to accept as reliable measurements. Various methods can be used to extract anomalous data (fliers). The approach was to remove fish with K values lying in the top and bottom 2.5%iles of the distribution of k, leaving 5,061 samples of which 1,962 and 1,547 were .0+ and .1+ maidens respectively, the remainder being various age/spawning combinations (See Harris, 2002 for details). The Harris sample covered the period 1996-1998. For this analysis the data were pooled across years because annual splitting rendered several samples unacceptably small.

Growth was compared with monthly and annual mean sea surface temperatures (0C) adjacent to the ten rivers, for the period 1996-1998. Sea surface (1m depth, see below) temperatures (SST) were satellite derived (AVHRR Pathfinder Version 5, http://poet.jpl.nasa.gov/) for a square of approximately 20km^2. Monthly averages were derived from daily data. Temperature values used were night time SST to approximate average daily temperature at 1m depth. Latitude was taken as the tidal limit of each river.

Growth increment was calculated as the different between mean lengths of .0+ fish and of .1+ fish pooled over the 3 year period (1996-98) for each river. The modal and median months of capture for .0+ and .1+ sea trout were July and June respectively (Table 7.4.1). There was some evidence of between-river variation in this timing, some of which is almost certainly due to atypical sampling (for example the River Lune October .0+ fish were taken in the fish trap), but the river/month sample sizes were small and highly variable between years, therefore data were pooled across years over all the rivers. No substantive error for the purposes of this analysis is considered to be incurred by this treatment.

Table 7.4.1 Monthly percentages and total numbers (N) of .0+ and .1+ maiden sea trout (all smolt ages) averaged for 1996-1998 (original data from Harris, 2002). Shading illustrates the frequency distributions.

.0+ maidens											
	ESK	KENT	LUNE	RIBBLE	DEE	CLWYD	DWYFOR	DYFI	TEIFI	TOWY	Total
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mar	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Apr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
May	4.3	2.2	0.0	0.0	0.3	0.0	0.0	1.8	0.5	0.0	0.6
Jun	41.3	13.0	9.5	9.7	10.4	8.8	1.1	25.5	26.3	11.3	14.3
Jul	47.8	17.4	7.6	51.6	51.3	45.1	7.4	30.0	41.3	51.4	37.9
Aug	4.3	19.6	19.0	32.3	24.9	32.4	42.9	32.7	22.1	30.2	25.3
Sep	2.2	37.0	7.2	3.2	7.0	8.8	39.4	7.3	8.0	5.7	10.3
Oct	0.0	10.9	55.9	3.2	4.2	4.9	9.1	2.7	1.9	1.4	10.8
Nov	0.0	0.0	0.4	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.7
Total N	138	46	263	31	672	102	175	110	213	212	100.0

.1+ maidens											
	ESK	KENT	LUNE	RIBBLE	DEE	CLWYD	DWYFOR	DYFI	TEIFI	TOWY	Total
Jan	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Feb	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Mar	0.0	0.0	0.3	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.1
Apr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.2
May	9.8	0.0	5.4	1.8	14.1	0.0	0.0	1.9	4.5	12.1	6.6
Jun	42.1	16.4	59.3	19.3	43.2	25.0	22.2	35.3	27.3	32.9	40.5
Jul	43.9	38.8	24.7	45.6	24.5	33.3	40.7	38.4	40.9	31.5	33.6
Aug	2.8	14.9	5.1	17.5	2.9	29.2	14.8	17.5	13.6	14.8	10.0
Sep	1.4	26.9	3.8	13.2	6.2	12.5	14.8	6.9	9.1	5.4	6.7
Oct	0.0	3.0	1.1	1.8	6.6	0.0	7.4	0.0	4.5	1.3	1.9
Nov	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.3
Total N	214	67	369	114	241	24	27	320	22	149	1547

Initially maidens of all smolt ages were analysed. But seasonal sizes of .0+ fish indicated that early returning .0+ fish were as large as later entrants. This might be due to an effect of older, larger smolts which typically leave rivers before (potentially up to 3 months) smaller younger smolts, returning earlier than the younger fish, having started at larger size and having a longer growth period. Larger starting size might be offset by longer growing period, so the overall increment outcome was uncertain. To remove this smolt age effect, the analyses were reworked using only 2yr old smolts which are the dominant group in all the Irish Sea populations (Harris 2002) and 87% of maiden fish (Table 7.4.2). In practice there was no detectable difference between the analyses and the 2yr old smolt data are shown here. Statistical tests used variously correlation, linear regression and analysis of variance.

Growth Modelling

Growth over the period July to the following June (11months) was modelled using the Elliott (Elliott *et al*., 1995; Elliott and Hurley, 1997) growth equation for brown trout:

$$W_t = (W_0^b + (b.c.(T-T_{LIM}).t)/100.(T_M-T_{LIM}))^{(1/b)}$$

Where:

W_t = Weight (g) after time t (days) at temperature T
T = water temperature (°C)
W_0 = starting weight at time t=0
b = an exponent for the power transformation of mass that produces linear growth with time =0.308
c = growth rate of a 1g fish at optimum temperature = 2.803
$T_{LIM} = T_L$, if T=< T_M or $T_{LIM} = T_U$ if T>$_{TM}$
T_M = the optimum temperature for trout growth = 13.56°C
T_L = the lower temperature at which trout will grow = 3.56 °C
T_U = is the upper temperature at which trout will grow = 19.48 °C

This equation and its parameters were derived for small brown trout growing in freshwater experimental tanks, with unlimited feeding on invertebrate food. Therefore its appropriateness for adult trout growing in salt water and feeding predominantly on a high protein and lipid fish diet can be questioned. L'Abée-Lund *et al*., 1989 using an earlier version (Elliott, 1975) of Elliott's model found that an optimum temperature of 15°C and T_U of 21°C optimised the model for sea trout in Norwegian waters. These alternative values were trialled here. The basic modelling and statistical analysis were done variously in Excel and R (R Core team, 2014).

7.4.3.1 Results: Historical Samples (Harris,1996-98)

Smolt age, size and time of whitling return

Considering the .0+ (whitling) group, mean smolt age varied significantly between rivers and months (ANOVA, P<0.05). Inspection indicated that the older smolts were slightly more prevalent in the more northerly rivers, and in all rivers were slightly more prevalent in the early season returnees, principally June and July (Figure 7.4.1).

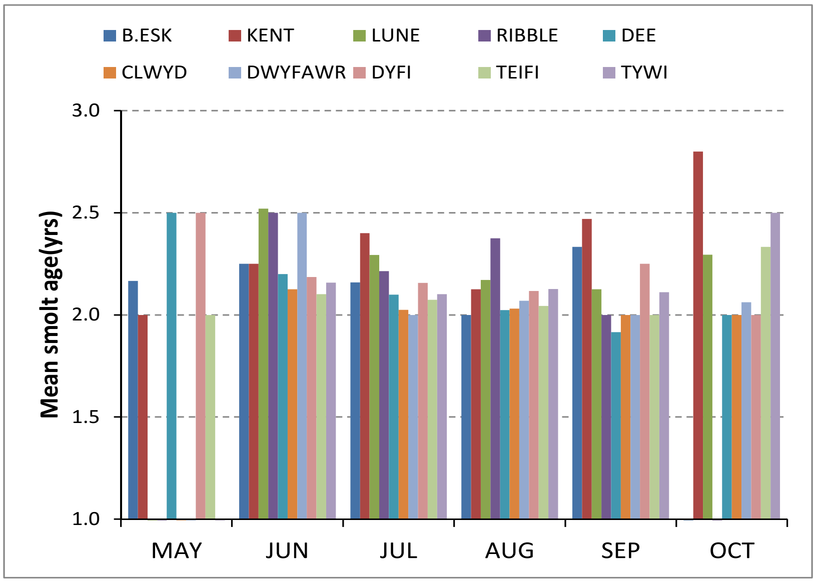


Figure 7.4.1 Seasonal and between river variations in mean smolt age (yrs) of .0+ sea trout (whitling). The coloured bars in each month are ordered left to right for north to south rivers. In most months mean smolt age was usually associated with the more northerly rivers. Data adapted Harris, 2002).

Pooling across rivers, mean whitling size was significantly (r=0.971, df =2, P<0.05) positively correlated with smolt age (Table 7.3.3).

Table 7.4.2 Length and sample size (N) of .0+ maiden sea trout (whitling) of different smolt ages (data after Harris, 2002).

	Smolt age (yrs)			
	1	**2**	**3**	**4**
mean length (mm)	286	333	351	426
SD (mm)	36	37	39	63
95%CL	21.5	1.9	5.2	191.5
N	13	1546	222	2
% N	0.7	86.7	12.5	0.1

There was a weak positive correlation between smolt age and latitude (Figure 7.4.2), but this was not statistically significant (r=0.420, df =8, NS).

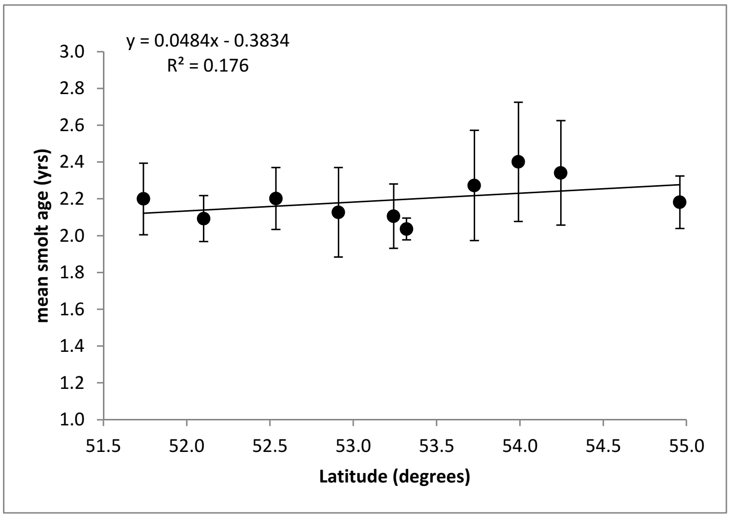


Figure 7.4.2 Relationship between mean smolt age (of maiden sea trout) and latitude of river tidal limit.

Monthly Variation in Length

Rod caught 2.0+ whitling sampled by the rod fisheries showed no consistent variation in length between May and November (Figure 7.4.3). Rather, mean monthly lengths remained relatively unchanged throughout this period, or indicated some decrease in size From May to September and some slight increase thereafter. Lengths of 2.1+ fish showed more evidence of increasing size in some rivers (Esk, Lune, Dee, Dyfi), but even in these the seasonal pattern was weak and non-significant.

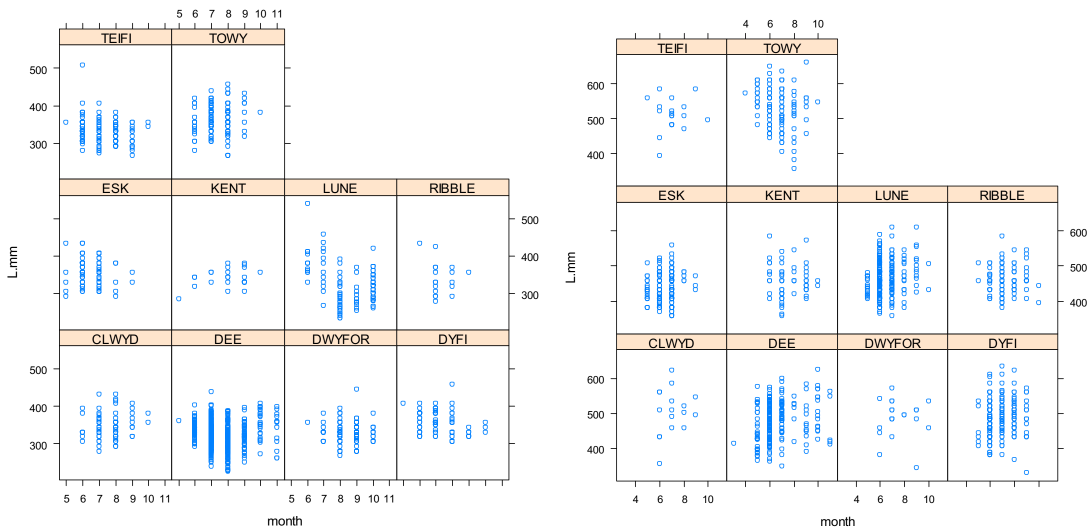


Figure 7.4.3 Lengths of (A) 2.0+ and (B) 2.1+ sea trout rod-caught in 10 Irish Sea rivers, pooled for 1996-98 (data after Harris, 2002).

On the basis of these results it was felt appropriate to pool length data between months in order to estimate an annual average size for each of the two age groups (2.0+ and 2.1+). Because whitling size varies with smolt age (Table 7.4.2), the comparison of growth between rivers could potentially be confounded by variation in smolt age composition and there was a weak if insignificant relationship with latitude (Figure 7.4.2). Strictly speaking the analysis of growth should be conducted on fish of the same smolt age to eliminate the smolt age effect. The analyses below were carried out both ways, on 0+ and 1+ maidens of all smolt ages and on those only of 2 yr old smolts, but no significant differences were found in relationships with latitude or sea surface temperature. However in order to avoid the potential problems the results reported here are based on 2 yr old smolts.

Spatial Variation in Size at Age

Considering only 2.n maidens (the 87% in Table 7.4.2) the lengths of 2.0+ fish varied significantly (P<0.01) between rivers (Figure 7.4.4A), but were independent of latitude (Figure 7.4.4B). However, 2.1+ lengths were significantly (P<0.01) related to latitude (Figure 7.4.4B).

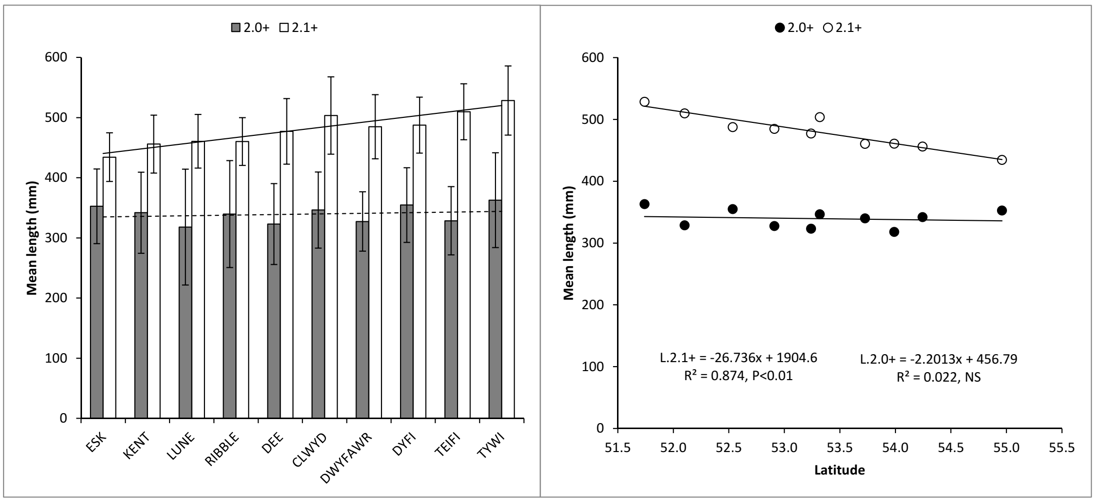


Figure 7.4.4 Mean lengths of 2.0+ and 2.1+ sea trout (A) between rivers (standard deviations shown) and (B) with latitude, data pooled 1996-1998.

The lengths in Figure 7.4.4 are mean lengths pooled over 1996-98 and the modal times of return for each age group was July and June for .0+ and .1+ respectively. Thus for each river the differences between these means are estimates of average length increments over an 11 month period. The increment (effectively an annual growth index, G) ranged between 82mm and 181mm (0.24 and 0.54mm d^{-1} respectively) and was significantly negatively correlated with latitude (L) according to G=-24.534.L +1447.9 (R^2=0.701), with higher growth in more southerly rivers. Mean annual sea surface temperature (T) decreased significantly with increasing latitude, according to T = -0.4206L + 33.647, R^2 =0.918, P<0.001); thus annual growth was significantly (P<0.05) correlated with temperature (Figure 7.4.5).

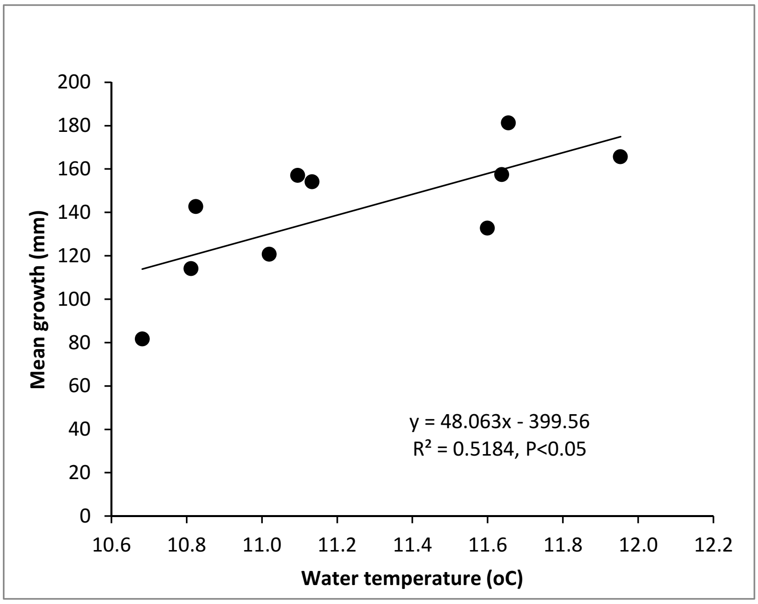


Figure 7.4.5 Growth rate (as length increment yr0 to yr1) variation with mean sea surface temperature, 1998-1998 in 10 Irish Sea rivers. Raw data from Harris (2002).

Modelled Growth

The Elliott (1995, 1997) model was used to predict growth in length over the 11 month period (end of July to end of June) for which the average (1996-98) observed growth was described above. Monthly sea surface temperatures were the same temperatures as used above. Across all sites average monthly mean sea surface temperature ranged between 6.9^{o}C (February) and 16.8^{o}C (August), and between rivers annual means ranged between 10.7^{o}C (Border Esk) and 12.0 ^{o}C (Tywi) (Table 7.4.3).

Table 7.4.3 Monthly mean sea surface temperatures (1996-1998) adjacent to ten Irish Sea rivers, used in growth modelling. Derived from satellite sources (see text).

RIVER	JULY	AUG	SEPT	OCT	Nov	Dec	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	MEAN
Besk	14.6	16.3	15.2	12.9	10.4	8.3	6.5	6.5	6.8	7.9	10.1	12.9	14.6	10.7
Kent	14.8	16.6	14.8	13.0	10.4	8.0	6.2	6.6	7.3	8.5	10.3	13.2	14.8	10.8
Lune	15.7	16.6	14.9	13.2	10.3	8.0	6.9	6.4	7.1	7.6	9.9	13.2	15.7	10.8
Ribble	15.4	16.8	15.7	13.5	11.1	8.3	6.8	6.2	7.0	7.3	10.7	13.5	15.4	11.0
Dee	15.7	16.9	15.6	13.5	11.7	8.3	7.6	6.7	7.2	7.5	10.3	12.5	15.7	11.1
Clwyd	15.3	16.8	15.9	14.0	12.2	8.5	6.4	6.7	7.2	7.6	9.7	12.8	15.3	11.1
Dwyfawr	16.3	17.2	15.8	13.9	11.2	9.4	6.7	7.2	7.8	8.6	11.5	14.2	16.3	11.6
Dyfi	16.3	17.3	16.1	14.1	11.0	9.2	6.7	7.3	7.9	8.5	11.4	13.5	16.3	11.6
Teifi	14.7	16.0	15.9	14.6	12.5	10.1	7.7	8.0	8.4	8.5	10.5	12.9	14.7	11.7
Tywi	15.7	17.0	16.3	15.0	12.6	10.9	7.7	7.4	8.0	8.4	11.0	13.4	15.7	12.0
MEAN	15.4	16.8	15.6	13.8	11.3	8.9	6.9	6.9	7.5	8.0	10.5	13.2	15.4	11.2

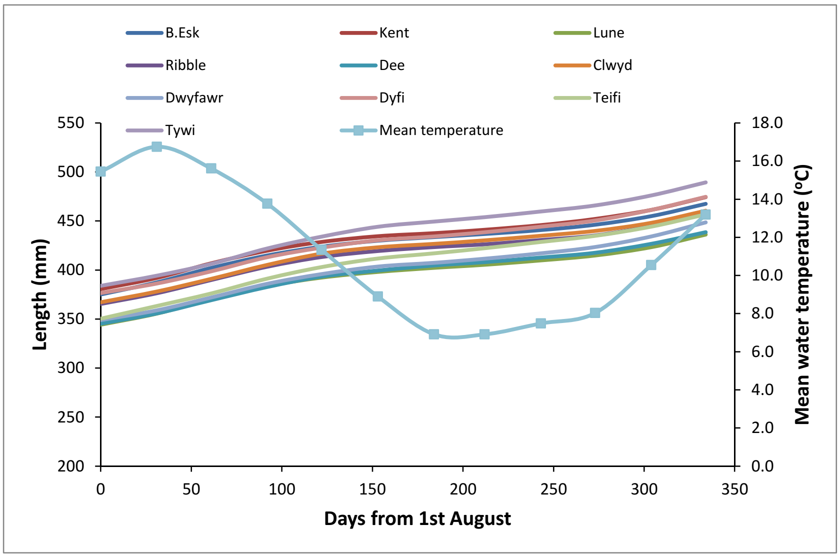


Figure 7.4.6 Modelled growth in length between July and June in coastal vicinity of ten Irish Sea rivers and mean monthly sea surface temperature.

Modelled growth exhibited characteristic fluctuations driven by seasonal temperature variation (Figure 7.4.6). Modelled growth rates (mm/day) over the period (July – June, 334 days) were closest to observed rate at the lowest temperature site (Border Esk) (Figure 7.4.7). Evidently the model greatly underestimated observed growth, from which its projections increasingly deviated as sea surface temperature increased. Analysis using degree days (over 4°C) did not improve these relationships. Therefore the model did not provide an acceptable predictor of growth with spatial variation in temperature. Several potential reasons can be proposed to explain this: the physiological status if the fish in sea water may alter the reaction norms, the predominance of high lipid and protein fish diet and the possibility of different temperature thresholds in fresh and salt water. Also it is possible that compensatory growth on entering freshwater might confound attempts to model growth (B. Jonsson, pers. comm.).

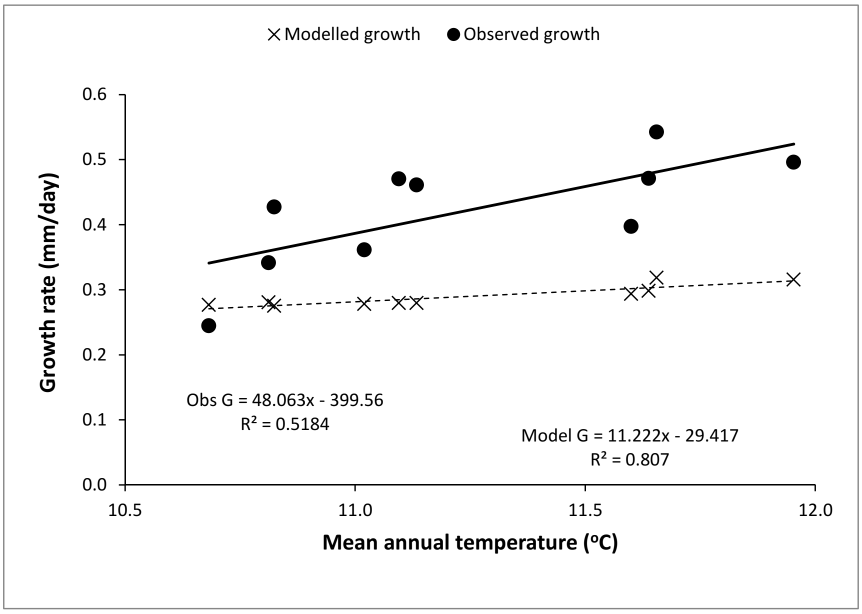


Figure 7.4.7 Comparison of modelled and observed (1996-98) growth rate (mm/day) as a function of mean annual sea surface temperature for ten sites in the eastern Irish Sea.

Observed growth rate over the whole period was differently related to mean temperature in different seasons (Figure 7.4.8). Temperatures in winter periods (January to March and October to November) were more closely correlated with the overall annual modelled and observed growth than were temperatures in the summer (April to June and July to September). This potentially illustrates the importance of winter growth in sea trout; but correlation is not a demonstration of the processes involved and so at this stage is only speculation. Ideally temperature and growth data for simultaneous seasonal periods are needed to test this, but they were not available.

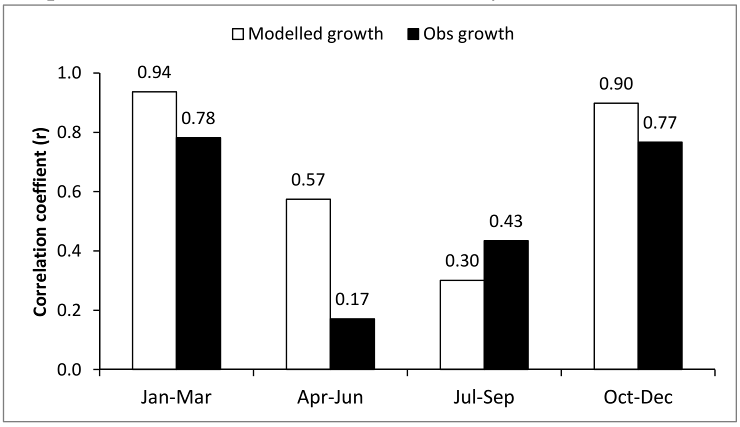


Figure 7.4.8 Relationships between modelled and observed (1996-98) growth rate (mm/day) over 11 month period and seasonal sea surface temperature for ten rivers in the eastern Irish Sea.

Condition

Fulton's condition factor (K) of both 2.0+ and 2.1+ maidens varied significantly (P<0.05) between rivers and between months (Figure 7.4.9). K was almost always lower in 2.1+ fish, but this is considered to be an effect of fish size in the estimation of K and not biologically significant. The nature of the between-river variation appeared to be different between the age groups: K of 2.1+ fish was more strongly correlated with temperature (r= +0.359, df=9) and latitude (r= -0.455,df=9) than in 2.0+ fish, although in neither case was this statistically significant (P>0.05) (Figure 7.4.10). Mean K values for the 2.0+ and 2.1+ were also correlated (r = + 0.500, df=9), but not significantly, and condition of 2.1+ fish was always significantly less (P<0.01) than that of 2.0+ fish.

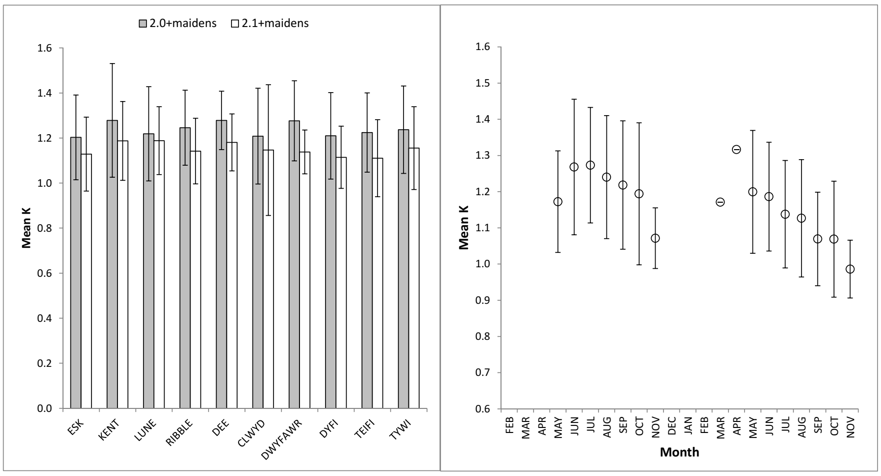


Figure 7.4.9 Condition factors in maiden sea trout sea trout in (LH panel) ten rivers in the eastern Irish Sea, and RH panel averaged across rivers over months, pooled over 1996-98, the 2.1+ fish have been lagged to the second year to illustrate better the seasonal variation in K over two years. Error bars are +/-1SD. (data after Harris, 2002).

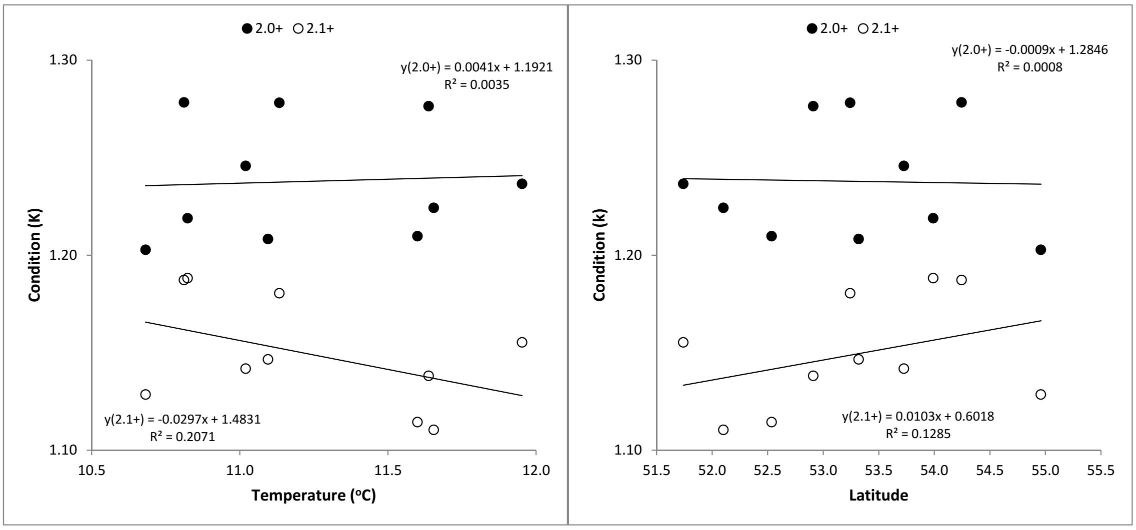


Figure 7.4.10 Relationships between condition factor (k) in maiden fish in individual rivers with (A) sea surface temperature and (B) Latitude. Solid circles are 2.0+, open circles are 2.1+. No regressions were significant.

The principal results from this basic analysis of condition are:

a) *Spatial variation*: There was evidence that K was independent of latitude and temperature for 2.0+ (whitling); but was more influenced by these factors in 2.1+ fish, although still not significantly.

b) *Seasonal variation*: K varied seasonally in both age groups, with 2.1+ and 2.0+ reaching peaks early in their run, on April and July respectively, thereafter declining to November.

Long-term Temperature Variation

The only long-term data available at the time of writing are shown in Figure 7.4.11. These were reported by Joyce (2006) and covered the period from 1960 (the Port Erin set extends to 1903). The data are from manual measurement from the shoreline, collected using methods that were consistent at least within sites (see Joyce, 2006).

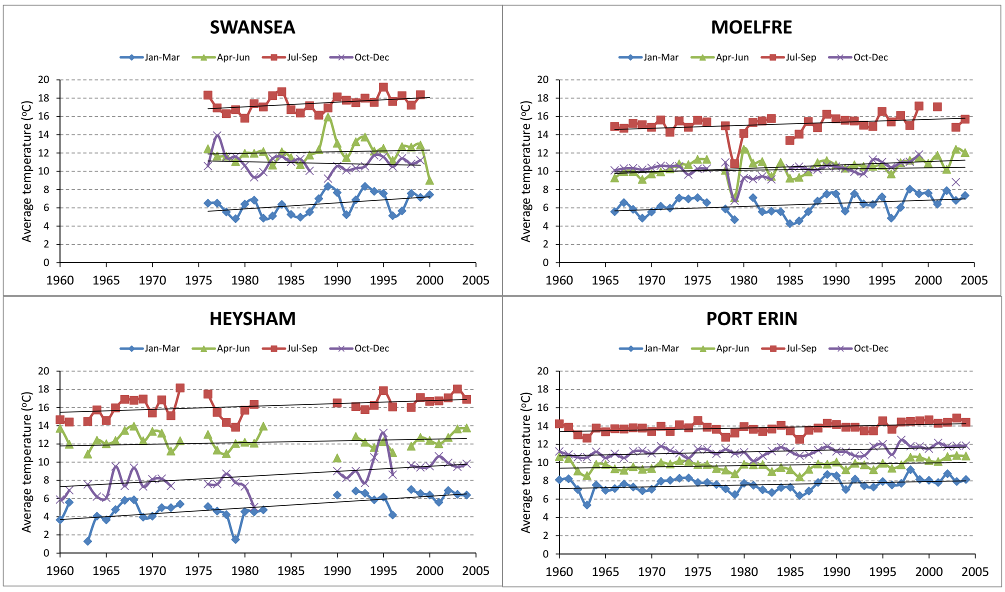


Figure 7.4.11 Long-term change in seasonal sea water temperature at four coastal sites in the Irish Sea. Data from Joyce, 2006.

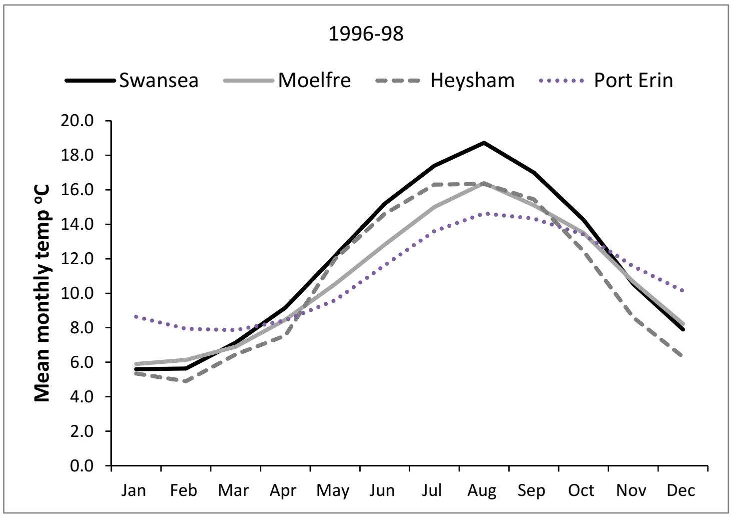


Figure 7.4.12 Spatial variation on monthly sea temperature at four coastal sites in the Irish Sea, averaged for the period 1996-1998. Data from Joyce, 2006

There was significant variation between sites, with Port Erin for example being cooler in summer and warmer in winter (more stable) than shallower mainland sites (Figure 7.4.12). There was no significant difference in the rate of change between seasons and simple linear regression (Figure 7.4.13) of the combined annual means (excluding Swansea due to its truncated time series, and Moelfre 1979 due to its suspect data) was used to forecast future mean temperature.

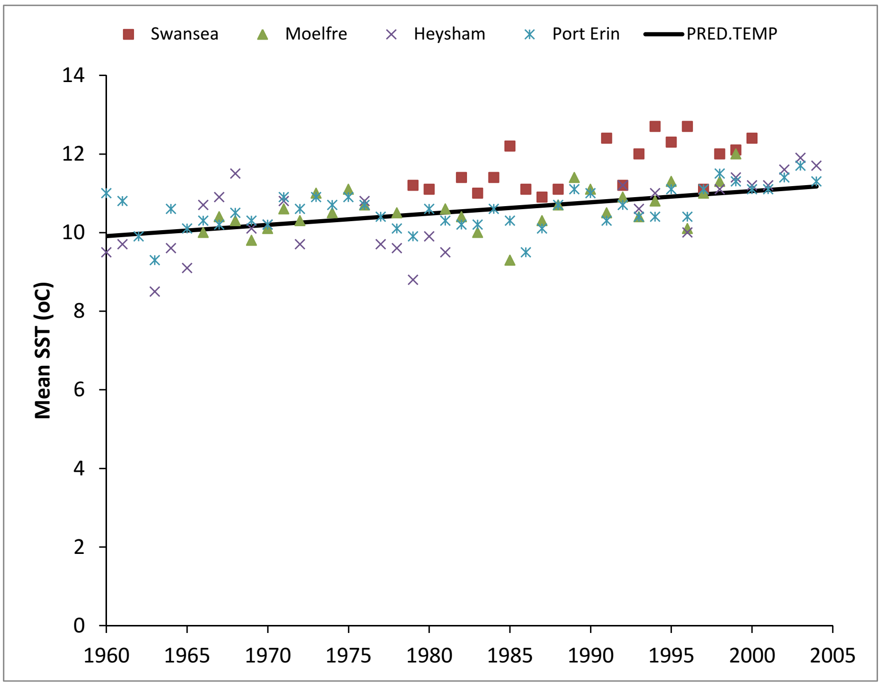


Figure 7.4.13 Long-term change in SST averaged for three coastal sites in the Irish Sea (Moelfre, Heysham and Port Erin), 1960-2004. NB Swansea data are shown, but were not included in the regression (Y =X0.0287 (se=0.0042) -46.3767(se=8.3217), df=102, adjR^2 =0.310). Data from Joyce, 2006.

Sea surface temperature of the Irish Sea has increased significantly between 1960 and 2004, at a rate of 0.29°C per decade. Mean annual temperature has increased from 9.9 to 11.2 °C (+1.3) over this 44 year period. It should be noted that these are sites located adjacent to the shoreline and therefore may be more subject to air and river temperature variation than offshore sites. Port Erin, located in the middle of the Irish Sea, was notably less variable that the other sites (Figure 7.4.12) perhaps reflecting its more open sea location, nevertheless the rate of change in annual mean temperatures were indistinguishable between sites. Coherence (temporal synchrony) amongst the sites was not tested, given the extensive missing data; but visual inspection (Figure 7.4.11) suggests that annual synchrony was much less than longer term variation, i.e. sites tended to vary independently of each other within years.

Effects of Long-term Temperature Variation on Growth

The two relationships of growth with water temperature (Figure 7.4.6) offer alternative simple models for predicting the response to long-term temperature variation. The Elliott model should be the soundest in principle, because it is based on controlled experimental data. In fact it may not be appropriate for use on adults in saltwater feeding mainly on fish diets (e.g. L'Abée Lund *et al*., 1989; Jonsson and Jonsson 2012) and it certainly under-estimates observed spatial growth variation. However, because it includes an important process element in which growth rate varies according to how close ambient temperatures are to physiologically critical thresholds (minimum, optimum and upper limit) it is regarded as more informative than the observed empirical relationship, for showing *relative* differences between temperature scenarios; but note the cautions discussed above about the functioning of this model for trout growth in salt water. The Elliot model was used to simulate growth change over plausible long-term temperature changes from present (assume 11°C) of +1, +2 and +4 °C. The actual future temperature changes are likely to be different between winter and summer months and that will affect the outcome; but in the absence of information on seasonal variation the increase has been uniformly applied across all months.

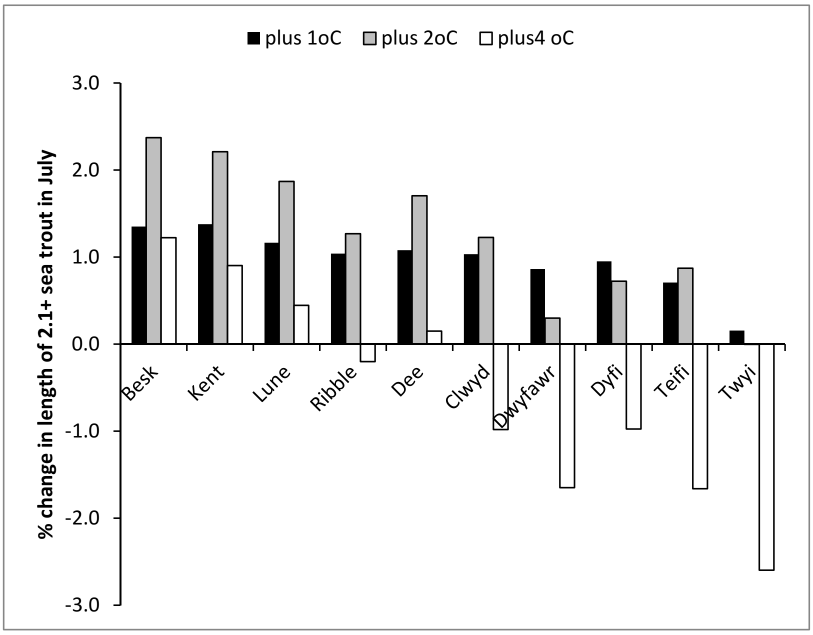


Figure 7.4.14 Predicted % change in length of 2.1+ sea trout, relative to 1996-98, following mean sea water temperature change of +1°C, +2°C and +4°C on 1996-98 temperatures at sites adjacent to ten Irish Sea rivers.

The Elliott model predicts different responses according to the level of water temperature increase. At +1°C, all sites show some growth increase, with more in the northerly sites, although the change is very small (<1.4%) (Figure 7.4.14). At +2°C the sites perform more variably, with northern sites showing a greater increase although still < 2.4% and at the Tywi, the most southerly river a slight reduction is forecast. At +4°C reductions are seen in the rivers south of the Dee (Lat 53.24°). These changes reflect the fact that as temperature increases sea trout approach their upper limits for growth, which are inevitably reached faster in the more southern sites which generally start with higher temperatures. The observed regression model (Figure 7.4.13) was not used for climate effect projection, because being empirical relationships; they imply continuously increasing growth with increasing temperature, which is unrealistic and uninformative.

7.4.4 Results

7.4.4.1 Age Composition, Growth and Condition in the Welsh Dee (2010-2012)

The river Dee has a permanent trap at the head of tide in Chester, North Wales, which is one of the national index assessment sites for salmon an sea trout (Davidson and Cove 2006; Cefas/EA 2013) in England and Wales. The data on size and age from this river are the best available because they are unbiased by season or angling selectivity and scale data are consistent because they have been read in the same way since 1991. Here, data from the years 2010 to 2012, covering the CSTP period are summarised to set a baseline for the other studies (see Davidson and Cove, 2006, for methods).

Age Structure and Time of Return

Over the period 2010 to 2012, 1,367 fish were randomly sampled from the run, were measured and 1,219 had scales with readable freshwater centres. Most sea trout (91%) migrated to sea as 2+ smolts, and 2.6% and 6.3% migrated as 1+ and 3+ respectively (Table 7.4.4).

Table 7.4.4 Smolt age composition for Dee (all sea ages combined)

Smolt age	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	%
1			2	19	4	1	3	3			32	**2.6**
2	2	2	113	562	285	107	13	13	11	2	1110	**91.1**
3			10	37	21	8			1		77	**6.3**
Total	2	2	125	618	310	116	16	16	12	2	1219	

First return time is relevant only to .0+ maidens (whitling) and for this group, where scales were readable, return time decreased with age, 3+ smolt returning in month 6.9 (late June) and 1+ smolts in month 7.3 (near to mid-July). However, whitling size (mean length) increased with smolt age (Figure 7.4.15).

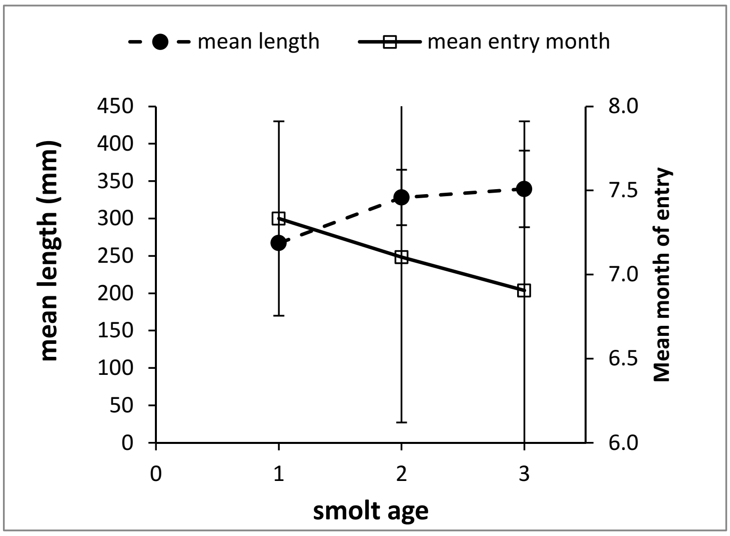


Figure 7.4.15 Size and mean return time of whitling (.0+) of different smolt ages, 2.0+(N=3, 2.0+ (N=488), 3.0+ (N=42) in the river Dee 2010-2012. Error bars are +/- 1SD.

This period presented 17 different adult life history categories (Table 7.4.5), the dominant being .0+ (41.9%) and .0+SM+ (24.7%), 1+ maidens formed 12.2%.

Table 7.4.5 Numbers and percentage frequencies of adult sea trout life history categories for the Dee, data pooled for 2010-2012.

Sea age	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	%
0+	0	0	1	140	285	117	9	8	9	1	570	41.9
0+SM+	0	0	54	247	20	7	3	3	2	0	336	24.7
0+2SM+	0	0	27	72	8	1	0	1	0	1	110	8.1
0+3SM+	0	1	12	22	1	0	0	0	0	0	36	2.6
0+4SM+	0	0	7	5	1	0	0	0	0	0	13	1.0
0+5SM+	0	0	1	2	0	0	0	0	0	0	3	0.2
0+6SM+	0	0	0	2	0	0	0	0	0	0	2	0.1
0+9SM+	0	0	0	1	0	0	0	0	0	0	1	0.1
1+	1	0	16	114	24	2	4	5	0	0	166	12.2
1+SM+	0	1	12	49	2	0	2	0	0	0	66	4.9
1+2SM+	0	0	6	10	3	0	0	1	0	0	20	1.5
1+3SM+	0	0	3	9	0	0	0	0	0	0	12	0.9
1+4SM+	0	0	1	1	0	0	0	0	0	0	2	0.1
1+5SM+	0	0	0	2	0	0	0	0	0	0	2	0.1
2+	1	1	0	9	2	1	0	0	1	0	15	1.1
2+SM+	0	0	1	3	1	0	0	0	0	0	5	0.4
2+2SM+	0	0	0	1	0	0	0	0	0	0	1	0.1
Total	2	3	141	695	348	128	18	18	12	2	1360	

The trap data demonstrated a seasonal pattern of sea trout returns typical of the eastern Irish Sea rivers. Previous spawners returned earliest (20% in June) and .1+ maidens returned before .0+ (whitling) maidens. Modal entry months were June, June and July respectively (Figure 7.4.16).

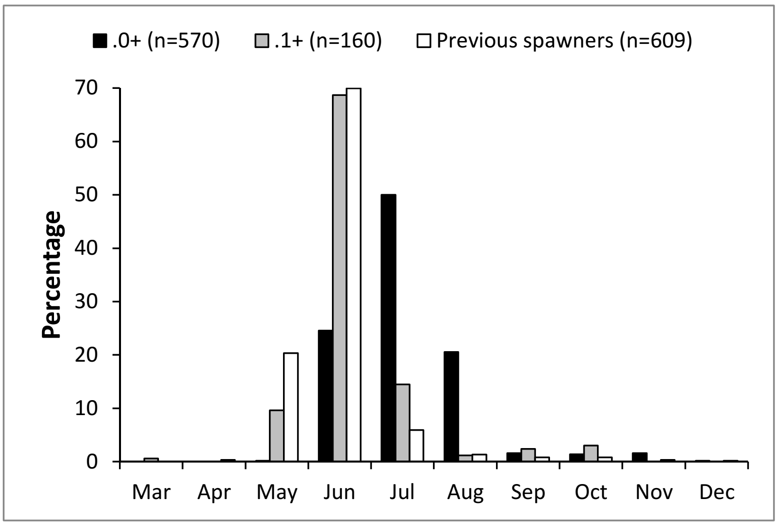


Figure 7.4.16 Seasonal return times of three key sea trout age categories, .0+ and .1+ maidens and previous spawners into the river Dee, as measured at the head of tide trap. Data pooled for 2010 to 2012.

Size, Growth and Condition

Whitling return to the Dee between May and December and in principle, if as expected they grow during that time, size should increase with arrival date (=duration at sea). However, it has been shown above that smolt size increases with age, which would increase the size of that whitling group, and that older smolts (which go to sea before smaller fish) return earlier than young ones, which might give the older smolt less time to grow (depending upon their emigration dates, which are unknown, if they grow at the same rate, which is not known). These counteracting effects may be why the expected increase in size with time is not seen in whitling (Figure 7.4.17). The actual pattern is complex, with smallest of the 2+ and 3+ whitling arriving mid-season in August and larger fish earlier and later. Moreover, whatever age-related size differences existed at smolting (there are no specific Dee data on this) they were not maintained by time whitling returned. This is the same pattern seen in the analysis of the Harris data set (1996-98).

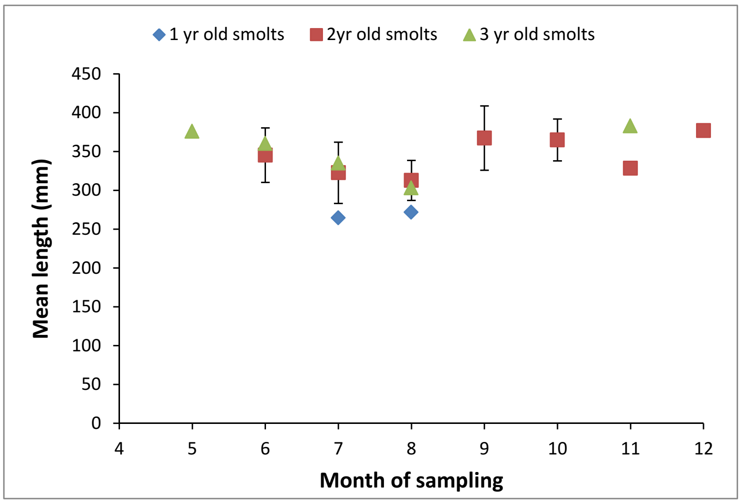


Figure 7.4.17 Seasonal variation in length of whitling (.0+) of different smolt ages, returning to the river Dee. Error bars, +/- 1SD are shown for 2.0+ only, for clarity.

Because of the small but present influence of smolt age on size of returning whitling the subsequent analyses on growth were done on 2+ smolts only, which were the majority of the run (91%) on the Dee. Between-year variation in 2.0+ lengths was significant between months, but as noted above no consistent pattern was seen. For 2.1+ maidens, the data are too few to inform about any seasonal or annual pattern in size (Figure 7.4.18).

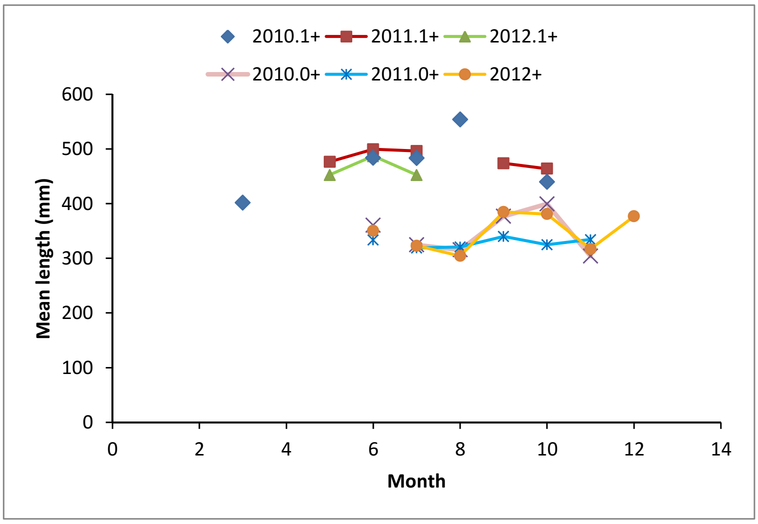


Figure 7.4.18 Between year seasonal variation in length of whitling (2+ smolts only) returning as .0+ and .1+ maidens to the river Dee, 2010 – 2012, showing no consistent seasonal trends in size between years.

In 2.0+ fish condition also decreased for most of the run, but with an upturn in all years in November, before decreasing again by December. Analysis of growth rate in the 1st year post-smolt phase using samples in freshwater is evidently complicated by smolt size, timing and river arrival patterns. Following the approach for the Harris data, growth in later stages was expressed by size difference between 2.1+ and 2.0+ maidens; but in the case of the Dee trap there were sufficient fish to do this for individual years, rather than pooled between years as used in the Harris set.

Table 7.4.6 Size at age (mean) of maiden sea trout returning to the Welsh Dee and increments (mm) between years, 2010 to 2012.

Year		Mean length (L_t, mm)		
		2.0+	2.1+	inc (L_t-$L_{(t-1)}$)
2010	mean	332	483	
	SD	38	40	
	n	188	45	
2011	mean	325	495	163
	SD	31	43	
	n	182	48	
2012	mean	326	476	151
	SD	44	41	
	n	115	22	

From the $G_{(11month)}$ *vs* Latitude relationship ($G_{(11mo)}$ = -24.534(Lat.) + 1447.9) for the period 1996-98 (Section 7.4.4.1), the growth increment for the Dee was 154mm, compared with these more recent (2010-2012) observations of 163 and 151mm, indicating no change in first year marine growth between these periods. The range of daily growth rate was 0.45-0.49mm.day^{-1} (assuming modal return months of June and July for 1+ and 0+ respectively, Figure 7.4.16).

Condition

Condition factor (K) in the Dee changed systematically with season in maiden fish (.0+ and .1+) and in previous spawners (here the various PS ages are grouped together). In 2.1+ and previous spawners their mean monthly condition decreased from June until the end of the year (Figure 7.4.19), although there were examples of low condition fish very early in the year, in both cases.

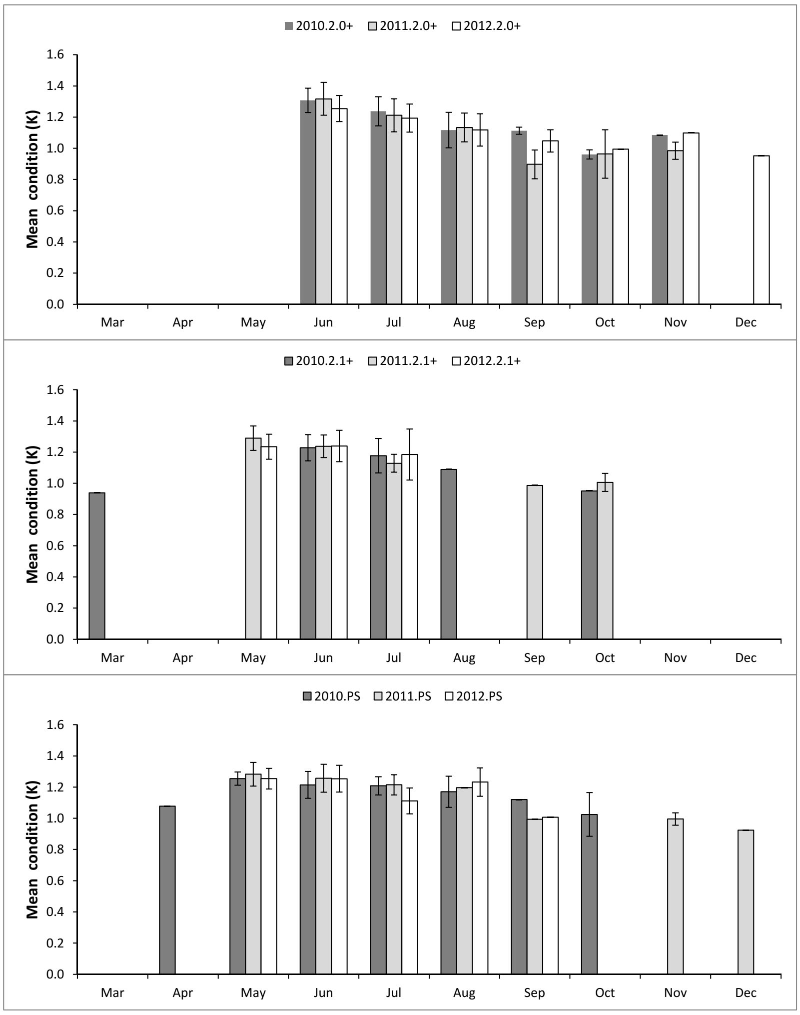


Figure 7.4.19 Between-year seasonal variation in condition (K) of sea trout (2+ smolts only) returning as maidens (2.0+ and 2.1+) and as previous spawners (2.PS) to the river Dee, 2010 - 2012. Error bars are +/- 1SD.

7.4.4.2 Growth in Adult Sea Trout from Selected Rivers (CSTP 2009-2012)

The CSTP scale samples allowed a comparison of growth (size at sea age) for 23 rivers around the Irish Sea. Whitling sizes increased with smolt age (Figure 7.4.20), as observed for the river Dee; and, as noted in that section, such variations could be due to various combinations of different growth rates, times of sea entry or times of return.

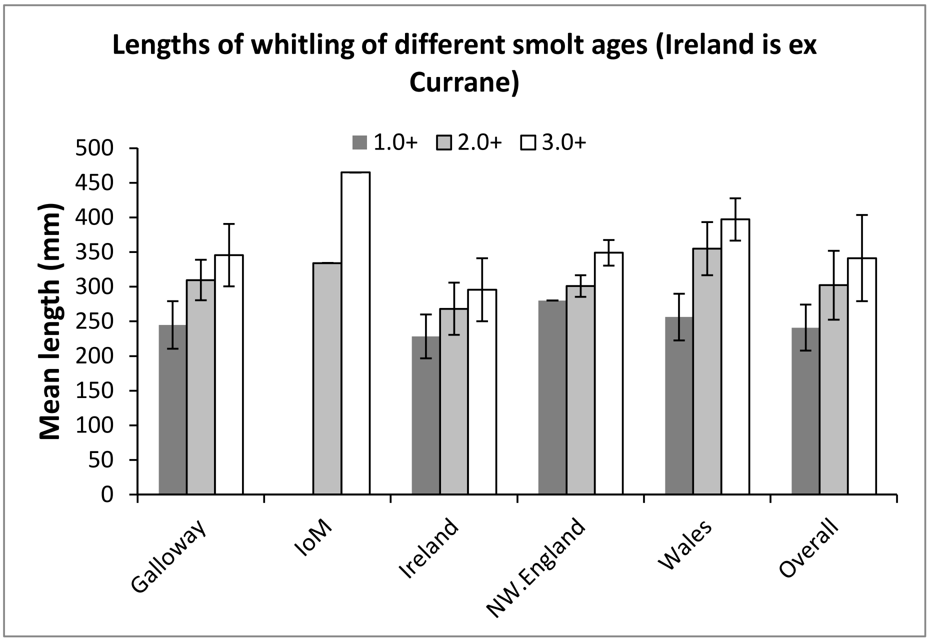


Figure 7.4.20 Comparison of whitling lengths in major regions around the Irish Sea; showing increasing size at older smolt age. The rivers allocated to each region are shown in Table 7.3.3.

In principle, because of the smolt age effect, size or growth comparisons between rivers should be made on fish of the same smolt age. Whitling mean lengths (pooled across months and years) for all smolt ages and for 2yr old smolts showed no significant difference between the two groups, but there were significant differences between rivers (Figure 7.4.21). 2 yr old smolts dominated the samples (82%, Table 7.3.3). Therefore, because in practice the smolt age effect is actually quite small (see also Section 7.4.4.1) and because sample sizes were small it was felt acceptable to make further comparisons of growth using data combined for all smolt ages pooled within each river; although the dominant categories of 2.0+, 2.1+ are also used in order to allow comparison with previous periods. For convenience, and not implying any geographical significance at this stage, growth curves based on size at sea age are presented in geographical groups corresponding to the major countries/regions (Figure 7.4.22). The Shimna (N Ireland) is grouped with the Ireland panel and the Isle of Man data, for which three rivers sizes (Neb, Sulby and Glass) pooled because of small samples are shown with Galloway rivers.

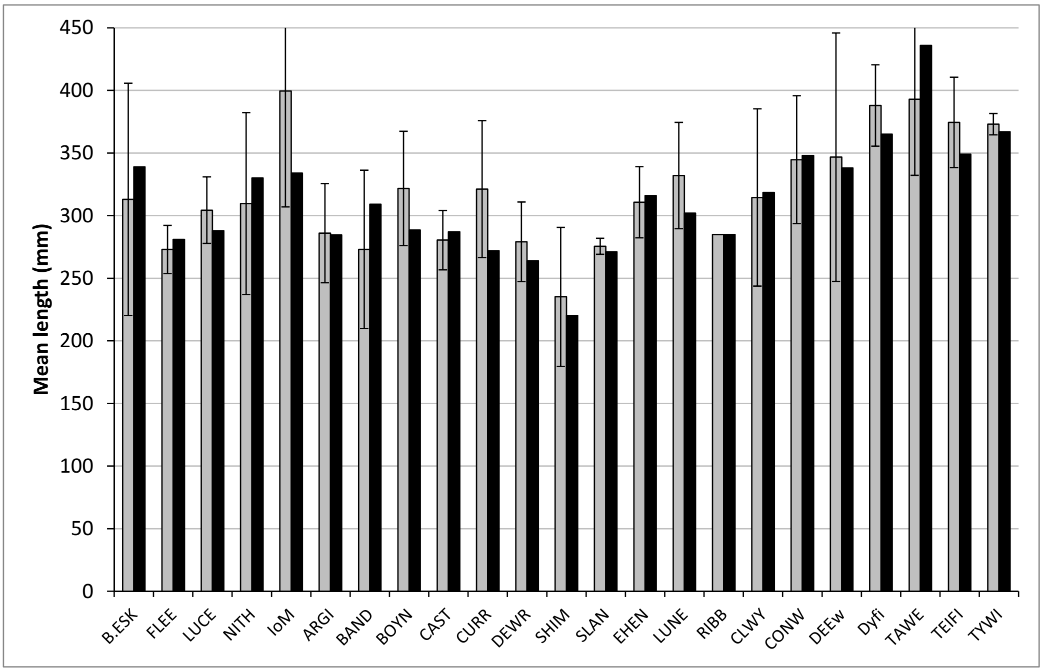


Figure 7.4.21 Between-river variation in whitling length for all smolt ages (grey bars) and 2.0+ whitling (black bars) in Irish Sea rivers (standard deviations shown). Data were pooled for all months, 2009-2012.

A visual inspection of Figure 7.4.21 and Figure 7.4.22 suggests a number of features broadly characteristic of the rivers and regions. First, the Irish coast rivers were mostly characterised by smaller whitling than elsewhere in the Irish Sea. The Currane (which is not in the Irish Sea), stood apart from the other Irish rivers because of greater whitling size and overall longevity. The Isle of Man sea trout were larger than fish of the same age from the Galloway rivers. The Welsh rivers mostly had larger fish of all ages than elsewhere, but with latitudinal variation seen in the data from 1996-98 (Section 7.4.4.1). It must be emphasised that these groupings are only a convenience for an initial presentation and the exceptions show that the influences on fish size at age might include river specific factors as well as geographical proximity. Furthermore, there are some measurement errors remaining in these data, hence the high standard deviations (Figure 7.4.21) and the inconsistent growth curves in older fish (Figure 7.4.22). It has not been possible within the timescale of present reporting to analyse and account for all the sources of error in an extremely diverse and complex data set, but that will be done in due course.

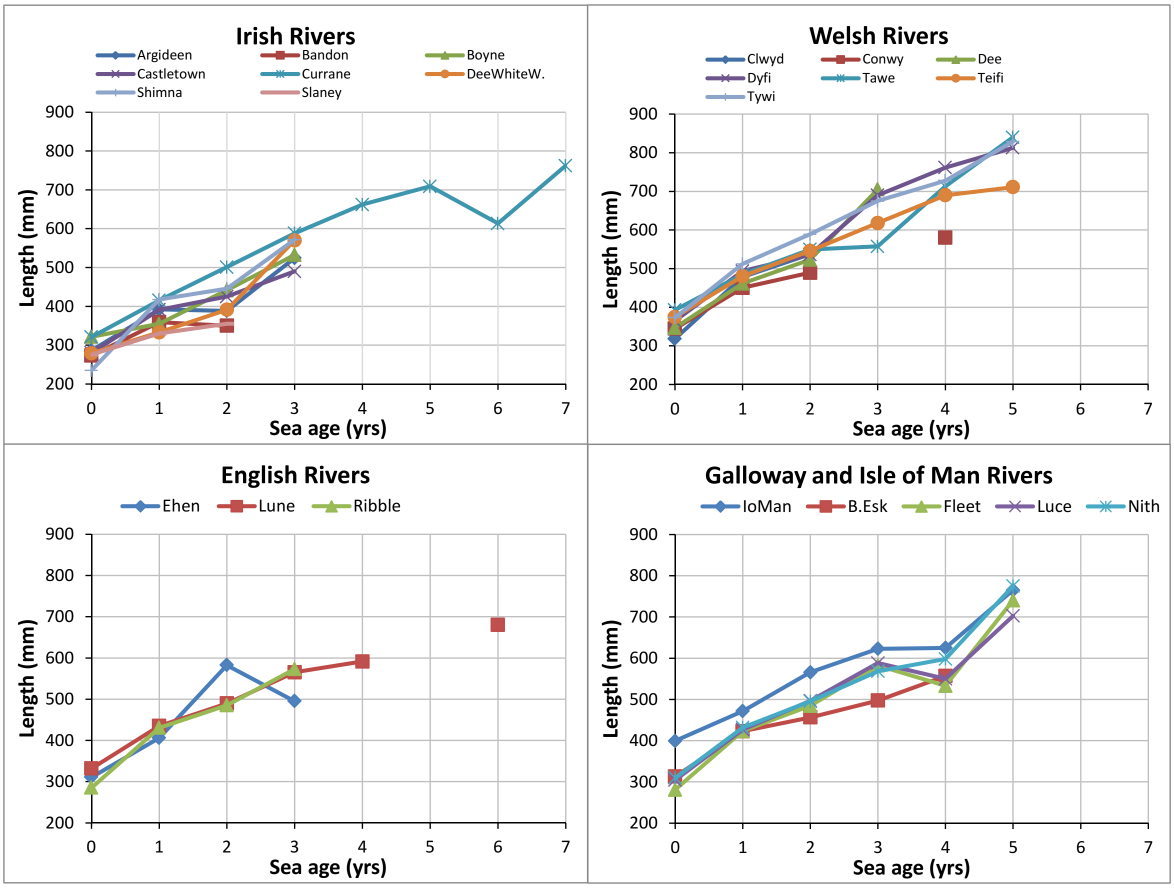


Figure 7.4.22 Comparison of size at sea age for sea trout in 23 Irish Sea rivers.

A more informative analysis incorporates location, as latitude (north/south dimension) and east / west sides of the Irish Sea, and temperature which is *a priori* a variable expected to influence size at age. The length variation on basis of location is summarised in Figure 7.4.23, showing that latitude had an effect on length of adult sea trout from rivers in east Ireland, but not in Wales and NW England. Statistically these effects of latitude (and mean annual surface temperature) were significant on the east side (England and Wales) coast and not on the west (Irish) side (Table 7.4.7).

Table 7.4.7 Correlations (Pearson) between various growth metrics (sizes at age and annual increments for the 2.n+ groups) of sea trout from rivers of the east (15 rivers) and west (8 rivers) sides of the Irish Sea and Latitude and annual mean sea surface temperature in the adjacent marine zone.

Growth metric	Latitude		Water temp	
	East	West	East	West
L0.all	-0.708	-0.296	0.772	0.216
L1.all	-0.856	-0.018	0.839	0.108
L2.all	-0.541	0.257	0.599	-0.286
L3.all	-0.563	-0.157	0.495	0.026
L4.all	-0.877		0.904	
L5.all	-0.585		0.627	
L2.0+	-0.801	-0.529	0.794	0.585
L2.1+	-0.838	-0.492	0.795	0.649
L.2.2+	-0.172		0.273	
g.0+-1+	-0.297	-0.203	0.238	0.338
p0.05	0.4973	0.664	0.4973	0.664
0.05<p >0.01	p<0.01			

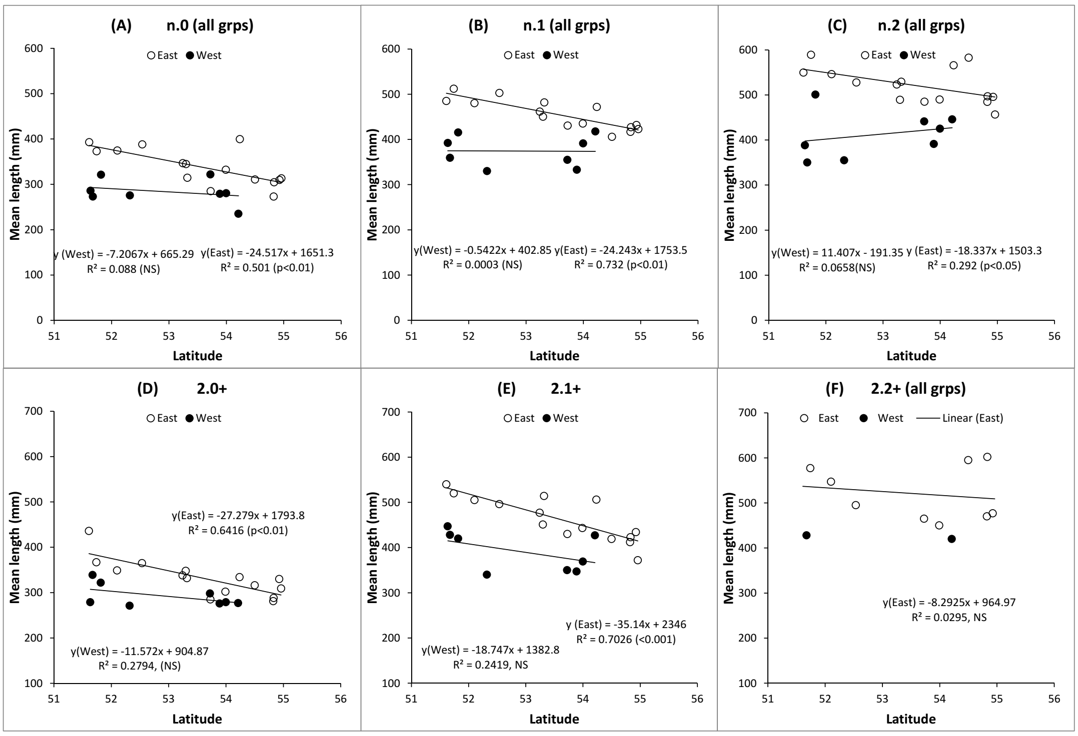


Figure 7.4.23 Variation in mean length of sea age 0(A), 1 (B) and 2(C) sea trout of all smolt ages combined from rivers on east (15 rivers) and west (8 rivers) sides of the Irish Sea. In figs D to F similar data are shown for the 2.0+, 2.1+ and 2.2+ age groups.

The fish in rivers from the west side were smaller at all ages than those from the east side (Figure 7.4.22 amd Figure 7.4.23). Comparisons were made between east and west coast rivers (Table 7.4.8) showing that, even ignoring the evident interaction between latitude and size in the east side group (Wales, England and Galloway), there were significant differences in mean sea age, H (diversity), lengths at ages 0, 1, and 2yrs (both for all groups and maidens) between the east and west sides (t-test, P<0.05). No significant differences were found in annual length increments between 1st and 2nd years at sea (yr0-1) or between 2st and 3rd years at sea (yr1-2). It should be noted however that the samples sizes for older fish were small within each age category and thus the power of the statistical tests were low.

Table 7.4.8 Summary statistics for sea trout from rivers on the eastern and western sides of the Irish Sea. Greyed cells indicate statistical significant at p<0.05.

					Mean length at age, all groups (mm)									Annual growth, all groups (mm)		Mean length at age, maidens (mm)			Annual growth, maidens (mm)	
Irish Sea	Statistic	Mean smolt age(yrs)	Mean sea age(yrs)	H	0	1	2	3	4	5	6	7	8	yr0-1	yr1-2	2.0+	2.1+	2.2+	yr0-1	yr1-2
East	Mean	1.98	0.93	1.62	337	454	521	594	630	772	680		925	117	66	332	463	520	114	45
	SD	0.07	0.39	0.43	40	33	40	69	80	52				24	35	40	49	60	32	50
	n	13	15	15	15	15	15	13	11	8	1		1	15	15	15	15	9	15	15
West	Mean	2.07	0.39	1.19	284	374	412	546	662	709	613	762		90	40	293	391	424	88	27
	SD	0.17	0.29	0.37	28	35	51	37						46	34	25	44	6	45	27
	n	8	8	8	8	8	8	6	1	1	1	1		8	8	8	8	2	8	8
	P(t)	0.155	0.002	0.023	0.001	0.000	0.000	0.068						0.162	0.098	0.009	0.002	0.001	0.1795	0.2830

Temperature data for the Marine Zone was satellite derived GHRSST Level 4 K10 SST Global 1 metre Sea Surface Temperature Analysis.

(http://podaac.jpl.nasa.gov/dataset/NAVO-L4HR1m-GLOB-K10_SST FILENAME: aggregate__ghrsst_NAVO-L4HR1m-GLOB-K10_SST.ncml FILEPATH : http://thredds.jpl.nasa.gov/thredds/dodsC/ncml_aggregation/OceanTemperature/ghrsst/).

Data was derived from a 0.1km grid point located at the centre of the each marine zone and were used to determine average monthly sea temperatures for each coastal marine zone over 2010 to 2012. Covariance analysis was used to examine the combined effects of latitude and east-west variation.

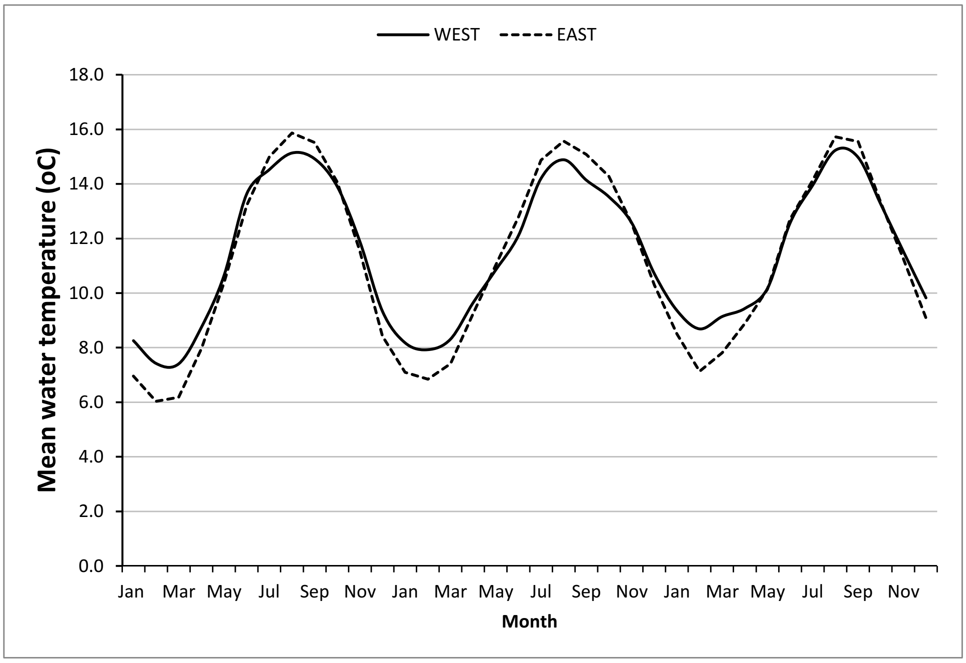


Figure 7.4.24 Variation in monthly mean sea surface temperature between Jan 2010 and Dec 2012 on east and west sides of the Irish Sea.

Data from *http://podaac.jpl.nasa.gov/dataset/NAVO-L4HR1m-GLOB-K10_SST FILENAME : aggregate__ghrsst_NAVO-L4HR1m-GLOB-K10_SST.ncml FILEPATH : http://thredds.jpl.nasa.gov/thredds/dodsC/ncml_aggregation/OceanTemperature/ghrsst/*

There were east-west side effects varying with season (Figure 7.4.24); thus the east side was statistically ($P<0.05$) warmer in summer (July-Sept) and colder in winter (Jan-March), but there was no east-west difference in spring (April-June) or in the autumn (Oct-Dec). Temperature decreased significantly ($P<0.05$) with latitude on both sides of the Irish sea in all season except summer. Overall annual mean sea temperature was not significantly different between east and west sides of the Irish Sea , but was significantly negatively associated with latitude ($P<0.001$). Summer and autumn sea temperature decreased with increasing latitude in the east, but not in the west (Figure 7.4.25). There was a trend of warming winter temperatures, but stable summer temperatures over this period.

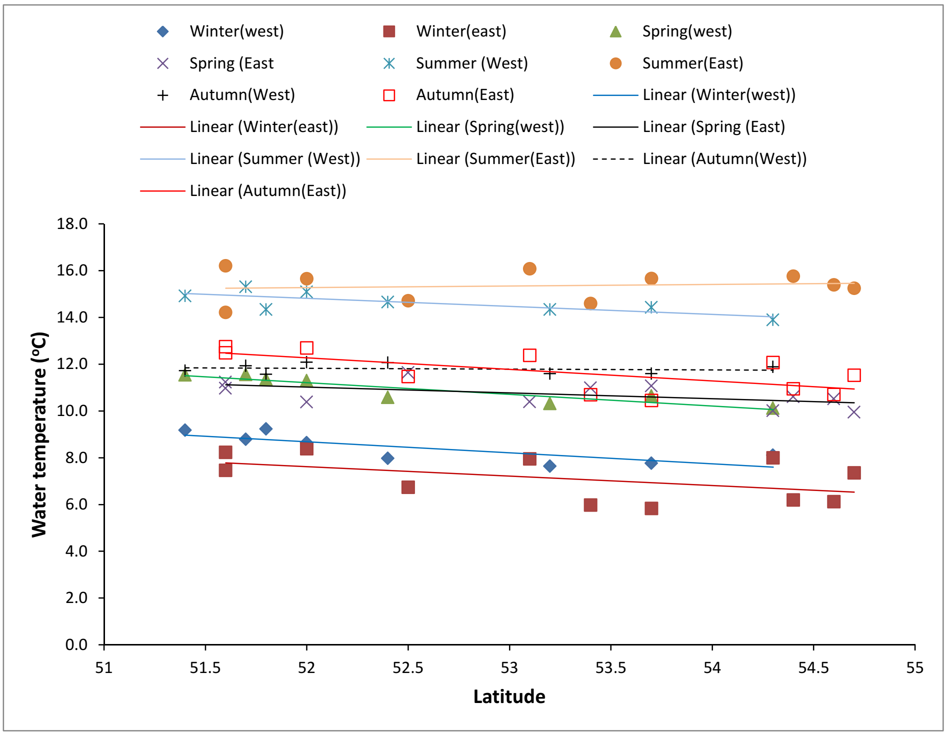


Figure 7.4.25 The relationship between latitude and seasonal sea temperatures on east and west coasts of the Irish Sea

Data from http://podaac.jpl.nasa.gov/dataset/NAVO-L4HR1m-GLOB-K10_SST *FILENAME : aggregate ghrsst NAVO-L4HR1m-GLOB-K10_SST.ncml FILEPATH : http://thredds.jpl.nasa.gov/thredds/dodsC/ncml_aggregation/OceanTemperature/ghrsst/*

The effect of water temperature on size of .0+ (whitling) was compared between latitude and east-west group. The temperature data (derived for coastal marine zones) were assigned to rivers according to which marine zone the river entered and this procedure will lose some discriminating power.

Size of whitling was positively associated with sea surface temperature in most seasons (Figure 7.4.26), but with the exception of the mean annual temperature/eastern side combination (Figure 7.4.26E) this was not statistically significant (Figure 7.4.26) and the effect was less for the west side (Irish rivers), but it should be noted that the sample size was smaller for that group. Similar results were found for 1yr old sea trout, but in the Irish rivers an even weaker association with temperature was indicated than for whitling.

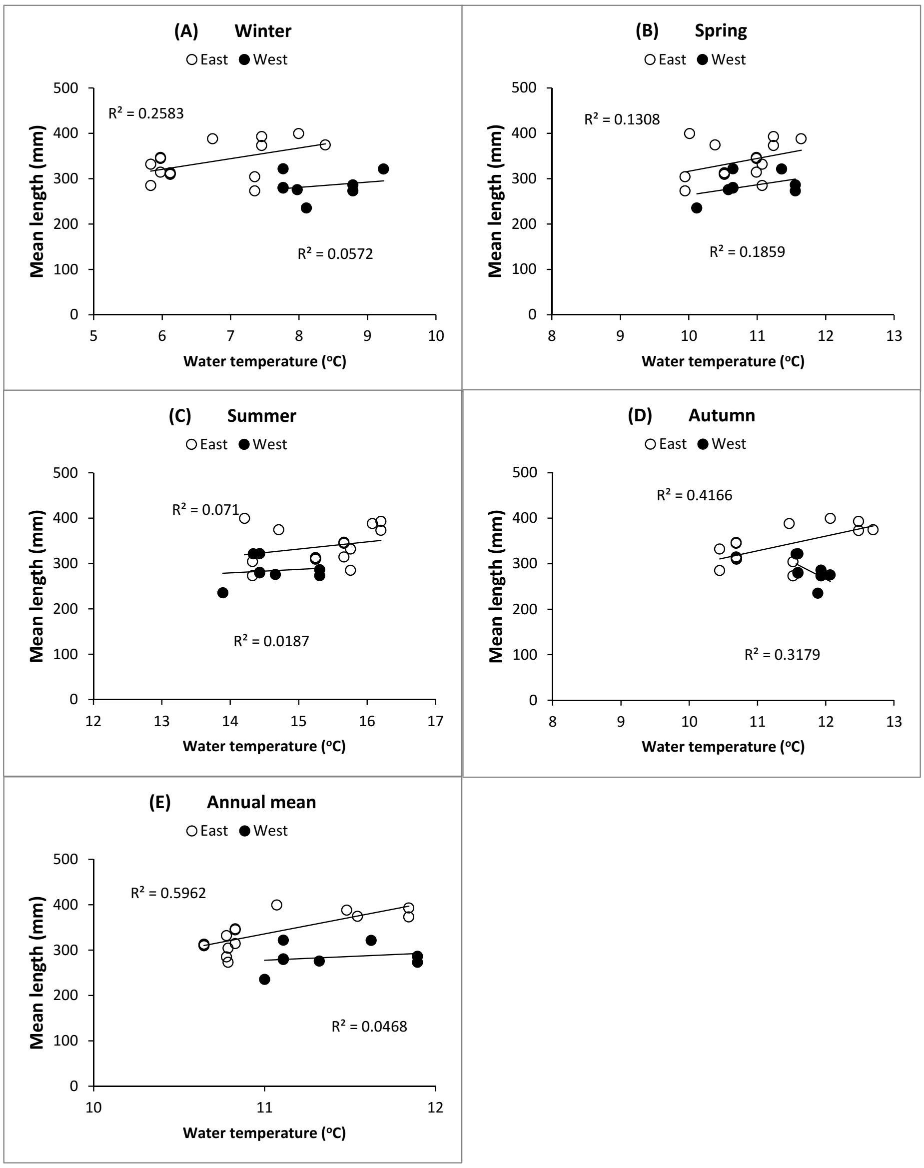


Figure 7.4.26 A-E Effect of water temperature on .0 lengths from different rivers on east and west sides of Irish Sea in different seasons. R^2 is the proportion of variance explained by each line.

Evidently the effects of latitude and water temperate are confounded, but it possible that the influence of latitude on size is mediated through water temperature on first post-smolt year growth. The unexpected result is that this was weaker for the west side than for east, although the temperature range was less than for the east side. The important result is that sea trout size at the same temperature (Figure 7.4.26) and latitude (Figure 7.4.23) was smaller on the east side compared with the west, and that on the west side the effect of temperature variation was far less (Table 7.4.7). This might point to sea feeding opportunity as a factor influencing growth and / or to a genetic effect.

7.4.4.3 Growth of Marine-Caught Sea Trout

The CSTP surveys produced 996 fish with full details for size and time of capture; but not all of these were aged and not all the size data proved reliable (in the editing procedure using z scores on K values, 47 fish were removed).

Table 7.4.9 Fish size sample distribution from Marine Zones, CSTP surveys

Marine Zone	Region	Counts of available data			Count of size data by month											Count of size data by year						
		with size	fw.yrs	sea.yrs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	2006	2007	2008	2009	2010	2011	2012
MZ01	SW Ireland	1	0	0								1										1
MZ03	South Ireland	2	0	0								2										2
MZ04	South Ireland	38	35	35		3	8	7	5	4	1	6	2	2					8	15	1	14
MZ05	Sout East Ireland	107	102	102		7		4	4	75	17									34	66	7
MZ06	Sout East Ireland	197	157	166		13	113	27	38	6										28	68	101
MZ07	North East Ireland	51	50	50			5			1	2	25	18			2				30	12	7
MZ08	North East Ireland	43	41	41			1	3	5		2	28	2	1	1		3	9	1		26	4
MZ09	Galloway	32	28	28				1	1	15	3	6	1	5						7	13	12
MZ10	Solway	232	98	98				3	67	135	26	1						87	30	68	27	20
MZ11	Morecambe Bay	17	16	16			1		4	5	5	2									5	12
MZ12	Liverpool Bay	88	88	88		6	23	42	5	5	7										7	81
MZ13	N.Wales	32	29	29					4	1	7	13	5	2						6	22	4
MZ14	NW.Wales	28	26	26	2		6	8	4				1	5	2					1	10	17
MZ15	Cardigan Bay	5	5	5					1		2		1	1				1			1	3
MZ16	Cardigan Bay	11	10	10				1		10							10			1		
MZ18	S.Wales	5	5	5					1	4								1			4	
MZ23	IoMan	50	32	32			5	2		7	10	22	4							13	24	13
MZ29	Liverpool Bay	15	14	14								15									15	
MZ30	Solway	42	42	42								42									42	
Total		996	778	787	2	29	162	98	139	268	82	163	34	16	3	2	13	98	39	203	343	298

The abundance of fish was not uniform across years or the marine zones (MZs) (Table 7.4.8) and in most cases the numbers were too small to analyse growth for individual zones.

Size at capture of .0+ fish in the sea is, in principle, an index of growth since they left the rivers as post-smolts, if the departure date does not vary systematically between smolt ages or size groups between regions. There are no data on regional variations in migration timing of smolts of the same age; but it is known that smolt run timing is age-dependent on the Dee (see Section 7.4.4.2) and is likely be so elsewhere in the Irish Sea. Therefore to minimise the confounding effects of age the analyses were done on three groups of fish: 1.0+ and 2.0+ whitling, with an assumption of smolting varying randomly around some fixed date, and all fish with more than one sea-winter (in this case including all smolt ages). Due to small sample sizes the data were pooled across marine zones and years, and cover the period 2006-2012; but most were from the period 2010-2012 (Table 7.4.9). The age splits for the 787 fish with sea age data are shown in Appendix 7.VI.

In contrast to fish sampled in rivers, length of sea trout caught at sea increased with time (days since 1st January) in all three groups (Figure 7.4.27A). This analysis accepted the ages of fish from scale readings at face value, even though some were probably erroneous. Inspection of the data indicated that some fish, assigned as whitling, were exceptionally large early in the year, given that most smolts emigrate in May and also some were found in January. Such early runs cannot be entirely ruled out, but they are extremely unlikely both in terms of the timing of smoltification cues (e.g. daylight and water temperature) and the biological concept of moving to sea when environmental conditions are like to be harsh. These large fish are likely to be due to ageing errors. In the analysis by Cefas (Section 7.7) these whitling were separated on the basis of size distributions. The comparison with the face value data (Figure 7.4.27B) shows that it was likely that these early large fish were older than whiting and either a winter growth check had not formed, or was not identifiable on the scales.

Omitting these pre-April samples for the 1.0+ and 2.0+ whitling, the average annual growth rates (from regression slopes in Figure 7.4.27A) were estimated at 0.46 and 0.28 mm/day for the whitling and 0.22 mm/day for the post-sea winter adults.

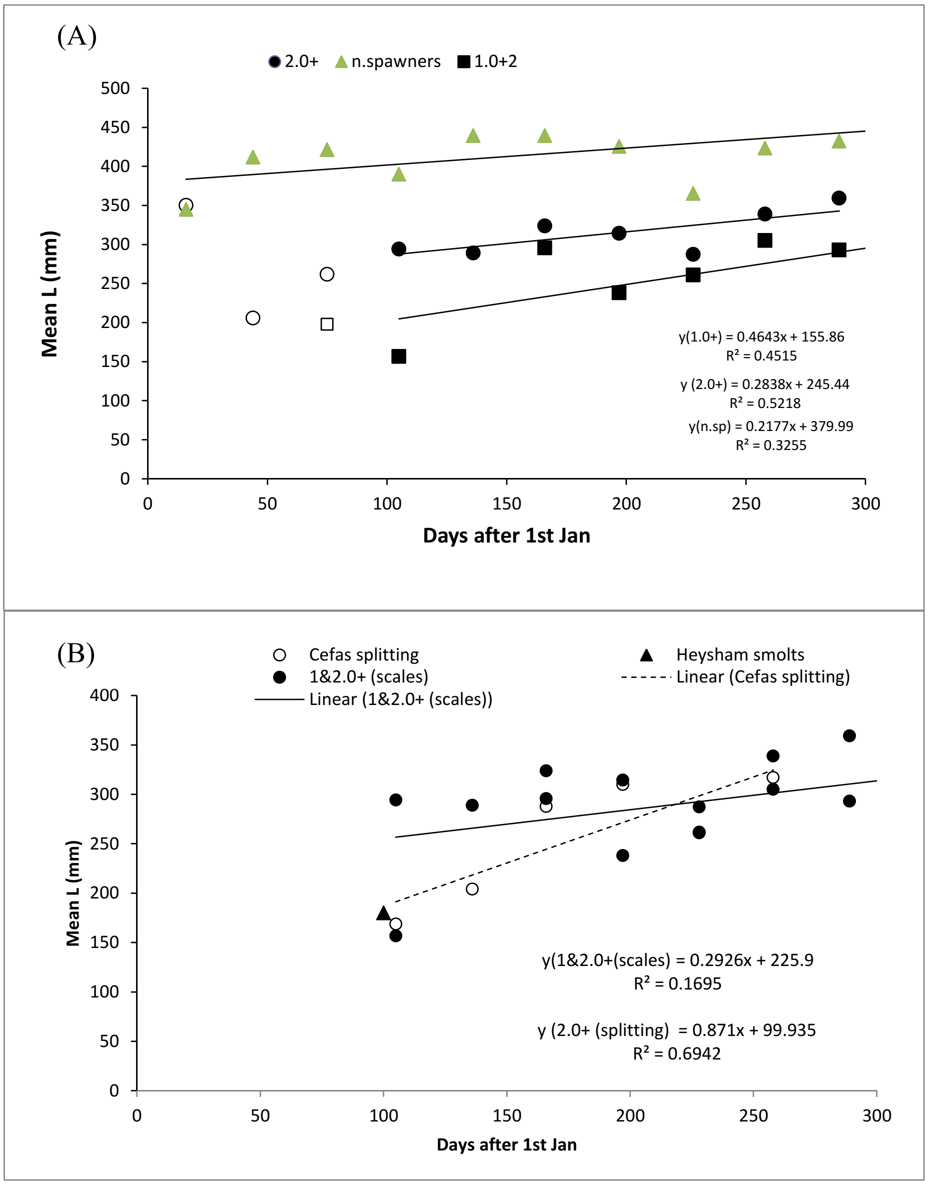


Figure 7.4.27 A & B Average size-at-time of sea trout in the Irish Sea (A) Comparison of size at time for three groups, 1.0+, 2.0+ and fish with at least 1 sea winter, data pooled from all marine zones, for 2009 to 2012. Three data points before April are omitted (see text). (B) scale based data for scale-aged fish compared with length distribution splitting method (see section 7.7). The triangle shows size at mean putative smolt date (i.e. capture at Heysham power station).

Fortuitously, samples of smolts had been taken in fish kills in Heysham power station (Lat/Long) and confirmed the assumed smolt size of 180mm for smolts used in the growth modelling (Section 7.4.4.1). Of the total sample of 73 fish, 59 had dates of samples reported. Of these, all were 2yrs old, mean length was 182 mm (SD=23mm) and 66.1 % were females. The mean date of capture was 10th May.

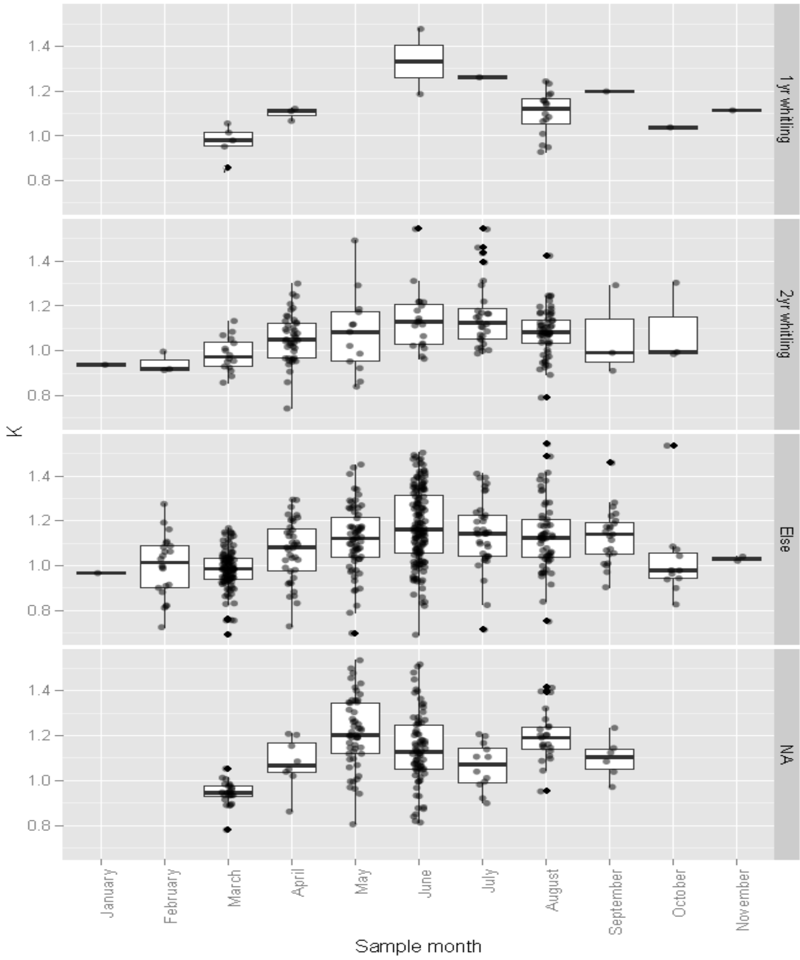


Figure 7.4.28 Seasonal variation in condition factor (K) for 1.0+ and 2.0+ whitling and older (Else) sea trout caught in the sea. The NA category is fish for which no age could be determined.

Condition (K) varied seasonally in fish caught at sea with patterns similar to those observed in fish returning to rivers. K increased from low points in November-February to peak in June for whitling and in May for other groups (Figure 7.4.28).

7.4.4.4 Comparison of Growth Curves

Life time growth curves, of length (mm) against sea age (yrs)) were compared by the parameters of the Von Bertalanffy growth equation:

$$L_t = L_\infty(1-e^{-K(t-t_0)})$$

Where, L_t is the length at age t, L_∞ is the theoretical maximum (or asymptotic) length for that species (*i.e.* the maximum size that the fish would attain if it lived indefinitely), K is the Brody's growth coefficient which describes the rate at which the maximum size is reached, t is age (in years) and t_0 is a scaling factor, the intercept of the growth curve on the X-axis, at the point where in theory the scale is zero length.

Ford Walford plots and von Bertalanffy plots were used to estimate the parameters, K, L_∞ and t_0 (e.g. King, 2007). Values were calculated for the 1996-98 data set and the 2010-2012 samples for individual rivers, and for the CSTP marine zone samples pooled for the Irish Sea. In some cases the data were too variable to allow estimates to be made in the CSTP river set. In the case of the Welsh

Dee the 2010-2012 data were taken from the DSAP trap samples and are regarded as reliable. There was no detectable difference between the periods for those rivers examined in both periods (Table 7.4.10). The lowest L_∞ values (range 376-602mm) were from the rivers of eastern Ireland, but the data were too few to test this statistically

Table 7.4.10 Von Bertalanffy growth equation parameters calculated from length at sea age, for two periods, 1996-98 (based on the data from Harris, 2002) and 2010-2012 (based on CSTP and DSAP data). NA signifies that no parameters could be derived.

		1996-99			2010-13		
Country /	**River**	**K**	**Linf**	t_0	**K**	**Linf**	t_0
IoM	**IOMA**				0.378	694	-2.094
Galy	**BESK**	0.261	730	-2.445	0.399	608	-1.720
Galy	**FLEE**				0.231	904	-1.486
Galy	**LUCE**				0.340	750	-1.093
Galy	**NITH**				0.399	671	-1.500
Ire	**ARGI**				0.547	544	-0.643
Ire	**BAND**				NA		
Ire	**BOYN**				NA		
Ire	**CAST**	0.335	721	-1.573	0.528	536	-1.307
Ire	**CURR**				0.130	1132	-2.494
Ire	**DEWR**				NA		
Ire	**SHIM**				0.645	602	-0.469
Ire	**SLAN**				0.779	376	-1.691
NW.E	**EHEN**				NA		
NW.E	**LUNE**	0.149	1055	-2.699	0.344	678	-1.865
NW.E	**RIBB**	0.421	666	-1.602	0.442	669	-1.216
Wal	**CLWY**	0.728	623	-1.255	NA		
Wal	**CONW**				NA		
Wal	**DEEw (DSAP trap)**	0.256	872	-1.663	0.428	769	-1.033
Wal	**DWYFAWR**	0.368	899	-0.971			
Wal	**Dyfi**	0.176	1150	-2.164	0.180	1092	-2.099
Wal	**TAWE**				NA		
Wal	**TEIFI**	0.315	834	-1.538	0.242	855	-2.248
Wal	**TYWI**	0.305	988	-1.660	0.154	1214	-2.540
	all Marine zones				0.229	937	-1.406

K decreased with increasing L_∞, according to a power function and this relationship was not significantly different between the two periods (Figure 7.4.29). Note that K is dimensionless and not an estimate of true growth, only the rate at which L_∞ is approached and the rate at which annual growth increments decrease. The parameters K and L_∞ are reported to enable comparison with other species and studies, although the parameters are not often reported for sea trout. Butler and Walker (2006) reported data for on sea trout in Loch Ewe, western Scotland sampled at intervals over the period 1926 to 1993, showing that L_∞ ranged between 760 to 819mm and K between 0.11 and 0.16. In a more recent period, 1997-2001, L_∞ was 456mm and K was 0.42, and these changes were attributed by Butler and Walker to the development of marine salmon farming.

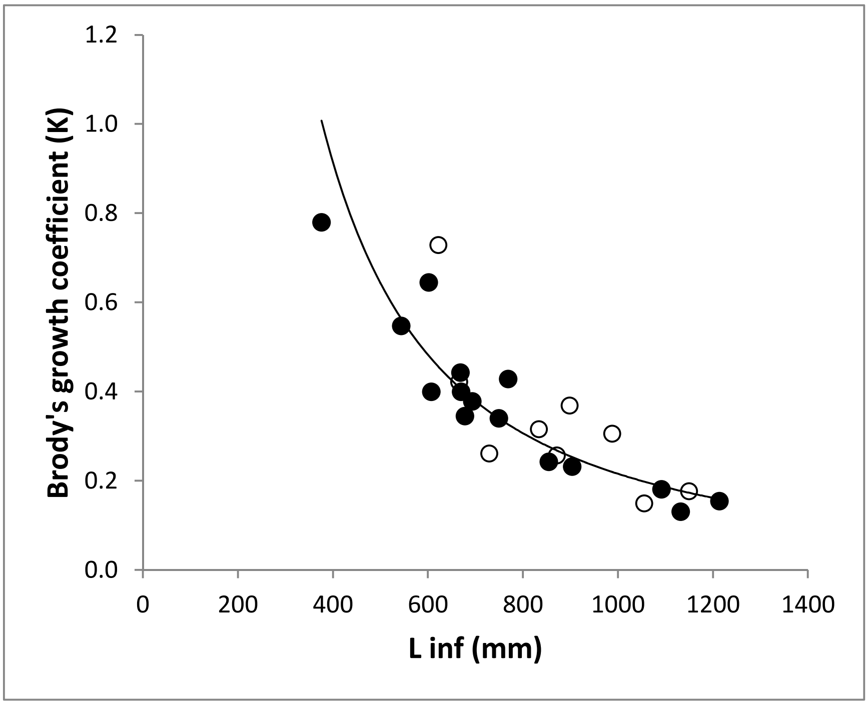


Figure 7.4.29 Relationship between K (Brody's growth coefficient) and L_∞ for rivers sampled in 1996-98 (open circles) and 2010-2012 (solid circles, and line). There was no significant difference between the period regressions and the combined line is described by ln(K) = -1.5759 (se=0.153).ln(L_∞)+9.349(se=1.018), N=25, adj R^2 = 0.807).

7.4.4.5 Long-Term Changes in Size Class Abundance and Size at Age

A premise of a life history approach to sea trout population analysis is that if environmental conditions systematically change over time the various attributes of anadromy (e.g. smolting, maturation, first return and multiple spawning) exhibited by populations should change also, to re-establish the lifetime fitness benefits of sea migration. This section briefly examines evidence for such changes. Long-term data on sea trout size and age composition are sparse. Historical age data, extending back to the 1930s have been collated by previous reviews (Solomon 1995; Harris, 2002). A more substantial set, but covering only years since 1976, have been reported by the EA and its predecessors in annual rod catch statistics. These data, which refer only to English and Welsh rivers, are based on weights of fish reported by anglers through the license return system and comprise individual data for fish larger than 1lb (either weighed or estimated) and total numbers of fish taken to be whitling (<1lb). Here, example data (converted to kg) are examined for selected Welsh rivers (Teifi, Dyfi, Conwy, Clwyd and Dee), because for reasons explained above the Welsh data set is considered to be the one collected most consistently over the full 1976 to present date. Only data to 2007 were available for this project.

Change in Mean Smolt and Sea Age

Scale reading for the 8 rivers (Border Esk, Lune, Ribble, Dee, Clwyd, Dyfi, Teifi and Tywi) in which data were available for two periods 1996-98 and 2010-2912 gave information on mean smolt age (MSA yrs) calculated from MSA = (%(S1)+%(S2x2)+(S3x3)…)/100. MSA decreased from 2.05yrs (sd=0.037) to 1.99 yrs (sd = 0.038) an average difference of 3.2% , significant (t = 3.5547, p<0.002, df=14) (Table 7.4.11).

Table 7.4.11 Mean smolt age (yrs) and sea age (yrs) in two periods, 1996-98 (Harris, 2002) and 2010-2012(CSTP)

River	Mean Smolt Age			Mean Sea Age		
	1996-98	2010-12	% change	1996-98	2010-12	% change
Besk	2.05	2.01	-1.87	0.91	1.06	16.50
Lune	2.1	2.00	-4.61	1.30	1.41	8.84
Ribble	2.09	1.92	-8.08	1.35	1.17	-13.26
Dee	2.06	1.93	-6.23	0.79	0.49	-38.33
Clwyd	2.01	1.99	-1.09	0.46	0.37	-19.77
Dyfi	1.99	2.00	0.30	1.13	1.27	12.50
Teifi	2.06	2.02	-2.09	0.40	1.11	177.54
Tywi	2.05	2.01	-1.82	0.88	1.46	65.55
mean	2.05	1.99	-3.22	0.90	1.04	15.52
sd	0.037	0.038		0.353	0.405	

In the same eight rivers, mean sea ages were 0.90 and 1.04yrs in the early and late periods respectively; but were not significantly different and the relative differences between river were mostly maintained. The comparatively high sea age of Dyfi fish was still evident, but was more closely matched by the other southerly rivers Teifi and Tywi.

Historical Rod Catch Size Distributions

Data were sorted by 4 weight categories based on an approximation to age split given by pooled data for the River Dee trap, from where accurate data on size at age were available (Table 7.4.12)

Table 7.4.12 Size / age key pooled for the River Dee 2003-2007, shaded/unshaded rows show the boundaries of the size categories used for describing long term variation in stock composition, namely <0.8kg, 0.8-2kg, 2-4kg and >4kg.

Midpoint (kg)	Wt upper class value (kg)	Sea age (yrs)									
		0	1	2	3	4	5	6	7	8	9
0.1	0.2	2255	0	0	0	0	0	0	0	0	0
0.3	0.4	18170	0	0	0	0	0	0	0	0	0
0.5	0.6	12691	51	0	0	0	0	0	0	0	0
0.7	0.8	3698	463	5	0	0	0	0	0	0	0
0.9	1	355	876	0	0	0	0	0	0	0	0
1.1	1.2	0	885	13	0	0	0	0	0	0	0
1.3	1.4	0	565	77	0	0	0	0	0	0	0
1.5	1.6	0	341	98	0	0	0	0	0	0	0
1.7	1.8	0	226	158	13	5	0	0	0	0	0
1.9	2	0	104	141	13	0	0	0	0	0	0
2.1	2.2	0	56	154	29	0	0	0	0	0	0
2.3	2.4	0	27	117	18	5	0	0	0	0	0
2.5	2.6	0	8	66	55	27	0	0	0	0	0
2.7	2.8	0	13	96	27	13	0	5	0	0	0
2.9	3	0	0	30	62	5	0	0	0	0	0
3.1	3.2	0	0	13	32	5	5	5	0	0	0
3.3	3.4	0	0	26	29	30	0	0	5	0	0
3.5	3.6	0	5	0	37	5	0	10	0	0	0
3.7	3.8	0	0	33	29	21	8	5	0	0	0
3.9	4	0	0	10	24	35	13	5	0	0	0
4.1	4.2	0	0	8	8	22	5	5	5	0	0
4.3	4.4	0	0	0	19	43	13	0	0	0	0
4.5	4.6	0	0	0	10	24	8	5	0	0	0
4.7	4.8	0	0	0	5	0	19	0	5	0	0
4.9	5	0	0	0	0	13	8	0	0	0	0
5.1	5.2	0	0	0	13	0	5	0	0	0	0
5.3	5.4	0	0	0	0	11	8	0	0	5	0
5.5	5.6	0	0	0	0	8	8	0	0	0	0
5.7	5.8	0	0	0	0	16	0	0	0	0	5
5.9	6	0	0	0	0	8	0	5	0	0	0
6.1	6.2	0	0	0	0	0	0	0	0	0	0
6.3	6.4	0	0	0	0	0	0	0	0	0	0
6.5	6.6	0	0	0	0	0	0	0	0	0	0
6.7	6.8	0	0	0	0	0	0	0	0	0	0
6.9	7	0	0	0	0	0	0	0	0	0	0
7.1	7.2	0	0	0	0	0	0	0	0	0	0
7.3	7.4	0	0	0	0	0	0	0	0	0	0

The lowest category of <0.8kg was assumed to be dominated by whitling (0 sea year), the 0.8-2kg category by 1 sea year, the 2-4kg category by 2 and 3 sea years and the >4kg category by older fish. All size groups <4kg showed distinctive changes over time, particularly the increase in the number of whitling (.0+ sea yrs) (Figure 7.4.30).

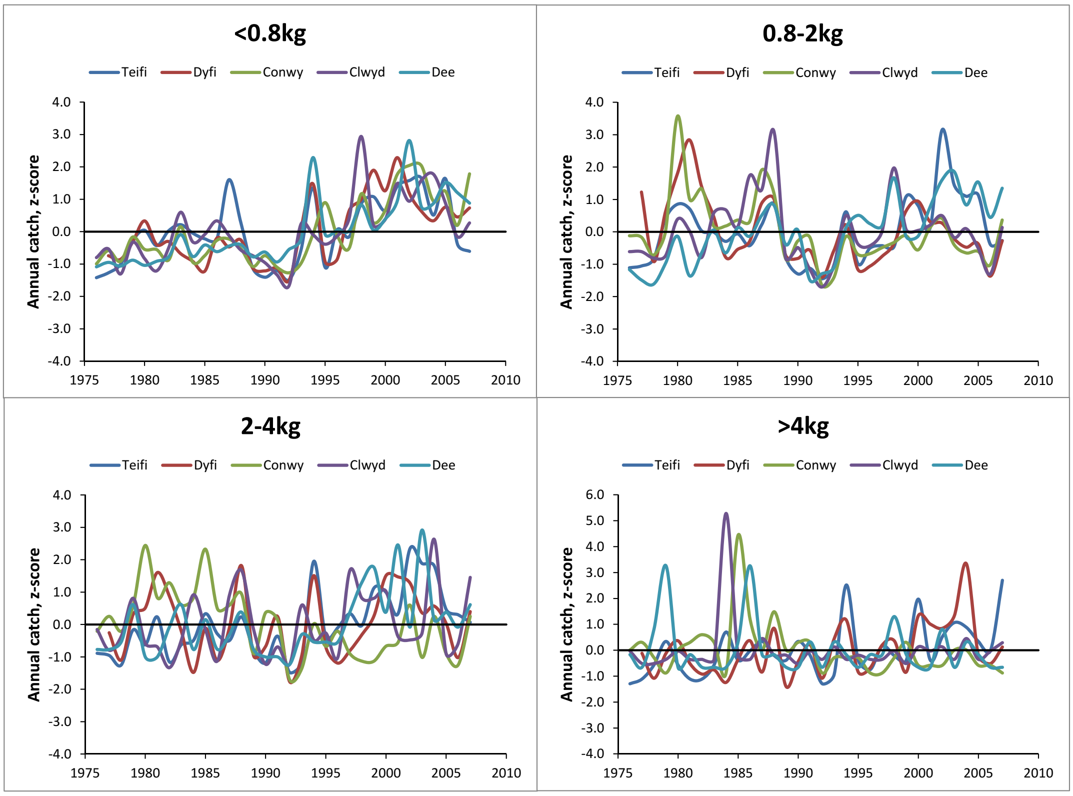


Figure 7.4.30 Long-term (1976-2007) changes in sea trout abundance (rod catch) of 4 size (kg) categories in five Welsh rivers, shown as z-scores of annual catch (a value of 0 shows no change from the long-term average for each river).

The dip in 1991/92 is thought to have been an artefact of the change in licence recording system and absence of catch return reminders in those years, probably leading to lower catch reporting. Proportional changes in size structure were also evident with contrasts between some rivers. There was a significant increase in the percentage of "whitling" in all rivers except the Teifi, the river with highest initial whitling proportion (Figure 7.4.31).

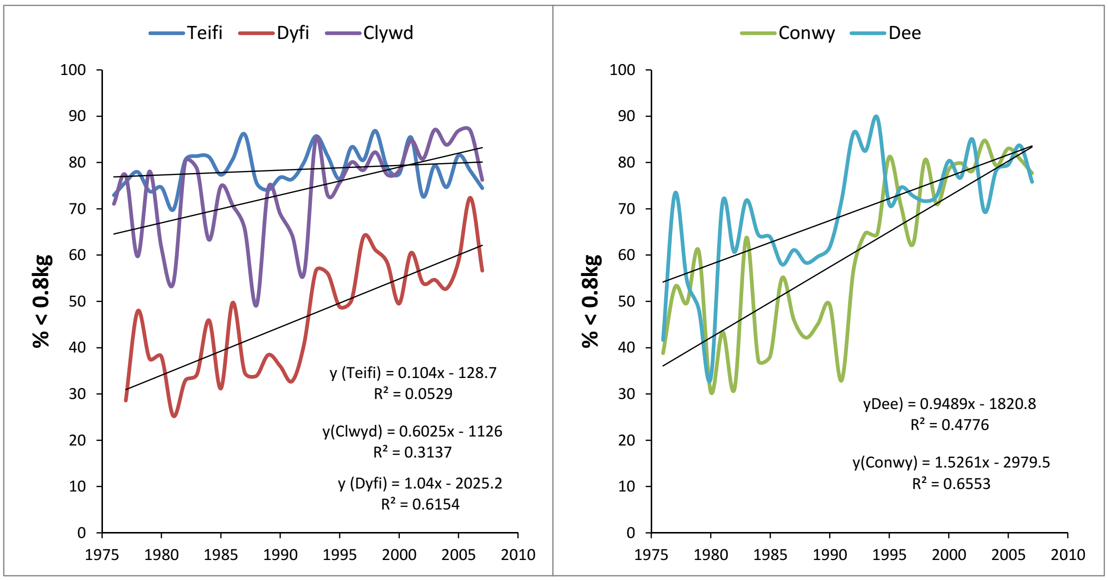


Figure 7.4.31 Long-term changes in percentage of the smallest sea trout size class (<0.8kg, equivalent to whitling) in rod catches of 5 Welsh rivers.

Also in all rivers there was substantial reduction in the proportions of the medium sized fish (0.8-2kg), mainly in the post-1989 years and particularly in the Dee (Figure 7.4.32). However, percentages of the larger size groups (>2kg) in the Teifi and Dyfi have increased, in contrast to the declines in three more northerly Welsh rivers, Conwy, Clwyd and Dee. While the largest fish (>4kg) were a small proportion of the total in both the Dyfi and Teifi, they were five to six times more prevalent on the Dyfi.

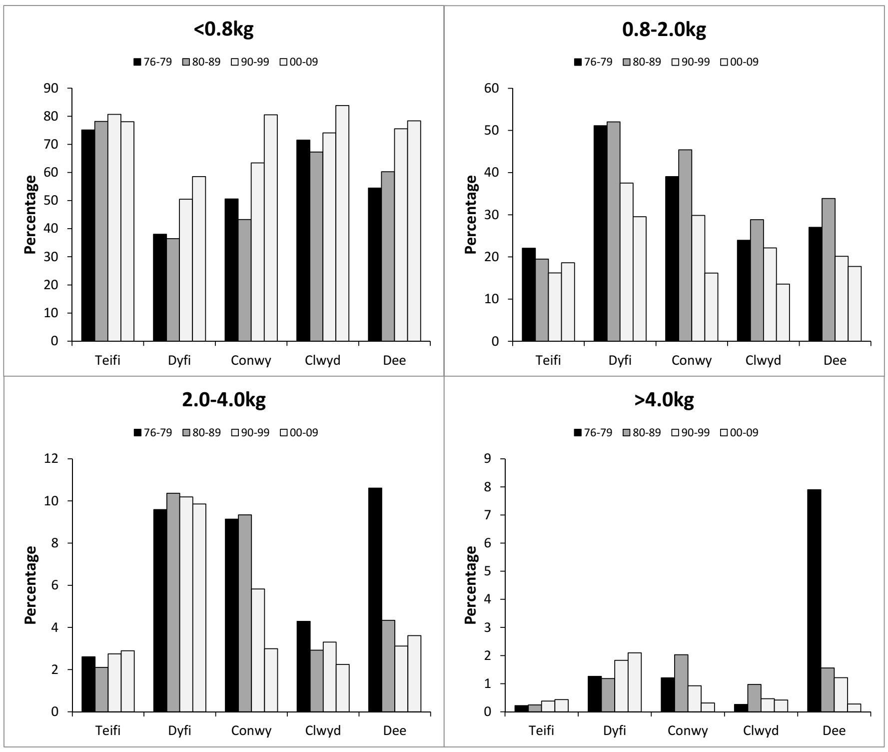


Figure 7.4.32 Percentage changes in abundance of size categories of sea trout in five Welsh rivers, from rod catch data, showing averages of periods 1976-1980, 1980-89, 1990-199 and 2000-2007.

Changes in relative size distribution could be due to various combinations of size- or age-selective changes in rates of growth, maturation and mortality. For example, faster growth is associated with earlier maturation in salmon. Earlier maturation of sea trout would bring more fish back as whitling and increase their prevalence in catches. An increase in post-maturation mortality would reduce the proportions of older, larger fish. Long-term increased growth rate could also shift the distribution of the size classes in Table 7.4.12. There are no direct long-term data on these variables, but two types of observation are relevant: records from historical scale data and the detailed studies on population dynamics of the Dee sea trout which do demonstrate medium term (decadal) variation in proportions of whitling (Davidson *et al*., 2006b). Historical scale data are described below. In addition, there are data from the two wide-scale surveys of 1996-98 (Harris, 2002) and 2010-2012 (CSTP), which allow some comparison between those two periods.

Historical Scale Data

Historical scale readings data have been reported for the eastern Irish Sea rivers (see Section 7.1.5). These were combined with the recent CSTP data to examine the historical trends on size of maiden fish at ages 0, 1 and 2 yrs (Appendix Table 7.7). The historical trend appeared to be strong for age 0+ fish, but more variable for older fish (Figure 7.4.33).

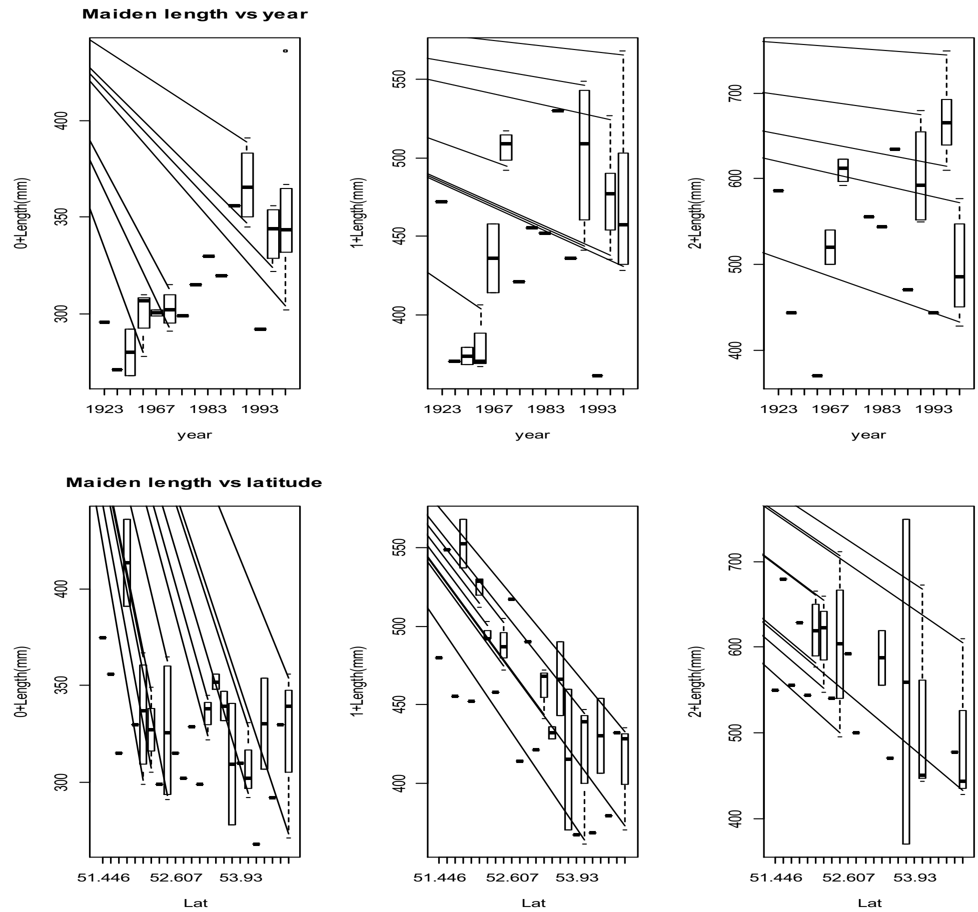


Figure 7.4.33 Variation in length of .0+, .1+ and .2+ sea trout over time (upper panels) and with latitude (lower panels). The data, based on scale readings from various disparate studies, are in Appendix 7.9.

The data from widely dispersed eastern rivers were not evenly spread over time; and because latitude is associated with growth variation (see above) this introduced a confounding effect on the relationship with time. Analysis of covariance demonstrated that individually both year and latitude were significantly associated ($P<0.05$) with size of .0+ (size decreased with latitude and increased over time) and that relationship varied differently between location. However, for the .1+ and .2+ fish, when the effects of latitude and year were combined, neither factor influenced size. This might be related to the high variance in the data introduced by variously smaller sample sizes, the effects of varying study protocols and scale readers. In conclusion, the historical scale data showed that the average size of whitling has significantly increased over time (1920-2000) even when the effect of latitude was accounted for.

Comparisons of 1996 and 2010-2012 Sea Trout Sizes

Previously it has been shown that sea trout size varied with latitude and temperature in the samples from 1996-1998 and 2010-2012 to varying extents depending upon sea age. This section compares the two sets of data to see if these relationships have changed over time. Common data were only available for 8 east coast rivers (Figure 7.4.34). In order to reduce confounding effects the analysis was restricted to 2.0+ and 2.1+ groups, which were the dominant age categories on most rivers.

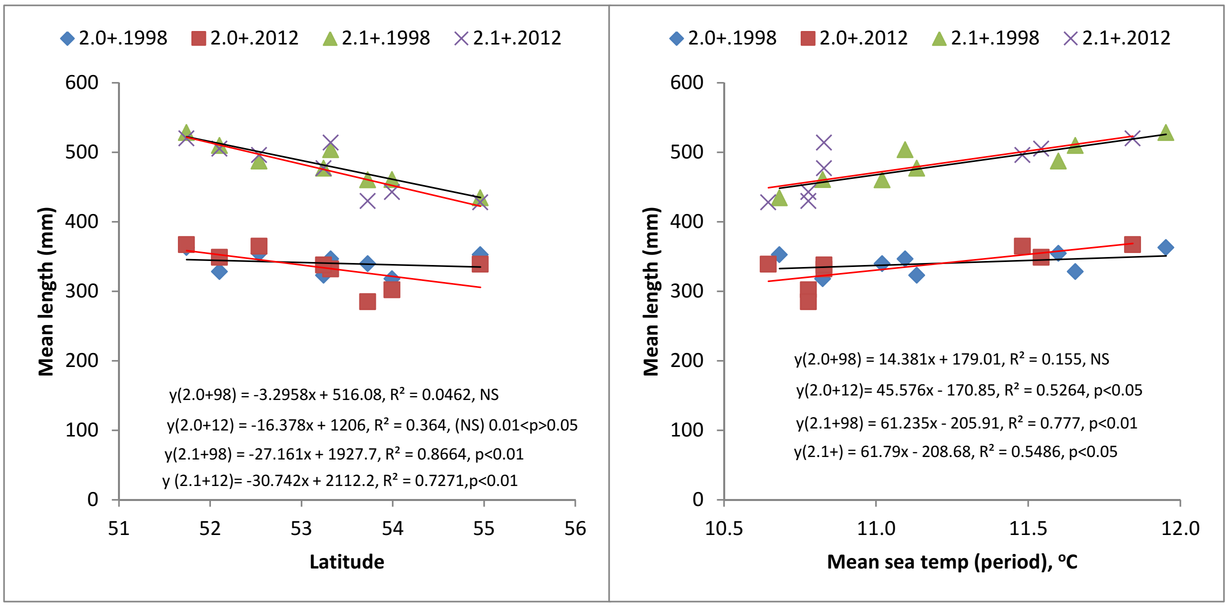


Figure 7.4.34 Comparison of the relationship between 2.0+ and 2.1+ lengths and latitude and mean annual sea temperature in samples collected in 1996-1998 (Harris, 2002) and 2010-2012 (CSTP).

The significant associations between fish size and latitude and sea temperature were similar in both periods. Analysis of variance and covariance demonstrated that the relationships did not differ significantly between the periods.

Mean lengths of the 8 rivers combined at 2.0+ and 2.1+ also were not statistically (t-test) significantly different (Table 7.4.13) and neither were the adjacent sea temperatures, which in all cases had decreased very slightly between these periods. Such temperature changes are not a contradiction of the overall long term temperature increase (1960s to 2004, Figure 7.4.13), but reflect small scale fluctuations in the temperature record.

Table 7.4.13 Mean lengths at age and sea temperatures in two periods, 1996-98 and 2010-2012.

	Mean lengths (mm) at 2.0+ and 2.1+				Mean sea temp (°C)		Latitude
River	96.2.0+	12.2.0+	96.2.1+	12.2.1+	1996-98	2010-2012	
BESK	353	339	434	428	10.68	10.65	54.96
LUNE	318	302	461	443	10.82	10.78	53.99
RIBB	340	285	460	430	11.02	10.78	53.73
DEEw	323	338	477	477	11.13	10.83	53.24
CLWY	346	332	504	514	11.10	10.83	53.32
DYFI	355	365	487	496	11.60	11.48	52.54
TEIFI	328	349	510	505	11.65	11.54	52.10
TYWI	363	367	528	520	11.95	11.84	51.74
mean	341	335	483	477	11.25	11.09	
sd	16.2	28.6	30.8	38.0	0.443	0.456	

7.4.5 Discussion and Conclusions on Growth and Condition

The purpose of examining growth in detail was to describe how it varies amongst the sea trout populations (here indexed by river), to see how it might vary with other life history variables and to explore its response to environmental factors. The estimation of growth of sea trout was complicated by their anadromous habit, the potential influence of smolt size and the difficulty of sampling known migratory groups and of knowing their actual growing environment. Adults sampled in rivers have been away from the sea, and mostly not feeding or growing in length for varying unknown periods, and have been on migrations that might have taken them to areas far from their natal river. These two processes cause uncertainties in the relationships between growth and environment. Nevertheless patterns were evident, but in order to draw conclusions a number of assumptions had to be made. These are outlined below.

1) *Extent of marine migration*. It was assumed that on average sea trout movements in the Irish Sea are comparatively restricted to the vicinity of their natal river mouth. For example, Cardigan Bay origin fish might be contained within Cardigan Bay, Solway fish to the Solway area etc. This parsimonious assumption was based on previous studies showing that sea trout tend to have a comparatively restricted dispersal from their natal river, particularly for post-smolts fish which return as whitling which have been found to remain in the vicinity of sea lochs (Pemberton, 1976; Middlemass et al., 20009), fjord systems (Finstad et al., 2005; Thorstad et al., 2007), estuaries (Davidsen, *et al*., 2014) and in coastal waters rather than open sea (Berg and Berg, 1987; Degereman *et al*., 2012). Median dispersal distance along the Swedish Bothnian coast was 30km (Degerman et al., 2014). However, this is tempered with observations that even in these studies long distance migration of a small proportion of the population are observed (e.g. 5% were recovered at >200km in the Degerman study). In other studies more extensive migrations are the norm, such as those of NE England sea trout (Potter 1990); together suggesting that dispersal can be asymmetric and influenced by residual current patterns (e.g. Pedersen *et al*., 2006; Degerman *et al*., 2012). Therefore it seems probable that coastal structure - the location of enclosures, embayments, large estuaries *vs* straight coast line - will influence the extent of movements. In the Irish Sea therefore, it is likely that outward marine migrations (dispersal might be a better term) are driven by the local circumstances of food availability and residual currents. The knowledge on sea trout marine migrations in the Irish Sea is still weak which is why other CSTP studies on genetics, microchemistry and hydrodynamic modelling were carried out and are discussed in detail elsewhere. In combination, these studies will show that in practice, the extent of marine migrations was quite variable between rivers and regions and

this is believed to have influenced, differently amongst rivers, the relationships between growth and assumed growth environments (see discussion in Section 7.7). However, the detail of river-specific movements is still elusive and the parsimonious assumption of uniformly restricted dispersal is a useful starting one against which to test these growth results.

2) *Fish cease growing in freshwater*. Some freshwater feeding does occur in sea trout; but most studies show that they feed very little and cannot replicate the quantity and quality of prey that is present in the sea (Elliott, 1997). Sea trout have been shown to lose weight in proportion to the length of their stay in freshwater (Berg and Jonsson, 1990), but length would not change. Therefore, it was felt safe to assume that sea trout length at capture in river represented satisfactorily the length at river entry.

3) *Fish are caught soon after river entry*. This timing is important because it determines the marine growing period that fish have had in any year and hence the estimation of growth rate. For example a fish caught in September might have entered the day it was caught or been in the river since June. The four months difference in this extreme case would greatly affect the estimated growth rate. On the basis of marine diet item in stomachs Elliott (1997) concluded that sea trout were caught soon after river entry in the Rivers Leven and Duddon, Cumbria; although this was less evident in three other rivers in SW England.

Accepting these assumptions and their caveats for the time being there are a number of conclusions from the results on growth and condition, summarised below.

1) There was evidence of wide-scale marine growth variation within the Irish Sea moderated by some more localised, factors which could be related to river-specific factors or to local sea feeding (de Leeuw *et al*., 2007). The CSTP has provided a comprehensive data set to describe this quantitatively and to explore some of the possible explanatory factors.

2) In general, for equivalent latitudes and temperatures, the sea trout of the eastern Irish Sea have higher growth rates in their first post-smolt year than those in the west. These differences, established as whitling are maintained throughout life, but later marine growth rate was not detectably different between east and west. In the east coast post whitling marine growth was positively related to temperature, but not statistically so in the west. This indicates the great importance of the first post-smolt year as a determinant of subsequent performance, particularly in the Irish rivers. The difference in relationship with latitude and temperature in the two seaboards might also be partly related to the dispersal patterns of sea trout in these two areas.

3) Within the east side group (Wales, NW England, Galloway) there was strong evidence of latitudinal (and temperature-based) variation in size of .1+ and .0+ fish; although the strength of the relationship for the younger (.0+) group was weaker and insignificant in the samples taken in 1996-98. This variation was attributed here in part to temperature, which was correlated with latitude. Clinal trends in sea temperatures have been invoked to explain latitudinal growth variation in Norway (L'Abée-Lund *et al*., 1989) and the Baltic (Degerman *et al*., 2012). In marked contrast, for sea trout size on the west coast, although there were weak relationships, they were not statistically significant. This is an important result that is consistent with the new information on sea trout marine dispersal (see Chapters 4 and 5).

4) The size patterns of whitling (.0+) were influenced by (a) smolt size/age effects (i.e. river and / or maternal effects) and (b) variation in smolt and whitling migration timings. Whitling size increased with smolt age in all rivers. The effect is a complex picture of seasonal size variation in whitling that obscures any underlying marine growth pattern and is characterised

(where data where adequate to show it) by mean size decrease during the summer and an increase again in the end of the whitling run.

5) There were some river-specific exceptions to the broad regional growth patterns. The Currane, in SW Ireland showed large smolt size in comparison to other Irish rivers, but subsequent growth rate was not detectably different. The Isle of Man group and the Tawe showed large smolt sizes. However there remain some concerns over the scale reading errors in that need to be resolved and which leave these latter exceptions equivocal.

6) Condition factor showed characteristic seasonal patterns that were the same in fish sampled in rivers and in the sea; although there was some weak evidence of higher K at higher mean sea surface temperatures. In most cases K increased in the spring and declined continuously from around May/June until the autumn. These seasonal patterns are similar those reported in sea trout from Normandy (Euzenat *et al*., 1999) and Norway (Rikardsen *et al*., 2006).

7) Growth modelling using temperature as the determining variable was not successful. A conventional model of trout growth did not describe observed marine growth well and this might be due to the high fish diet of sea trout and the effects of compensatory growth. The lack of an effective marine growth model remains a limitation (one of many others) on predicting effects of climate change on sea trout.

8) Sea surface temperatures have increased in the Irish Sea at average of 0.29°C per decade since 1960. It is thought likely that, if the warming trend continues, the effect on growth will vary geographically with more northerly rivers of the east coast increasing growth for longer than the southerly rivers, an effect due to the rate at which temperatures approach the optimum temperature for trout growth (as used in the model). However, the predicted growth effects were small (of course this might be incorrect due to the model issues). It is probable that factors other than temperature such as marine productivity and prey species availability, plus changes in freshwater will be more important influences on sea trout life history.

9) Observed growth variation between two periods 1996-98 and 2010-2012 as indexed by mean size of 2.0+ and 2.1+ fish showed no significant change in 8 rivers for which data were available. The mean sea temperatures in those periods were also not significantly different and had slight reduced in the later period.

10) Mean smolt age ranged between 1.81 and 2.43 years, and mean sea age between 0.17 and 1.41. Neither was related to latitude.

7.5 Fecundity and Gonado-Somatic Indices of Marine Sea Trout

7.5.1 Introduction

Published accounts of sea trout fecundity in or around the Irish Sea include investigations by Harris (1970) on the Dyfi in Wales and Elliot (1995) for some smaller rivers in England. O'Farrell et al., (1989) carried out a detailed study examining fecundity on the River Erriff on the west coast of Ireland and Walker (1994) investigated fecundity on the River Tweed, Earn and Ewe in Scotland. Solomon (1997) reviewed sea trout fecundity from riverine stocks across an extensive latitudinal range extending from Norway to the north of France including the UK and Ireland. Fecundity studies are usually presented on a single river basis although Euzenet et al (1991) combined data from three French rivers.

For the CSTP project fecundity was investigated to support matrix population modelling (See Section 7.6.5) and only marine caught fish were included in the analysis. As fish mature the size of their gonads increases in proportion to their body size. This can be expressed as the gonado-somatic index (GSI= gonad weight / total wet body weight x 100) which also provides a simple index of maturation status. GSI was calculated for whitling, older maidens and previous spawners from marine caught fish only.

7.5.2 Materials and Methods

Samples were collected using various methods in sampling zones (Figure 3.4.1), including direct sampling using different types of nets and targeted trawling, from fish screens, and from angling. Various sampling methods were utilised because the standard survey netting methodology developed for the project, which was carried out on a seasonal basis in Year 1, failed to yield sufficient sample numbers. Adapting the sampling programme, to include non-standard sampling methods to ensure that sufficient samples were available for all workpackages, introduced selectivity bias which resulted in underrepresentation of fish < 30cm forklength.

Table 7.5.1 Total number of sea trout gonads (male and female) examined for CSTP by year

Sex	2007	2008	2010	2011	2012	Total
Female	7	3	143	286	248	687
Male	5	0	41	70	73	189
Total	**12**	**3**	**184**	**356**	**321**	**876**

Captured fish were individually wrapped in a plastic or ziplock bag and labelled, as soon as possible post-capture. Any trout sampled by project personnel were transported to the laboratory and frozen at -18C within two hours. The exception was a sample of trawled fish which were held on ice for the duration of the 8 day sampling trip and subsequently transferred to -18C storage. Samples collected by external samplers were generally frozen in bulk at -18C and subsequently transported to project laboratories for individual processing. Fish processing methodology is described in Task 3 – Sampling in this report.

In the laboratory adult fish were thawed under controlled conditions, dissected and sexed by examination of the gonad. Female and male gonad were removed and weighed to the nearest 0.01g. 687 female and 189 male gonads (Table 7.5.1) were extracted, weighed (to nearest 0.01g) and frozen immediately at -18C for further analysis. Where designation of sex was difficult due to gonad underdevelopment the examination was carried out using a hand lens or under a microscope. Maturity status was classified according to FAO (1974) (See Appendix 3.15).

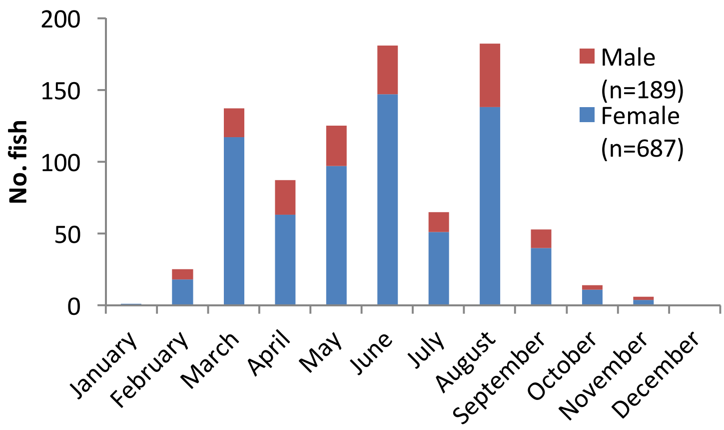


Figure 7.5.1 Numbers of female and male gonads sampled by month from marine caught sea trout. All years pooled.

Samples were collected from February to November and peaked in summer, primarily June and August (Figure 7.5.1). Females dominated the total sample (3.63:1) and this was relatively consistent in all months. GSI was calculated for a broad size range of fish although the sample was dominated by fish in the 40 – 50 cm range (Figure 7.5.2). See Section 3.7 for marine fish sampling details.

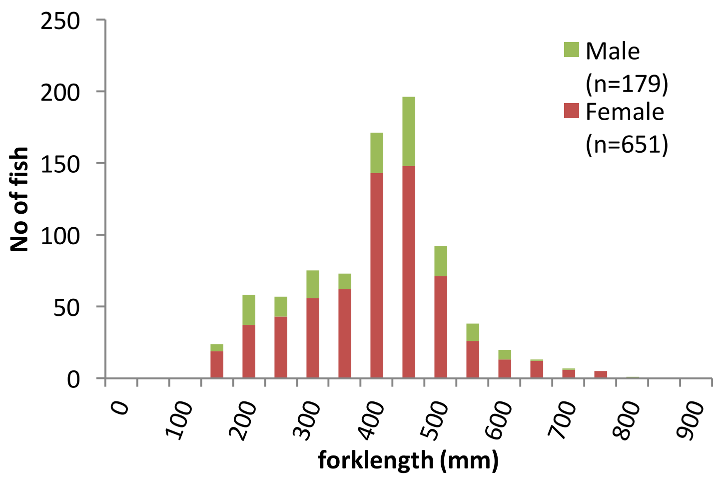


Figure 7.5.2 Forklength (mm) of marine caught sea trout used for GSI determination. No length data available for 10 female and 36 male fish.

Gonado-somatic index was computed by expressing gonad weight (g) (wet weight) as a percentage of total thawed body weight (g).

Samples selected for fecundity estimation were widely distributed in the Irish Sea (Figure 7.5.3) and only fish captured between July and October, at maturity stage ≥4, with increasing GSI were included.

Fecundity determination is time consuming and many workers have devised methodologies to reduce sample processing time. For example, Klibansky and Juanes (2008) developed a rapid method which entailed capturing images of egg samples on a flatbed scanner and analysing with image analysis software but the methodology requires storage of the gonad in formalin for 4-5 months to preserve the sample and eventually to separate the eggs. Within the limited timeframe available for the CSTP fecundity study (1 month) development of a simple, cost-effective egg separation methodology, without resorting to use traditional fixatives, was required. Gilson's fluid is a commonly used fixative for fecundity studies but has a 2% mercuric chloride content, which requires a toxic waste disposal protocol to dispose of sampling residues, and was therefore not used. For CSTP rapid egg separation was attempted by application of indirect heat via a water bath, to a weighed subsample, to break down ovarian tissue and release eggs that would have hardened off. The basis for this is a method used by Bell and Kent (2012) for Chinook salmon. The CSTP methodology was refined as sample processing proceeded.

According to Klibansky and Juanes (2008) the gravimetric method (Kjesbu and Holm, 1994) remains the most commonly used method of fecundity estimation, whereby eggs in a pre-weighed sub-sample are counted manually and the result is multiplied by the weight of the entire ovary. For the current study the preferred approach was to use a gravimetric approach and two methods were tested. Method 1 involved estimation from a single sub-sample per ovary (i.e. two samples per fish) while Method 2 was based on three sub-samples. Both involved excising a sub-sample from a thawed gonad, weighed to the nearest 0.01 g, which was placed in water in a 100ml glass beaker in a water bath operating at 90˚C. After 15 min the ovarian tissue was sufficiently degraded and 40-60% of the available eggs within the egg mass were freed for counting. Where eggs remained attached to the tissue the sample was transferred to a plastic 100ml screw cap sample bottle, sealed and shaken gently to loosen the remainder from connective tissue. Subsequently the mixture was allowed to settle after which approximately 90% of the water was decanted. The remaining water/egg mixture was transferred to a gridded examination tray where the eggs were enumerated. Some teasing apart of any residual hardened egg mass using forceps or a soft paintbrush was necessary which resulted in rupturing of some eggs (< 3% of total count). A ruptured egg was counted as a whole egg where ≥ 50% of the individual egg membrane was visible. Fecundity was estimated from the single sub-sample count of ovary of known weight and raising this number to the individual ovary weight; the totals for both ovaries were summed. The subsample, which was approximately 10% of ovary weight, was removed from the central section. This methodology was applied to gonads from 16 maturing fish (all Stage V) which were captured in August and September and would most likely have spawned in the following winter (Table 7.5.2). A total count was carried out on one gonad to assess estimation efficiency.

For the three sample method three sections (totalling approximately 10% of each ovary) from the front, middle and rear were excised, weighed and heated in the water bath as described. Individual counts of each section were carried out and summed. This total was divided by the summed weight of sections to provide an estimate of number of eggs per gram of ovary. This was multiplied by the total ovary weight to generate a total count per ovary. Both counts were summed to provide an estimated total fecundity per fish. A total of 39 fish were sampled using this method and five of these were also subjected to a total count (Table 7.5.2). In all cases data from different years were pooled.

Table 7.5.2 Summary statistics for marine sea trout used for fecundity determination by method

Fecundity estimate method	Marine zones	Sample months	Sample years	Mean thawed fish length (mm)	Mean thawed fish weight (g)	Maturity status	n
1 sample per gonad	MZ08	Aug-Sep	2010 - 2012	516.7 (440 – 668)	1702.0 (826 – 3346)	V	16
3-samples per gonad	MZ05, 07, 08, 10, 12, 14 & 23	July-October	2010 - 2012	462.5 (290.0-660.0)	1322.6 (338.0 – 2933.0)	IV - VI	39

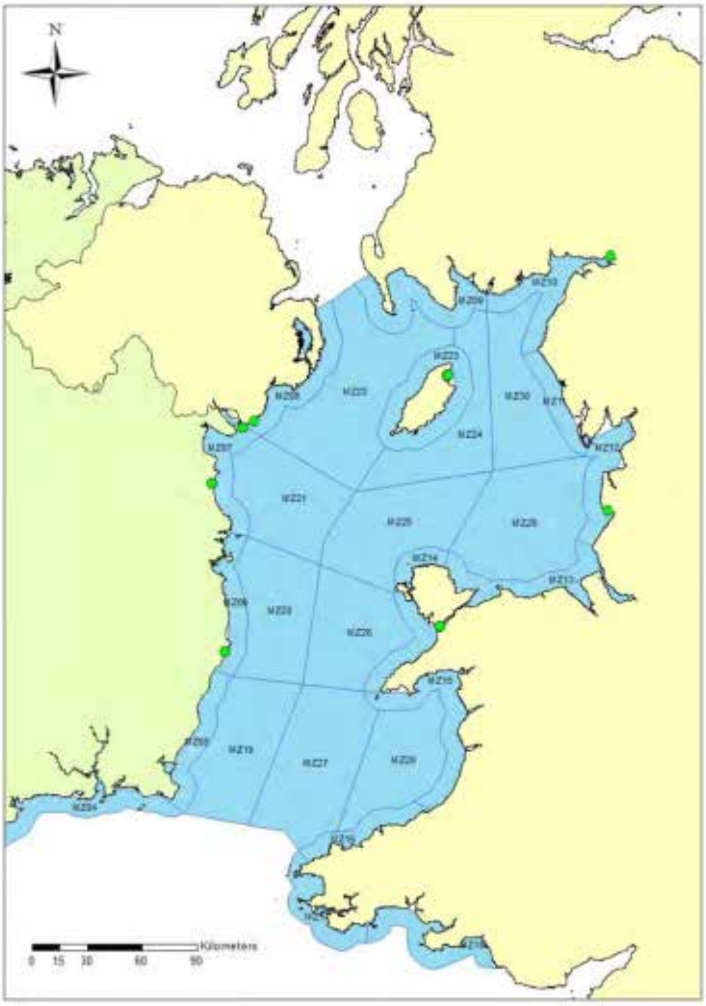


Figure 7.5.3 Distribution of sampling locations for fish used for fecundity estimation.

7.5.3 Results & Discussion

Sex ratio

The sex ratio for the total sample was 1:3.63 (♂:♀); n=896. Similarly high ratios were recorded for a marine population in Ireland (1:2.5) by Fahy (1985b) while Pemberton (1976) recorded a 1:3.44 ratio for a post-smolt population from Scottish sea lochs.

Gonado-Somatic Index

GSI for finnock (whitling), 1SW maidens and previous spawners, both male and female, is shown in Figure 7.5.4. GSI for 'Other' is presented and this includes sea trout with various life histories and some with uncertain spawning histories. Lowest GSI values for females in all groups, ranging from 0 to approximately 1%, were recorded from January to April. From May onwards values for female finnock increased steadily up to a maximum median level of 4.5% in August. A similar pattern was observed for 1SW maidens although the highest median value (10%) was recorded in September. This was the highest recorded for the entire GSI dataset. For previous spawners the maximum GSI value was 5% which was recorded in August. Low values were a feature of GSI for previous spawners.

In males GSI peaked in September (Figure 7.5.4) in finnock having increased steadily from June onwards. The maximum value was 6%. For maiden fish and previous spawner males the highest GSI values occurred in August. Median GSI values for the three groups of sea trout (finnock, 1SW maidens and previous spawners) were consistently lower in males in all months and demonstrated the higher investment in gonad development by females.

Similar GSI values for male and female finnock were observed by Maisse et al., (1991) between July and December in a river in northern France; highest mean values from that study were 4% in October and 13% for females in December. Jonsson and Jonsson (2006) quote a population range of 17.7 – 26% for females from several studies of anadromous trout from a number of river systems.

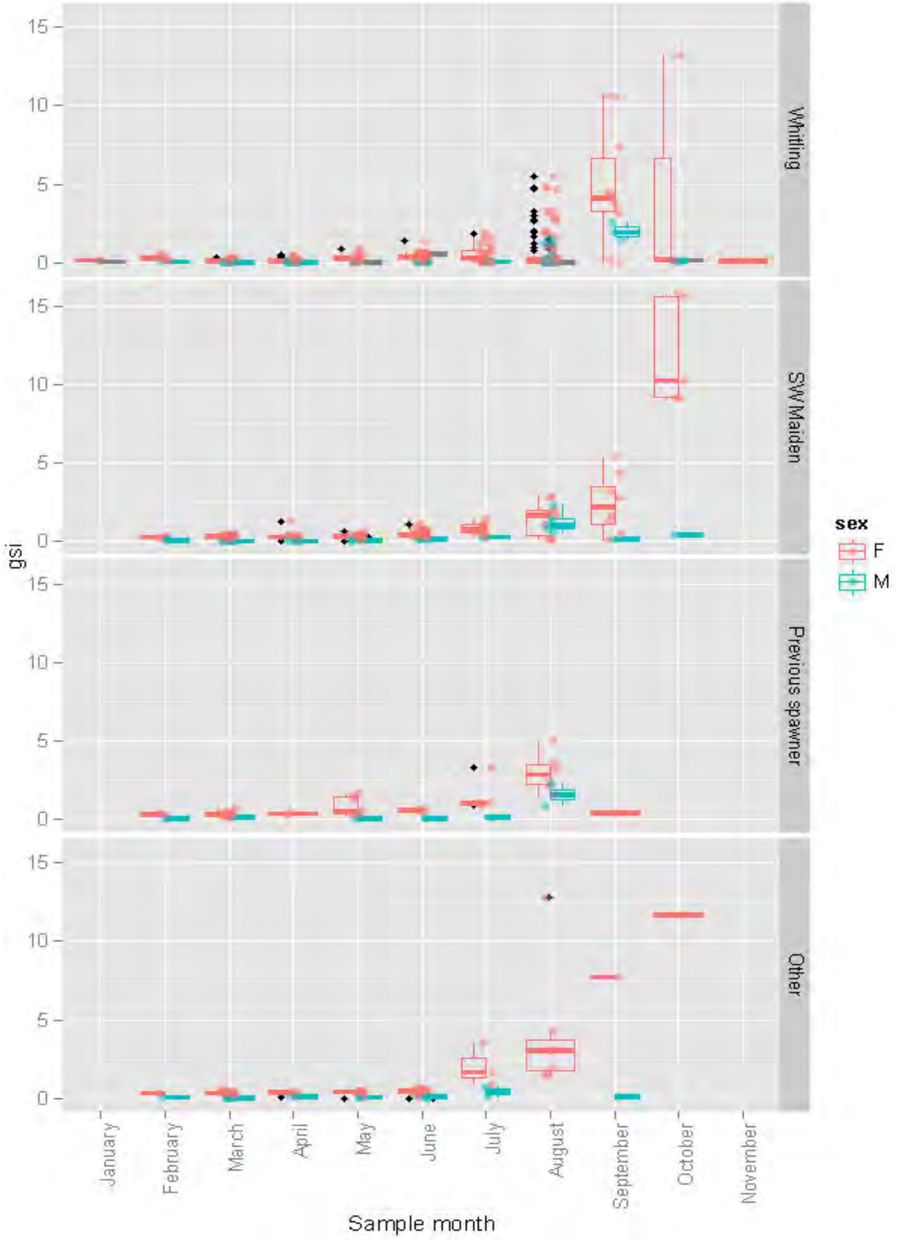


Figure 7.5.4 Gonado-somatic index (GSI) for three groups of sea trout caught at sea: whitling, 1+SW Maidens and Previous Spawners, showing males (n=179) and females (n=651) separately. Individuals not assigned to either whitling, .1+1SW maidens, or previous spawners were classified as "Other". This group includes sea trout with diverse life histories, such as .2+ maidens and individuals with uncertain previous spawning records (IM).

Fecundity

Samples came from fish which were distributed throughout the Irish Sea, mainly in inshore areas (Figure 7.5.3), but the majority were from MZ07 and MZ08 on the east coast of Ireland (Table 7.5.3). The largest contribution (49%) was from MZ08 (both 1-sample and 3-sample combined). This sampling bias arose from the availability of mature fish from this zone.

Table 7.5.3 Details of fish sampled for fecundity, using 3-sample method, by Marine Zone and Year

Marine zone	Year	n	Mean length (mm)	SD
MZ05	2011	5	381.2	97.6
MZ07	2010 & 2012	15	450.2	24.8
MZ08	2011 & 2012	11	501.9	58.1
MZ10	2010	1	417.0	
MZ12	2011	1	518.0	
MZ14	2011	2	416.5	91.22
MZ23	2010	4	522.8	101.90

Total egg counts were carried out on six fish to validate the two methodologies; 5 were processed using the 3-sample method (Table 7.5.4). The 3-sample method provided the best estimate with a lower % mean variance from the actual count compared to the 1- sample estimate (Table 7.5.4).

Table 7.5.4 Percentage variance of estimated count of eggs by method versus total count for one- sample and three sample method

Method	Total count	Estimated count	% variance
1 sample	1170	1275	+9.04
3 sample	1455	1440	-1.05
3 sample	2221	2209	-0.55
3 sample	1708	1777	+4.08
3 sample	1093	1139	+4.24
3 sample	2313	2405	+3.98
Mean of 3 sample variance			**+2.14**

Fecundity was positively correlated with fish length, Figure 7.5.5. For the 3 sample method fish size was large with mean fork length of 462.5 ± 71.86 mm, mean weight was 1322.6 ± 594.57 g and mean number of eggs per female was 2077 ± 770 eggs. Minimum and maximum values were 779 and 4276 eggs respectively.

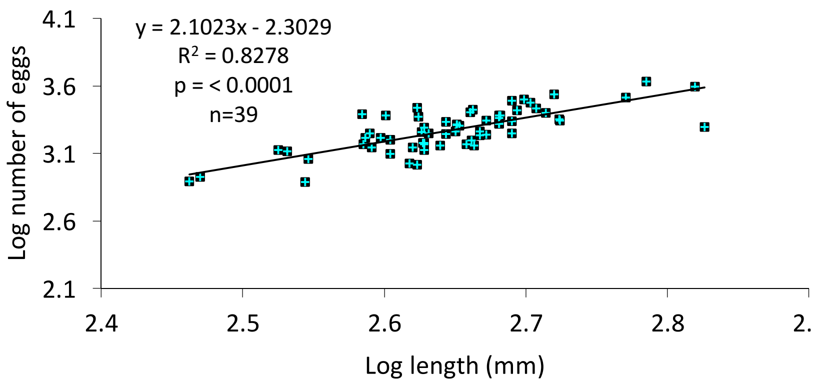


Figure 7.5.5 Forklength-fecundity relationship for sea trout based on 3 samples per gonad.

These data can be compared with an earlier set for the Irish Sea collected by Harris (1970) from the River Dyfi and reworked here for length and weight sizes (Figure 7.5.6). In the Harris study eggs were taken from 52 dead rod-caught fish by breaking down the ovaries with Gilson's fluid. For completeness, the wet weight (W,g) / length (W, cm) relationship for the 52 fish was given by:

$$W=0.0107.L^{2.9926} (R^2 =0.975)$$

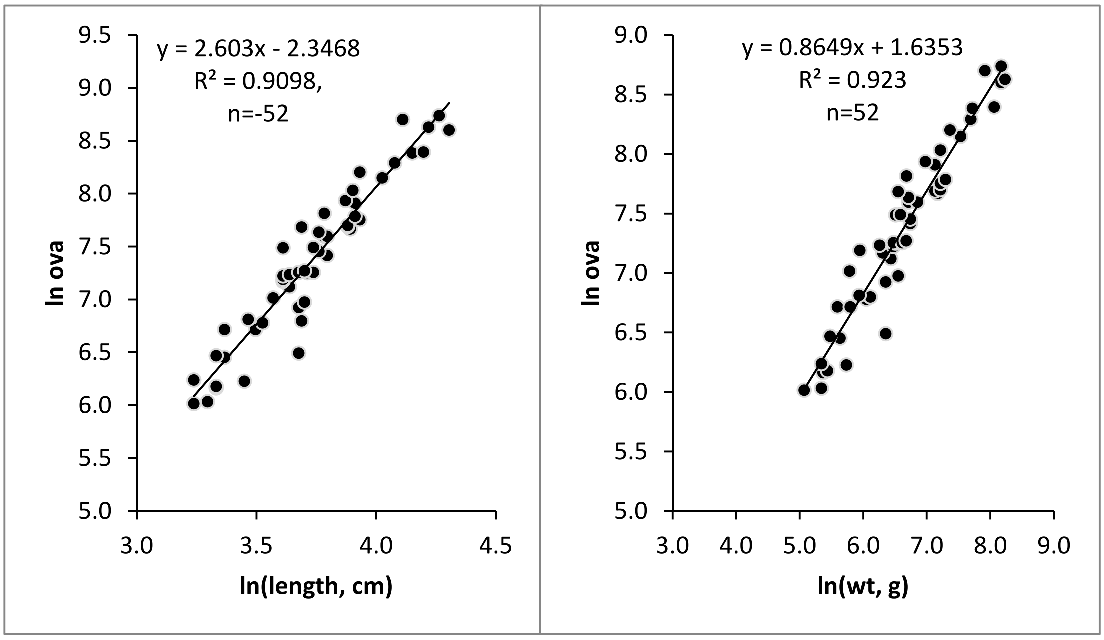


Figure 7.5.6 Size-fecundity relationships for River Dyfi sea trout. (A) Length, (B) Wet weight. Data from Harris (1970).

Fahy (1985) noted that a 50 cm sea trout from an Irish Sea population, characterised by good feeding and associated growth, could yield approximately 2700 eggs which is generally consistent with current data. Specific comparisons with other systems shows that Irish Sea fecundities are intermediate between a fecund stock from the River Bresle in France (Euzenet, 2006) and a relatively low fecundity stock, in a UK and Ireland context, from the River Erriff on the west coast of Ireland. Erriff fish are typical representatives of 'Atlantic type growth' sea trout (Fahy, 1978) characterised by slender, poorly conditioned fish with poor growth rates.

7.6 Population Dynamics

7.6.1 Estimating Survival Rates

Mortality (M) and its complement, survival (S) are key features of life histories. Many impacts, predation and fishing for example, act by changing M at various stages. The rate at which abundance of a cohort declines defines the mortality rate. In practice, decline can be due to true mortality or to fish becoming unavailable by for example dispersal from the sampling zone or changes in vulnerability to the sampling method. Therefore in the following account mortality may be more correctly termed loss. This section looks briefly at marine survival based in the numbers of fish (N) at successive sea ages (t, yrs) derived from scale reading. Making a basic initial assumption of exponential loss, the instantaneous loss rate (a surrogate for mortality) z, is given by:

$$N_t=N_0e^{-zt}$$

where N_t is the abundance in year t and N_o is the initial abundance. Transformed to logs Equation gives a straight line regression:

$$\text{Ln}(N_t) = \ln(N_0) - zt$$

Regression of ln(N+1), (N+1, to account for zeros) against sea age gives a slope that estimates -z, the instantaneous loss rate, in this case over one year, from which % annual survival (%S) is calculated by exp(z+ln100) and annual % mortality (M) = (100-S).

It must be emphasised that the true abundance (N) of the year class is not directly measured by scale sampling programmes for two reasons. First, the rod-caught samples (or even trap counts) are just those fish which return to the rivers each year and a further component, which can be substantial, remains at sea to form the maiden fish cohorts returning in later years. Once sea trout have spawned then they usually keep returning annually, but this is only the older, less abundant part of the population. Second, the sample size is subject to many biases and random errors because rod catch is not tightly linked to run size, angling is selective and catch reporting is biased and imprecise. Unless a trap is present there is no reliable independent method to check these errors. It can be argued that, while some river-specificity might arise, the second category of problems is equally present on average across all rivers sampled by angling. So, accepting that catch is just an index of N, the problem for estimating population N by this sampling method lies in the split between the sea and freshwater components.

The biggest spatial partitioning (between freshwater returners and the sea residents) occurs during the first post-smolt year when the proportion of whitling returning can vary considerably between rivers. It has been shown above how important whitling are in many Irish river sea trout catches compared with say the NW English rivers. One approach (called method A in following text) is to ignore the catch of sea age 0 fish (whitling) and begin the mortality estimation at sea age 1, if it can be shown or assumed that thereafter annual M is comparatively constant with age. This is thought to be preferable to including age 0 fish, although even this is subject to partitioning errors because some fish remain at sea in their 2^{nd}, 3^{rd} and (rarely) 4^{th} sea years, but far fewer than in the first year. The effect of this incomplete recruitment to the younger sea age classes is to underestimate N in the early years, leading to shallower slopes (under-estimates of z and over-estimates of % survival). This needs to be borne in mind when interpreting results. The life history optional tactic of earlier return as .0+ in sea trout is a complication in estimating z from catch curves: higher whitling frequency would lead directly to lower apparent z. Moreover, in the case of rivers dominated by whitling if it happened that marine mortality was high and the numbers of sea ages were correspondingly low, then to omit the whitling might lose information on population size. Therefore both methods (excluding and including N_0) were used to examine the differences.

Ideally, N would be estimated by following abundance of a single year class in successive years; but because samples sizes were small and seasonally inconsistent (with the exception of the Dee trap), abundance were pooled across years within each of the two periods available, which were 1996-98 for the rivers described by Harris (2002) and 2010-2012 for the CSTP sampled fish. Eight rivers (Tywi, Teifi, Clwyd, Dyfi, Dee, Ribble, Lune and Border Esk) were sampled in both periods.

7.6.2 Survival and Mortality Estimates for 1996-98 and 2010-2012

Data on abundance at sea age (=sample size) were extracted from raw data files from the 1996-98 surveys (Harris 2002). Pooling data across years (Table 7.6.1) and plotting on logarithmic scale shows the typical variation in such data and the anomaly in which N was often lower in sea year 0 than in year 1 (Figure 7.6.1).

Table 7.6.1 Sample sizes, as indices of N, from scale sampling in 1996-1998 in east coast Irish Sea rivers (data adapted from Harris, 2002)

River	Sea Age (t), yrs								Total
	0	1	2	3	4	5	6	7	
BESK	152	296	54	21	5	1			529
KENT	48	114	26	14	5	5			212
LUNE	49	127	32	19	9	7	1		244
RIBBLE	33	205	57	25	10	2			332
DEE	751	539	201	61	18	5	3	1	1579
CLWYD	111	45	8	1	2	1			168
DWYFAWR	184	39	4	1	1				229
DYFI	124	384	80	33	14	10	1		646
TEIFI	227	54	11	8	4	1			305
TYWI	233	209	62	34	12	7			557

The plots show a comparatively constant loss rate after age 1, although with deviations at older ages due to low samples sizes. Based on an assumption of exponential loss, Equation 2 was used to estimate z values after age 1 (t_1) and to derive average % survival (Table 7.6.3). The regressions are shown in Figure 7.6.2 to illustrate the method and to include the data (Table 7.6.2) from the later period (2010-2012). For the eight rivers with results from both periods, neither method demonstrated any statistical significant change in % annual survival between the periods (Figure 7.6.3).

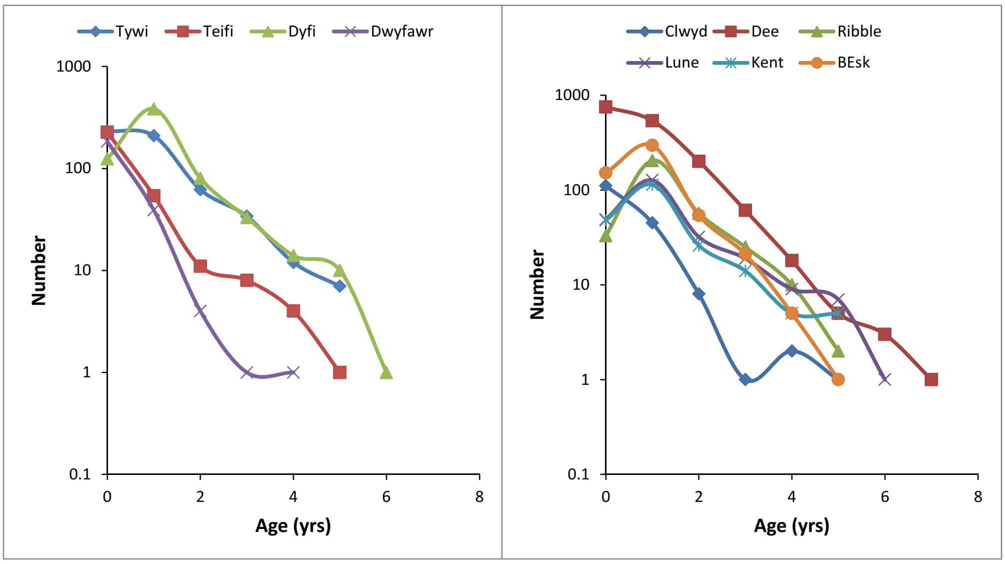


Figure 7.6.1 Logarithmic plots of sea trout abundance (N) at sea age for ten east coast Irish Sea rivers. Data adapted from Harris, 2002.

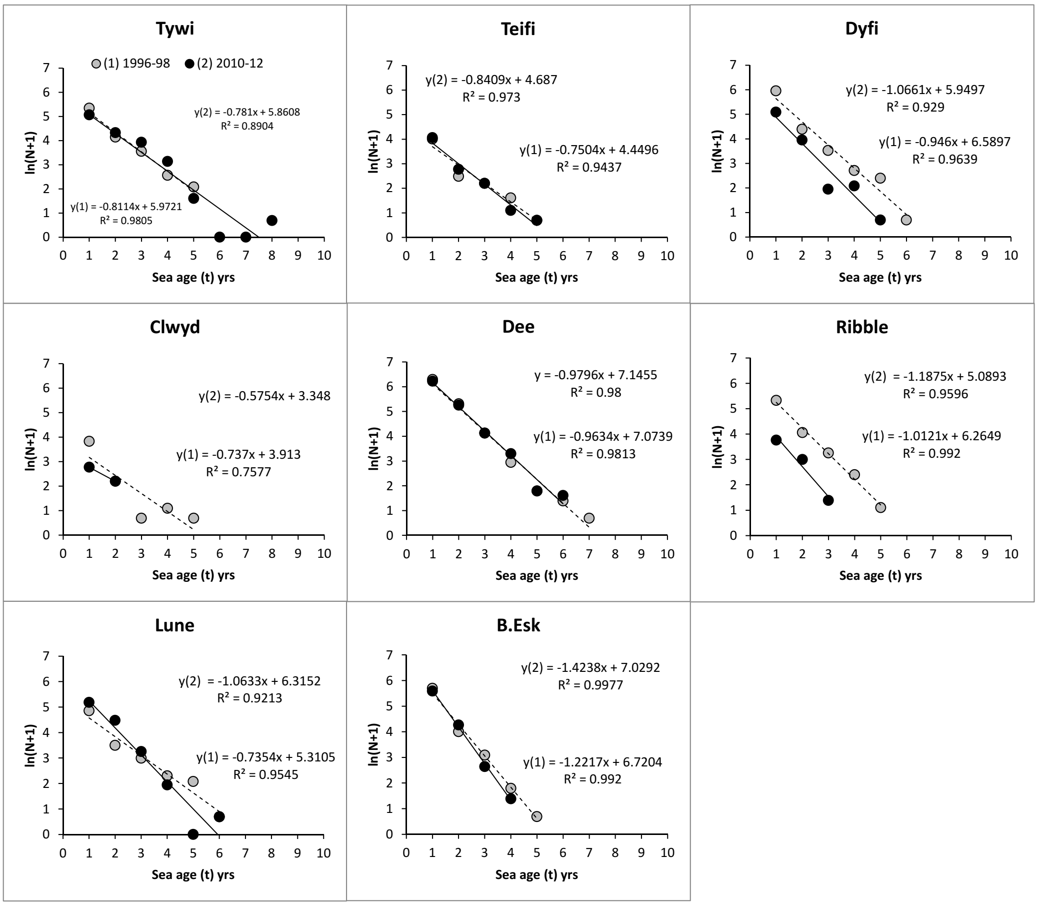


Figure 7.6.2 Regressions of abundance (ln(N+1) on age (years, t) for eight rivers for which data were available in two periods: 1996-98 (grey dots and dashed lines) and 2010-2012 (black dots and solid lines). The steepness of the lines gives a visual comparison of the mortality (loss) rates. The differences between the intercepts (heights of the lines) reflect only the sample size, which is uninformative with respect to abundance between periods.

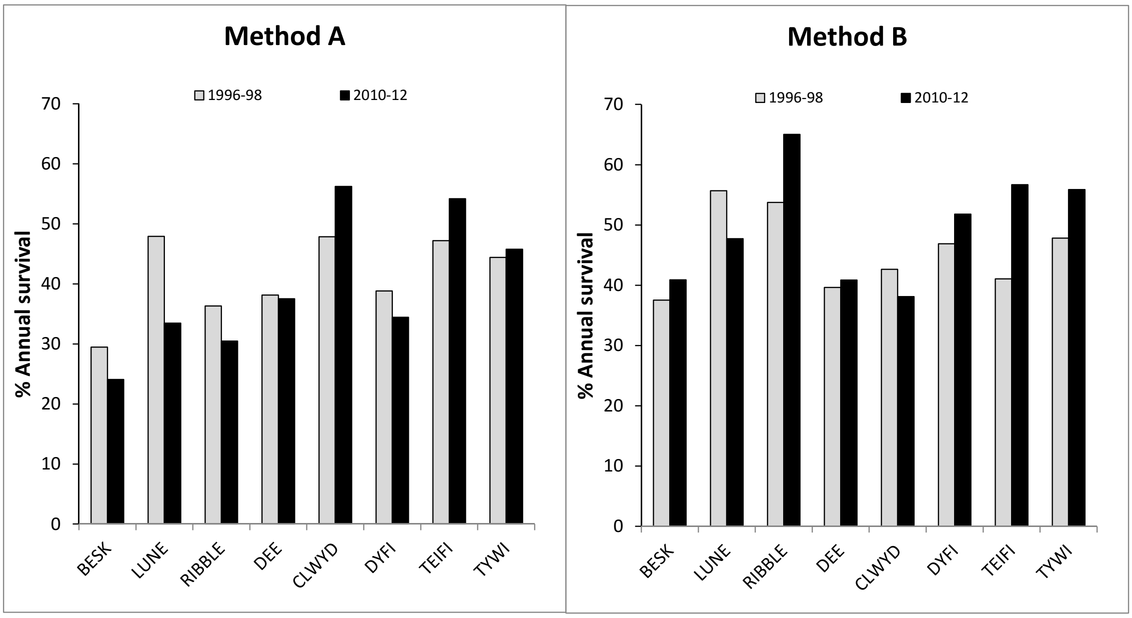


Figure 7.6.3 Comparison of annual % survival rates for sea trout in eight rivers sampled in two periods: 1996-98 and 2010-2012. Two methods were used to estimate survival: Method A (excluding N_0) and Method B (including N_0), see text.

Table 7.6.2 Numbers (N_t) at sea age t (years) for different rivers 2010-2012

Country/region grouping	River	Sea Age (yrs) 0	1	2	3	4	5	6	7	8	no data	Total
G&IoM	IoM	34	16	6	4	3	2					65
G&IoM	FLEE	117	34	9	3	1	1				1	166
G&IoM	LUCE	86	112	28	8	3	3				1	241
G&IoM	NITH	64	170	52	11	6	2				1	306
G&IoM	B.ESK	79	267	70	13	3					12	444
Ire	BAND	37	45	2								84
Ire	SLAN	157	27	2							5	191
Ire	DERW	200	28	5	1						2	236
Ire	BOYN	188	43	9	2						4	246
Ire	ARGI	133	105	12	3						3	256
Ire	CAST	294	50	3	1						3	351
Ire	CURR	136	180	36	7	3	3	7	4		6	382
Ire	SHIM	336	37	18	3						8	402
NW.E	RIBB	12	42	19	3						1	77
NW.E	EHEN	164	38	6	2						1	211
NW.E	LUNE	26	178	87	25	6		1			40	363
Wal	TAWE	10	13	4	3	1	1					32
Wal	CONW	34	31	7		1					2	75
Wal	CLWY	61	15	8							1	85
Wal	TEIFI	34	57	15	8	2	1		1			118
Wal	DEEw	69	40	7	1						5	122
Wal	Dyfi	21	161	51	6	7	1				9	256
Wal	TYWI	84	158	75	50	22	4			1	5	399
	Total	2376	1847	531	154	58	18	8	5	1	110	5108

The calculations on the remaining CSTP (2010-2012) rivers (Table 7.6.3) demonstrated the bias that resulted from including N_0 (Figure 7.6.4). The deviations in S% estimations between methods were least in those rivers with high whitling proportions and in these cases slightly over-estimated S%, giving a risk averse result compared with other rivers. It was considered more accurate to base the further analysis on the method A estimates (excluding N_0), but both sets are shown for comparison.

Table 7.6.3 Estimates of z and annual survival (S,%) for rivers sampled in 1996-98 (Harris, 2002) and 2010-2012 (CSTP). Results from two alternative methods, (A) excluding and (B) including whitling abundance (N_0) are shown, see text.

		1996-1998					2010-2012				
		Method (A)		Method (B)			Method (A)		Method (B)		
Country / region	River	z	S %	z	S %	%0+ of popn	z	S %	z	S %	%0+ of popn
IoM	IOMA						**-0.277**	**76**	-0.485	62	52
Gallo	FLEE						**-0.733**	**48**	-0.854	43	71
Gallo	LUCE						**-0.866**	**42**	-0.760	47	36
Gallo	NITH						**-1.011**	**36**	-0.756	47	21
Gallo	BESK	**-1.222**	**29**	-0.980	38	29	**-1.424**	**24**	-0.894	41	18
Ire	BAND						**-2.730**	**7**	-1.269	28	44
Ire	SLAN						**-2.234**	**11**	-1.982	14	84
Ire	DEWR						**-1.576**	**21**	-1.541	21	85
Ire	BOYN						**-1.482**	**23**	-1.391	25	78
Ire	ARGI						**-1.639**	**19**	-1.263	28	53
Ire	CAST						**-1.619**	**20**	-1.753	17	84
Ire	CURR						**-0.519**	**60**	-0.549	58	36
Ire	SHIM						**-1.126**	**32**	-1.399	25	85
NW.E	RIBB	**-1.012**	**36**	-0.621	54	10	**-1.187**	**30**	-0.430	65	16
NW.E	EHEN						**-1.282**	**28**	-1.374	25	78
NW.E	LUNE	**-0.735**	**48**	-0.586	56	20	**-1.094**	**33**	-0.740	48	8
Wal	TAWE						**-0.481**	**62**	-0.417	66	31
Wal	CONW						**-1.040**	**35**	-0.919	40	47
Wal	CLWY	**-0.737**	**48**	-0.852	43	66	**-0.575**	**56**	-0.965	38	73
Wal	TEIFI	**-0.750**	**47**	-0.890	41	74	**-0.613**	**54**	-0.568	57	29
Wal	DEEw	**-0.963**	**38**	-0.926	40	48	**-0.980**	**38**	-0.895	41	42
Wal	DYFI	**-0.946**	**39**	-0.757	47	19	**-1.066**	**34**	-0.658	52	9
Wal	TYWI	**-0.811**	**44**	-0.738	48	42	**-0.781**	**46**	-0.582	56	21
NW.E	KENT	**-0.741**	**48**	-0.570	57	23					
Wal	DWYFAWR	**-0.990**	**37**	-1.205	30	80					
	Mean (repeats)	-0.897	41.3				-0.965	39.5			
	SD	0.172	6.7				0.292	11.5			

The overall average annual survival rate in the 23 Irish Sea rivers in the recent (CSTP) period, pooling data across rivers was 39%. Comparing those rivers sampled in both periods, the previous and recent survivals were 36% and 42% respectively, which were not significantly different.

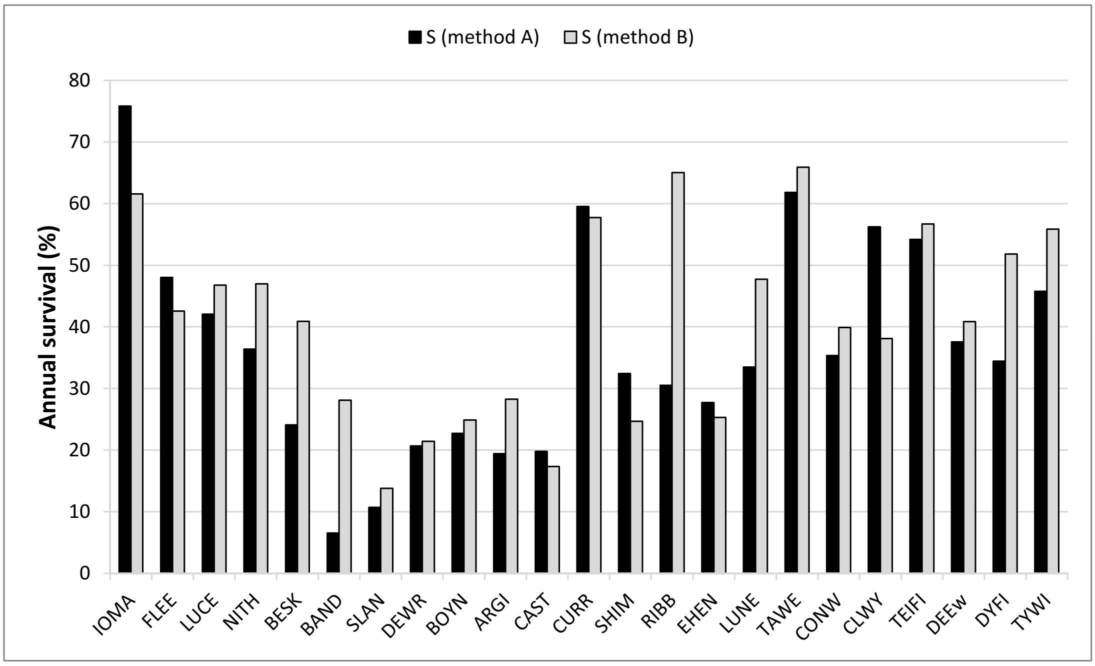


Figure 7.6.4 Comparison of % annual survival rates for 23 rivers in the Irish Sea, using methods A (black bars) and B (grey bars), see text for details.

The survival rates showed substantial river-specific differences and some evidence of between-region variations (Figure 7.6.3). In the Irish set the Currane stands out with a high survival rate of nearly 60%, compared with values nearer 20% for the Dee/Whitewater, Boyne, Argideen, and Castletown. The Slaney was very low at 10% and the lowest was the Bandon (7%), but the data were very few for the Bandon (Table 7.6.2) and that value (probably the Slaney too) is considered suspect. Unlike the Bandon, the other Irish rivers gave similar values using methods A and B, further suggesting that 7% was not an acceptable measure of sea trout survival in the Bandon. Survival elsewhere was higher than in the Irish (ex. Currane) rivers. The Isle of Man group returned highest survival (>76%) and the Welsh Dee was comparatively low (23%). The Dee calculations were repeated with the Dee trap abundance data (supplied by the EA) and gave consistent values (Figure 7.6.5) using method A of mean S% for years 2010, 2011 and 2012 of 43%, 37% and 41%, and when pooled (i.e. equivalent to the CSTP data set) gave a survival of 38%. It was concluded that the CSTP scale set was unrepresentative of the Dee population. For which a survival value of 38% was regarded as more likely than 23%. This is a further example of the caution needed in deriving and interpreting population data from comparatively small scale samples.

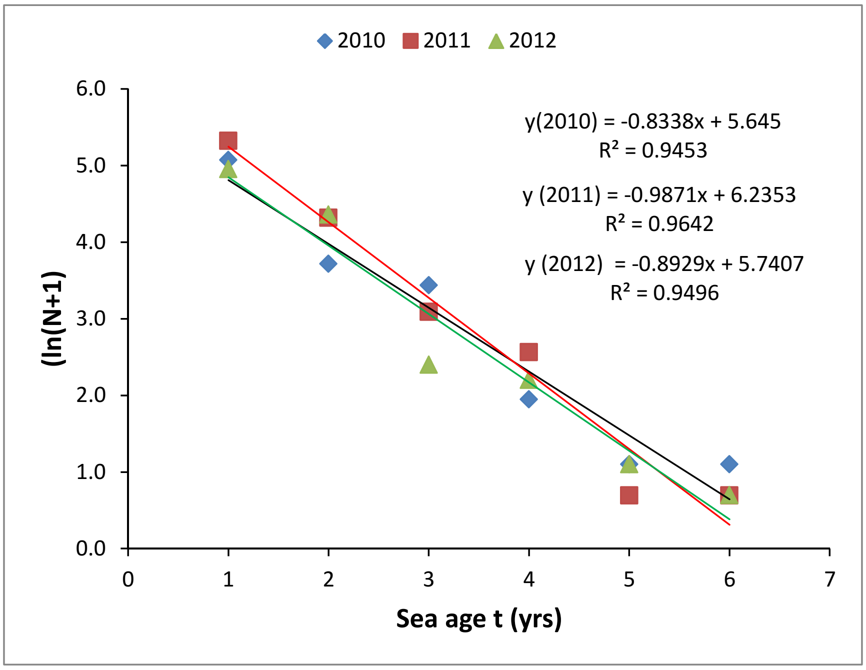


Figure 7.6.5 Sea trout survival in the River Dee, over three years, based on trap data (data from Ian Davidson).

Survival was not statistically associated with latitude, but mean annual survival in the west coast rivers (omitting Currane and Bandon) (mean= 21%, SD=7.0, n=6) was significantly lower (t-test, P=0.0004) than those of the east coast (mean 42%, SD=15.1, n=15).

As noted above the comparison of between-river variation in loss rates based on the scale data alone should be with caution. Nevertheless because of the rather consistent patterns across rivers the conclusion of lower survival in most of the Irish coast rivers compared with rivers on the east side seems sound. The obviously fewer age classes, even with comparatively low sample sizes (Table 7.6.2), was itself indicative of lower annual survival in those Irish rivers.

Comment on Survival

The method to estimate annual mortality (z) assumes that it remains constant after the first post-smolt year, which whilst appearing visually consistent with the data, may be a simplification of reality. In practice, marine survival is likely to vary with age and size (as fish move through different predatory fields, their optimal prey size and availability change systematically), between years as environmental conditions including prey availability (Kallio-Nyberg *et al*., 2006) vary and with effects of senescence, if these apply. In Atlantic salmon and sea trout the mortality rates of post-smolt in the first weeks after sea entry have been shown to be high and critical to later recruitment (McCormick *et al*., 1998; Kallio-Nyberg *et al*., 2006). This early phase mortality is probably due to a combination of predation (Dieperink *et al*., 2002) and prey availability (Kallio-Nyberg *et al*., 2006); both processes are related to smolt size which is positively correlated with survival in hatchery reared salmon (Salminen, 1997) and sea trout (Kallio-Nyberg *et al*., 2006). Although caution has been raised about transferring results from hatchery to wild fish, the strong likelihood on the basis of conventional biological theory is that survival is positively related to size in wild fish, up to senescence.

Berg and Jonsson (1990) reported survival rates in sea trout from the Vardnes river in northern Norway, showing that about 37% of whitling survived their first stay at sea (about 70 days duration) compared with 56-68% in repeat migrants (previous spawners). Annual minimum survival was 25% for first time migrant (whitling), 37% for second time migrants (n.n1SM+) and 50% for older fish, indicating that in that population survival rate increased with age. At least the likelihood is that survival in the first sea year is lower than in later years, when constant marine S might be acceptable approximation, but the data for most rivers in the CSTP study were not suitable for testing this.

There is a potential conundrum in the evaluation of mortality using catch curves for sea trout, because a disposition to early return as whitling would have the inevitable consequence of higher abundance (catch) of .0+ fish and hence, if they were included in the analysis, a higher apparent loss rate (z). This was removed or minimised in the analysis by estimating z omitting the 0-yr sea age group (method A). After this adjustment there was still an association between the incidence of whitling and higher post 1yr marine S in the rivers of SE Ireland, indicating that, spatially between rivers, there was a genuine association between those two life history traits (early maturation and low sea survival).

7.6.3 Abundance, Survival and Maturation of Whitling In The Welsh Dee, 1994 to 2009

As discussed above, survival rate variations directly influence population structure. It was not possible to describe and investigate these processes in detail on most rivers within the CSTP because they require good, precise and unbiased estimates of population size and age structure. Such data are available for the River Dee, North Wales through the Dee Stock Assessment programme (Davidson *et al*., 2006b). This section describes how this can be done given suitable data. A key element of sea trout population modeling/life-table analysis lies in understanding processes of growth, maturation and mortality in the post-smolt phase, not least because much of this phase occurs in the marine environment where such information is hard to get, even on the best monitored rivers.

Trapping, tagging, run and mortality data from the Welsh Dee are used to explore the maturation schedule of whitling (.0+) sea trout. This run group comprises large numbers of fish which return to the river in their first summer and go on to spawn. However, it also includes a lesser component which runs the river at the same time and (from scale reading) doesn't appear to spawn in the first winter but returns again to spawn either as .1+ or, rarely, .2+ maiden fish. Finally, a third group of fish from the same cohort remains at sea throughout their first year and returns to spawn for the first time as .1+ or .2+ maidens.

Run estimates for (i) whitling (.0+) which return in their first summer and (ii) older (>.0+) sea trout, were obtained on the Dee from mark-recapture – with fish trapped and tagged each year (n) at Chester Weir and recaptured at the same site the following year (n+1) as previous spawners (Davidson, Cove and Hazlewood, 2006). The .0+ component dominated returns, with run estimates over the last 20 years (1991-2010) averaging ~8,200 fish compared to ~1,800 for >.0+ fish. Ageing information from scale reading is used to further divide >.0+ estimates into separate sea age components.

The schematic in Figure 7.6.6 identifies sea age groups recorded on the Dee up to a total sea age of 3 years. For groups circled with a dashed line, run estimates are absent or include only part of the population. For example, for .0+ fish, run estimates are directly available only for fish returning in their first summer (based on recaptures of .0+SM+ fish the following year). As described above, this group is largely made up of fish that go on to spawn in their first winter, but it also includes smaller numbers which will eventually spawn as .1+ or even .2+ maiden fish. Actual numbers of fish tagged aged .0+ and recaptured one year later aged .0+SM+ or .1+, or two years later aged .2+, are shown in Table 7.6.4 These numbers represent average numbers tagged and recaptured over the period 1994-2009 and raised for trap efficiency in the year of recapture.

In order to estimate what the single fish recaptured aged .2+ (Table 7.6.4) would have represented in terms of tagged .1+ fish alive a year earlier, a common daily instantaneous loss rate (‘Z1 to 2’) of 0.0046706 has been applied for fish moving from total sea age group 1 to group 2 (Figure 7.6.6). This common loss rate was identified by analysis of covariance of loss rates from all sea age group transitions in this category derived from the full time-series of total population estimates. *[Similarly, although not used in this example, a common daily instantaneous loss rate (‘Z2 to 3’) of 0.0039768 was also identified by analysis of covariance for fish moving from total sea age group 2 to group 3]*

The derivation and application of instantaneous daily loss rates (or “coefficients of mortality”) is described in Bagenal (1978). For the purposes of this calculation, mean (observed) return dates of 1329 and 1706 days from an assumed 1st November spawning date have been used for fish of total sea age 1 and 2 (this also assumes that all fish emigrated to sea as 2-year old smolts). Applying the ‘Z1 to 2’ loss rate, then the single fish recaptured aged .2+ would have been equivalent to ~7 fish a year earlier at age .1+.

As the complement of recaptured fish of total sea age 1 is now complete at 98 fish aged .0+SM+ fish and 22 plus 7 fish aged .1+ (127 fish in total); and the total number of tagged fish aged .0+ is known (1,122 fish in total); then the daily instantaneous loss rate (‘Z0 to 1’) can be estimated for fish moving from sea age group 0 to 1. This loss rate (expressed as an average of all years) is 0.0067826 and is based on mean return dates at total sea age 0 and 1 of 993 and 1329 days after spawning, respectively (Figure 7.6.6).

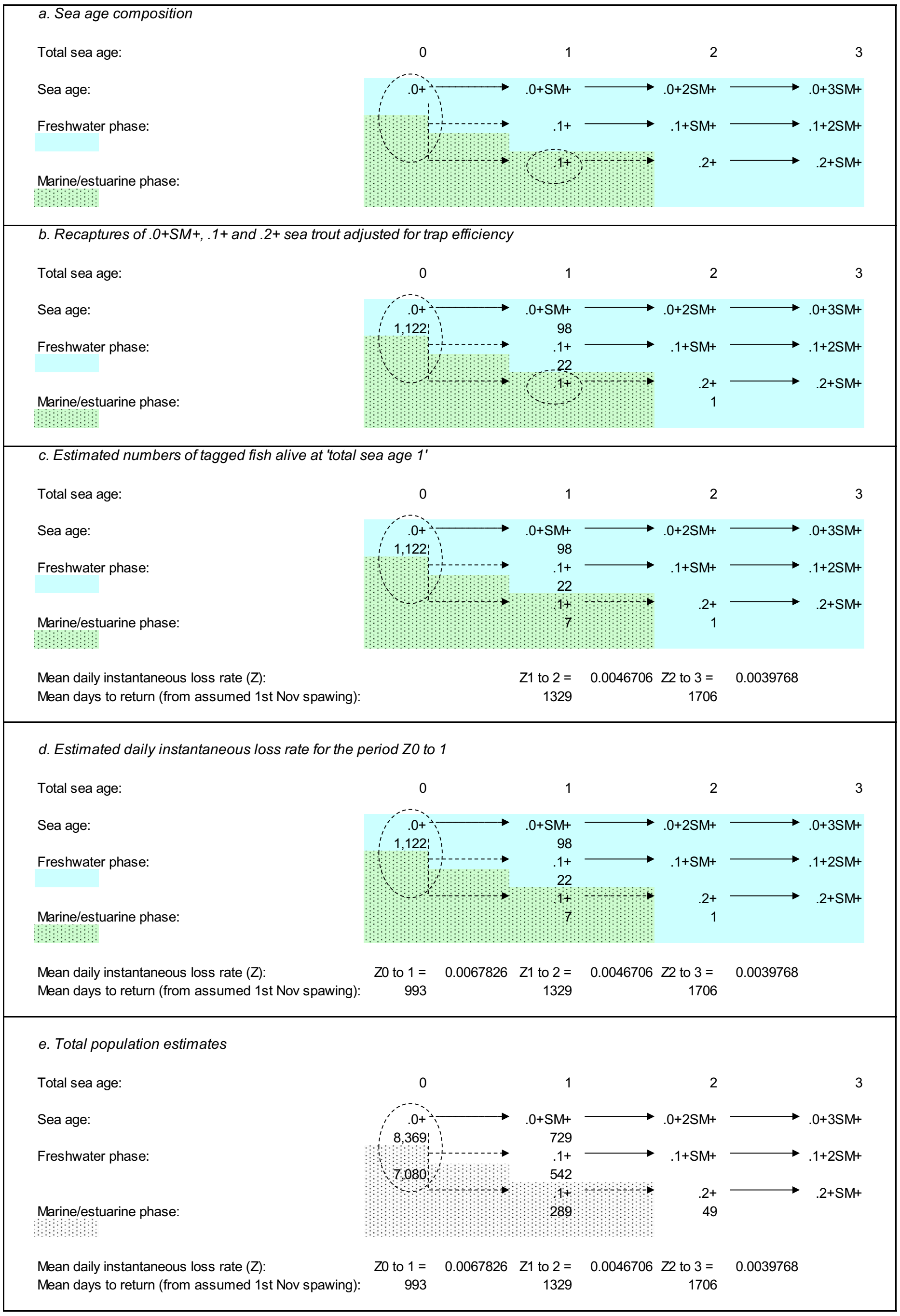
Table 7.6.4 Tagging and recapture details and maturation rate estimates for whitling (.0+) sea trout sampled on the Welsh Dee at Chester Weir, 1994-2009.

Year (n) tagged as .0+	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Mean
Number tagged as .0+	968	880	1069	1061	1388	905	602	1704	1246	1199	1428	1953	1448	597	939	565	1122
Recaptures adjusted for tagging year:																	
.0+SM+	42	33	38	47	35	28	18	40	30	33	39	43	36	12	4	16	31
.1+	31	11	17	19	7	4	5	2	2	2	3	1	2	2	0	2	7
.2+	0	0	2	0	0	1	0	0	1	0	0	1	0	0	0	0	0
Total	73	44	57	66	42	33	23	42	33	35	42	45	38	14	4	18	38
Recaptures adjusted for trap efficiency:																	
.0+SM+	119	73	118	186	102	99	59	153	102	77	96	164	120	42	20	44	98
.1+	94	24	52	77	19	14	16	8	7	5	7	4	7	7	0	6	22
.2+	0	0	9	0	0	3	0	0	2	0	0	4	0	0	0	0	1
Total	213	96	180	263	122	116	75	161	111	82	103	171	127	49	20	50	121
Raised recaptures adjusted to common return date (1329 days after 1st Nov spawning):																	
.0+SM+	119	73	118	186	102	99	59	153	102	77	96	164	120	42	20	44	98
.1+	94	24	52	77	19	14	16	8	7	5	7	4	7	7	0	6	22
.2+	0	0	66	0	0	17	0	0	13	0	0	19	0	0	0	0	7
Total	213	96	236	263	122	130	75	161	122	82	103	187	127	49	20	50	127
%Maturation as .0+SM+	56.1	75.5	50.2	70.8	84.3	76.0	78.4	95.3	83.7	94.4	93.1	87.7	94.7	85.8	100.0	88.0	82.1

Finally, utilising loss rates ‘Z0 to 1’ and ‘Z1 to 2’, and, known population estimates (long term average estimates are used in the example in Box 1e) then a figure for the number of .0+ fish which remain at sea and do not return in the first summer can be derived. For the long-term (1994-2009) average state on the Welsh Dee this equates to 7,080 whitling at sea compared to 8,369 that return to the river in their first summer; i.e. 45% and 55% of the total .0+ population, respectively. *[Note that, the instantaneous daily loss rates used in deriving these estimates are, unavoidably, based on groups of fish which are post-spawners. As such, they are likely to be higher than loss rates experienced by the equivalent groups of maiden fish which remain at sea and, as a consequence, the numbers of whitling which remain at sea during their first summer may be over-estimated - although the extent to which this is the case is difficult to quantify.]*

Numbers of fish tagged and recaptured by sea age group, including adjusted recaptures as described above, are given in Table 7.32 for the years 1994 to 2009 (this updates a similar Table given in Davidson *et al* 2006). Maturation rates for whitling are also given in Table 7.6.4; these averaged ~82% overall for fish returning in their first summer.

Figure 7.6.6 Estimates of whitling (.0+) sea trout abundance on the Welsh Dee; tagging years 1994 to 2009.



7.6.4 Grouping of Some Life History Features

In previous sections attention was drawn to the broad scale geographical variation (measured in latitude, and east west location in the Irish Sea) in certain derived variables such as length at age (particularly of .0+), mean smolt age and average lifetime survival rates and the main environmental variable (water temperature). Tree regression (Crawley, 2009) offers one way to summarise simply and visually some of these relationships. This was applied to the data set for the 23 rivers using the CSTP data described above. Tree models using R (R Core Team, 2014) were devised for mean fork length (mm) at age 0 (L0.av), as the most variable and informative metric of marine growth, and for % annual survival (S.A). The data used are shown in Figure 7.6.7.

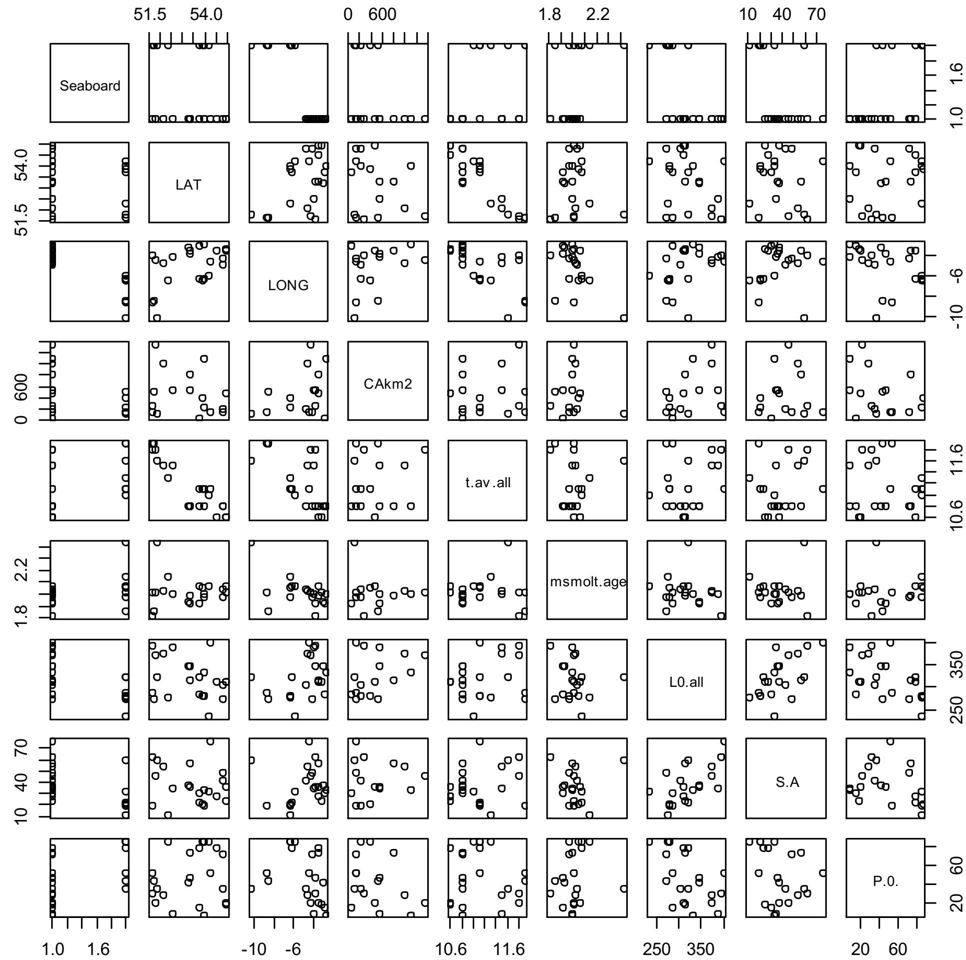


Figure 7.6.7 Pairwise correlations for the variables used in the tree regression analysis. Sea board = east or west; LAT=latitude; LONG=longitude;CAkm2=cathment area (Ha); t.av.all=sea surface temperature; msmolt.age=mean smolt age; L0.all=mean length (mm) of all .0+ fish; S.A=% annual survival; P.O= proportion of .0+ fish.

L0.all was found to be split initially on an east-west basis, giving mean length of 284.0mm for the western (Irish) rivers (Figure 7.6.8). Of the eastern side rivers, those north of latitude 53.309 had a mean length of 304.6mm and the remaining more southerly east side rivers had a mean length of 370.2mm.

For survival (Figure 7.6.9), the model showed a first split on the basis of L0.av, with the smallest length group having lowest survival (mean S.A =27.69%). Of the group of larger sized fish, those fish that experienced (putatively – we do not know their actual temperature history) higher water temperatures (>11.15^{o}C) had the highest survival of 51.16%. This group comprised the South and Mid Wales rivers. The remaining more northerly rivers, with lower mean temperature, had an intermediate mean survival of 40.70%.

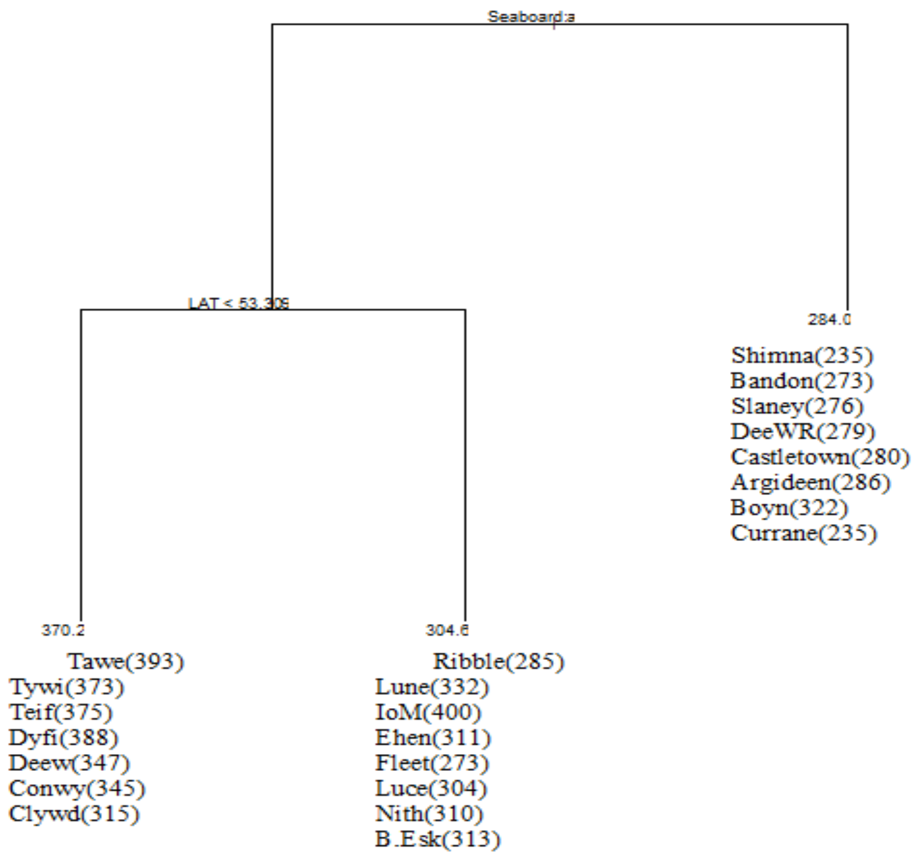


Figure 7.6.8 Tree regression model for mean length (mm) at sea age 0 for 23 rivers in the Irish Sea (including the Currane). Rivers grouped in each category are shown with their mean L0.av lengths. The first node (seaboard) is either west or east coast of the Irish Sea, the second is latitude.

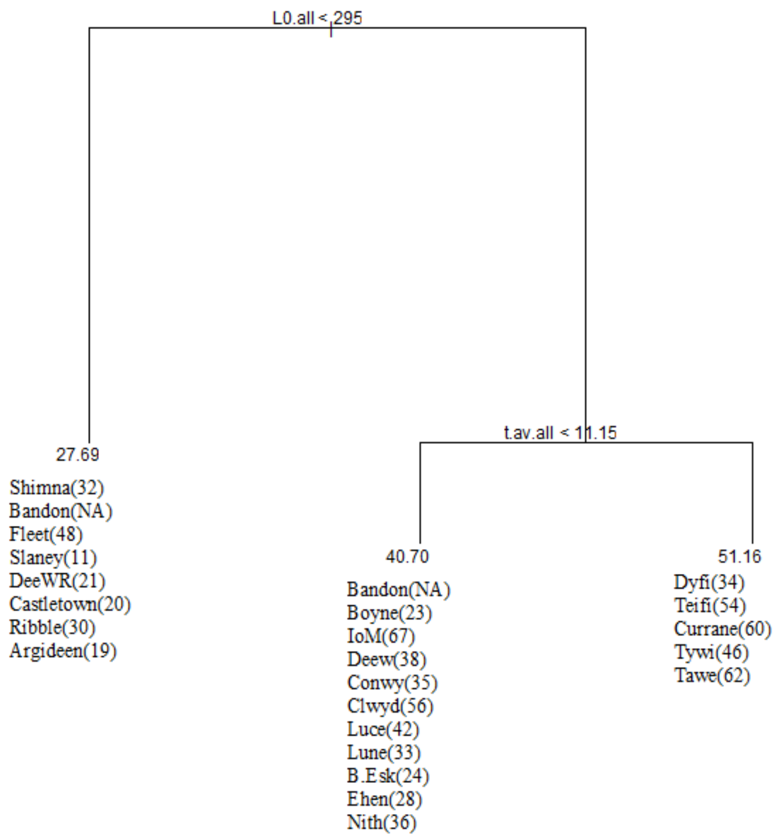


Figure 7.6.9 Tree regression model for mean annual survival (from Table 7.nn) for 23 rivers in the Irish Sea (including the Currane). Rivers grouped in each category are shown with their mean % annual survivals. The first node is size and the second is mean annual sea temperature (^{o}C).

Such procedures are a convenient way to group rivers, but do not necessarily convey causality and are sensitive to the variables entered into the analysis, the errors of the various metrics and collinearity amongst them. Here variables were chosen through trial and error to minimise such affects. As noted above there are a few major exceptions such as the Currane which grouped with the south and mid Wales rivers, clearly contrasting with the majority of the Irish coast CSTP rivers which lie on the east and south east Irish coast.

7.6.5 Matrix projection modelling[1]

7.6.5.1 Introduction

One of the aims of the CSTP was to develop life history based population dynamics models to better understand the biology of sea trout, and its variance among populations around the Celtic and Irish Seas, which could have practical applications to fisheries management and conservation of this valuable wildlife resource. Key life history traits include age- or stage-specific survivorship, somatic growth, maturation rate, and fecundity, population genetic structuring and connectivity, which control population recruitment, rates of population growth and age structure and thus ultimately fisheries attributes of catch size and composition. The applications of these models, if they prove practicable with the available information, include estimating the effects of variables, such as environmental characteristics, genetic traits, and fishing regulations and conservation policies, which are likely to alter population dynamics parameters.

Using the data collected during the CSTP, the aim of this report is to analyse the variance among rivers in population demographic dynamic parameters of the anadromous contingent (sea trout) of some of the trout populations studied by the CSTP. When modelling population demographics, it is important to choose the variable with the largest influence on the demography (Caswell 2001). For many organisms, age is a critical variable determining onset of reproduction, fecundity and senescence. For others, size or developmental stage are more critical in determining fecundity or survival. In sea trout both stage (parr age, number of full years at sea, and number of years as a spawner) and size are critical in determining reproduction onset, fecundity and mortality, more so than age *per se*. Hence a stage based model was employed. Stage models allow individuals remaining in a stage for more than one year (i.e. a parr spending 2 years in fresh water), or jumping stages (e.g. a whitling which returns before spending a winter at sea, can spawn without going through a sea winter phase). Such flexibility allows modelling the complexity in life history patterns found in sea trout previous to reproduction onset, and preserves the variance among populations in the length of time from fry to first reproduction. The increase in fecundity as sea trout age is captured by having several spawning classes as stages, as many as the oldest fish encountered in a population, which behave as an age model, i.e. individuals have to proceed to the next stage and cannot jump stages.

Matrix projection models were developed using stage specific approaches with stages defined by the re-created life history based on the scale reading, *viz*: number of years in freshwater (FW), number of full years at sea as maiden fish (sea winter stage: SW; .0+,.1+,.2+), number of full years at indeterminate stage (IM, as for SW), number of years as spawner (SM*n*, where *n*= the number of previous spawning events), and dead (D). The analysis was based on those individuals for whom age, life history, and fecundity could be estimated. The age and life history were estimated from scales collected at the time of capture. The scale reading methodology is described in the CSTP report, but in summary, life history events were inferred from the number of winter and spawning marks encountered on the scales. Fresh water winter marks can normally readily be distinguished from sea winter and spawning marks. However, the distinction between the latter two can sometimes

[1] *This section was based on analysis carried out with the funding support of the Atlantic Salmon Trust and reported to the AST Honorary Scientific Advisory Panel (see Tysklind et al., 2015). The section is reproduced with kind permission of the AST.*[1]

be ambiguous: scale erosion may be limited, or only present on the shoulders of the scales. There is discrepancy among expert sea trout scale readers on the interpretation of these scale features, and there are several observed life events that could explain such incomplete erosion including erosion at sea, partial migration to estuary, migration to river without spawning, and actual spawning. Aiming to manage such ambiguity, marks of uncertain origin (sea winter/spawning) were classified as indeterminate marks (IM). (See Section 7.3.1 for further detail). For population dynamics, IM marks could be considered as sea winters, thus not spawning, or as partial spawners in which a fraction of the individuals recorded as IMs are true spawners. The following analysis considers IMs as non-spawning, but it is possible to do a parallel analysis where IM are given a reduced fecundity compared to SM1 (i.e. a percentage equal to that of the proportion of IM believed to be true spawners).

7.6.5.2 Materials and Methods

Data Description, Variable Management

The initial dataset contained 20,902 individuals for which there was a maximum of 116 variables, although many of them were only collected for subsets of individuals (i.e. sex data only collected for some adult sea trout). The variables river and marine zone were given a specific geographical order: starting from the west of Ireland, around the Irish Sea, and finishing in the south east of Wales Figure 7.6.10). All sea trout collected from the three rivers in the Isle of Man were combined into a single composite sample (IOM). The sequence of months from January to December was specified for the variable Month. All missing data was set to NA.

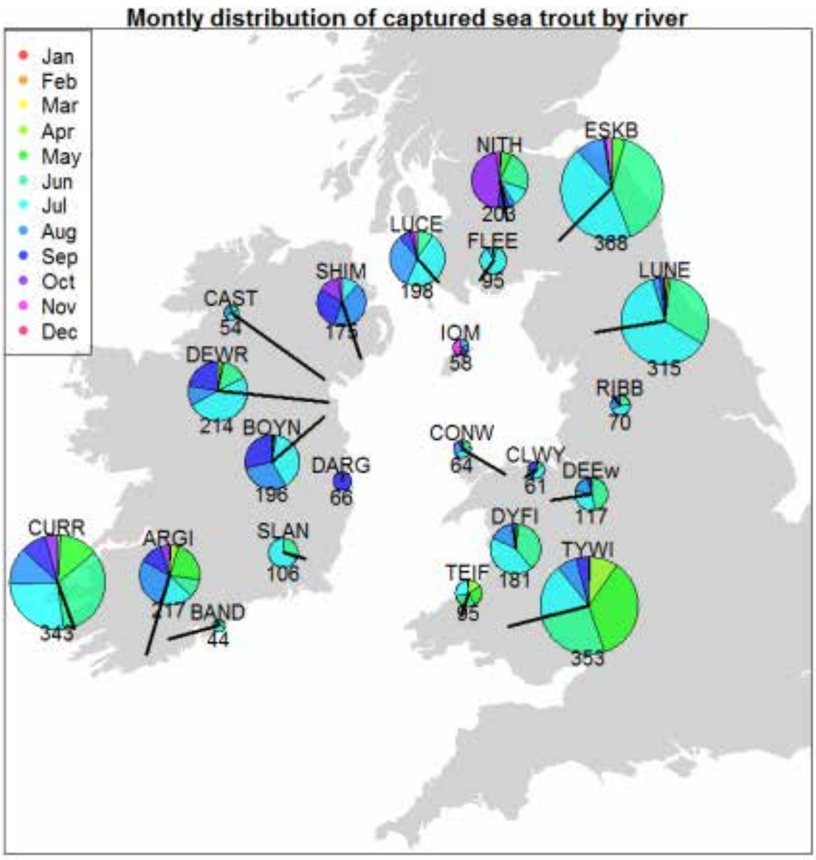


Figure 7.6.10 Monthly distribution of captured sea trout by river. Monthly proportions are depicted as pie charts coloured by month. River codes are indicated above pies, while sample size numbers are below pies

Data Checking

Sea trout weight and length measurements were collected fresh, thawed, or both fresh and thawed. The individuals with both fresh and thawed measurements were used to inspect the effects of freezing and thawing on the weight and length measurements (N=1295 for weight; N=1603 for length). For some of these individuals the relationships between fresh and thawed measurement was very skewed and are most likely due to data input errors (Figure 7.6.11). These outliers were removed by creating an index (fresh/thawed) for each individual, assigning a standard score (z-score) to each index, and removing individuals with standard scores over 2 and below -2.

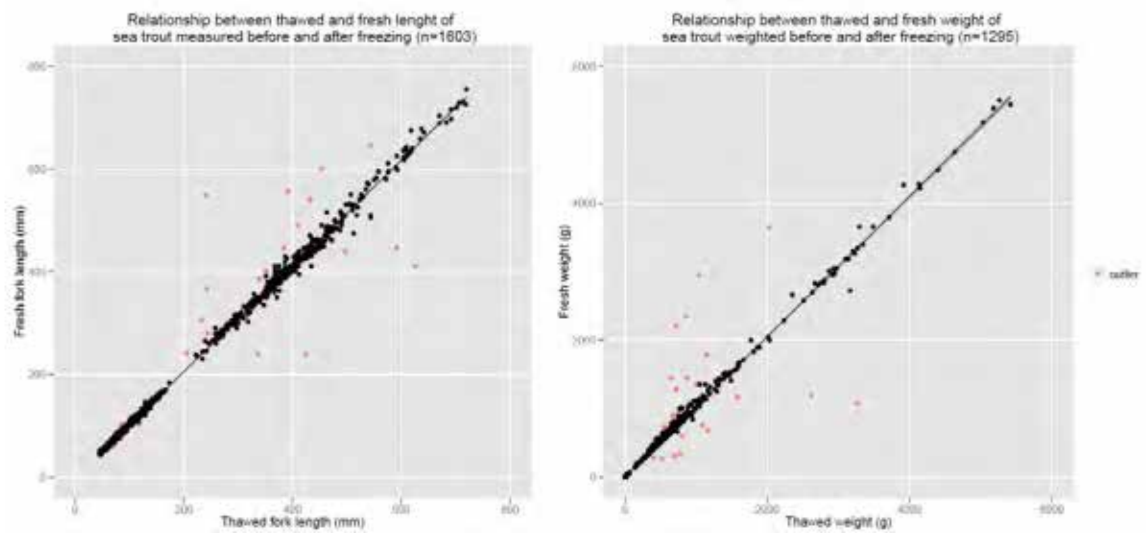


Figure 7.6.11 Relationship between thawed and fresh length and weight of sea trout.

Models predicting fresh measurements from thawed measurements were constructed from the remaining individuals and used to estimate fresh measurements for all individuals with only thawed measurements (N=2699 for weight; N=2405 for length):

$$W_{estimated}(g) = 2.526 + 1.032 * W_{thawed}(g)$$

$$L_{estimated}(mm) = -0.2195 + 1.0294 * L_{thawed}(mm)$$

The relationship between length and weight of adult sea trout (N=9753) was also studied to check for input errors. Some individuals had no data for either length or weight (N=2772) or had unlikely lengths for an adult (< 50 mm; N=3) and were thus not included for evaluation of the weight-length relationship. k-factors were calculated for all remaining individuals (N=6979).

$$k = \frac{W * 100000}{L^3}$$

Each k-factors was assigned a z-score, and only individuals with z-score between -1 and 1.8 were considered to be realistic (N=6839; Figure 7.6.12; 140 individuals removed). The standard values of -2 and 2 were not considered to be stringent enough, as many obvious entry errors remained when using two standard deviations. The difference in upper and lower cutting values is due a more stringent cutting needed at the bottom of the distribution. The trimmed dataset was used for all analysis involving weight or length.

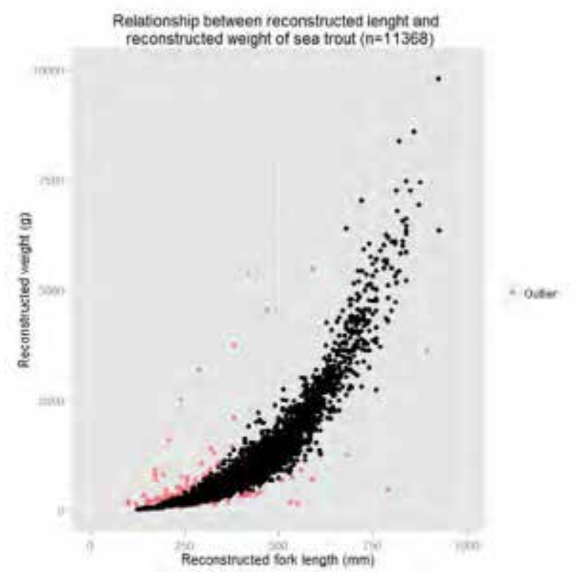


Figure 7.6.12 Relationship between reconstructed length and reconstructed weight of sea trout.

Of the individuals included in the trimmed adult dataset, 4965 had ageing data. However, ages derived from scale readings were sometimes flagged as unreliable (e.g. mismatch between scales, patterns too unclear, or very unlikely age for size), and individuals with clearly unreliable ages were excluded from the adult aged dataset (N=4710; 255 individuals removed).

Life History Reconstruction

The CSTP population genetic analysis, based on 18 independent microsatellite loci, revealed that sea trout from different rivers around the Celtic and Irish Seas are all independent populations exchanging few migrants among themselves, therefore, the returning adults from each river were analysed independently as separate populations. The life history of each individual was reconstructed based on the year of capture and the ageing formula. For example, a 2.1+3SM+ sea trout is captured in 2012 on its way up to its spawning grounds. Based on the ageing formula, said sea trout was born in 2006, it stayed in fresh water during the summer of 2007, it smolted and spent a summer and winter at sea in 2008, and then spawned in 2009, 2010, and 2011. As all individuals were caught on their way up to spawning grounds, they were all assumed to contribute to the eggs produced on the year of capture (i.e. 2012) and then die before the next spawning season (i.e. 2013). Such an assumption may exaggerate the number of eggs produced each year, as some individuals may not reach the spawning grounds. However, the alternative, assuming that all captured fish die and do not contribute to the next spawning event, creates an even more unrealistic effect where: 1) all individuals returning for the first time (whitling) do not contribute to the next spawning event; and 2) undermines the importance of repeat spawners, as the increase in fecundity associated with their larger size in their latest effort to reach the spawning grounds is not accounted for. Furthermore, the individuals caught are only a sample of the population, which should be representative of the remainder of the population. Thus, assuming successful reproduction for caught individuals should resemble the fate of the remainder of the population. Similarly, assuming that all caught individuals die after the next spawning event may seem drastic, as obviously some individuals will return the following year as repeat spawners. Nevertheless, assuming all caught individuals die, allows the between-spawning events survival rate to be be estimated effectively from the frequency of repeat spawners in the dataset (those individuals that are known to have survived to a certain age).

Construction of Population Specific Individual Size at Age Somatic Growth Model

The fecundity of females is dependent on their size (length or weight), and thus, the lifetime egg contribution of a female to a population will be dependent on its size each time it spawned. Von Bertalanffy models such as:

$$L_t = L_\infty\left[1 - e^{-K(t-t_0)}\right]$$

were constructed based on the distribution of the total age / length relationship. The length at age relationship varies among rivers and regions, and thus, to avoid losing important river specific growth traits that may influence the dynamics of the population, river specific models were constructed for each river. Variance among life strategies can be observed on the length at age graphs if the different combinations of sea winters and spawning marks are highlighted (Figure 7.6.13). In the example from the river ESK (Border), trout returning in their third year of life (total age=2) are larger a winter has been spent at sea (triangles) compared to those who have gone to sea for a few months in summer (circles); while total age 4, individuals who have already spawned (yellow) are larger than those who have not spawned (blue). The variance among life strategies has an important effect on the relationship of length at age, but creating independent somatic growth models for each life strategy (n=87) would be impractical. Instead, river specific somatic growth models combined with individual corrections were employed. The individual difference between fitted and real values at capture was used to calculate an individual percentage of divergence from the somatic growth model. It was assumed that if a sea trout was 12% larger than predicted on the year of capture, then that sea trout would have been 12% larger throughout its life. These somatic growth models were then used to reconstruct the length of individuals in previous years until age 1.

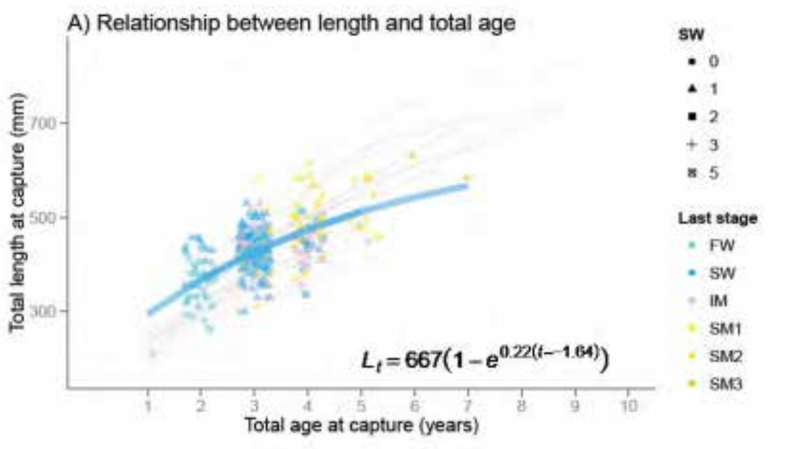


Figure 7.6.13 Relationship between length and total age for the River ESK (Border)

Effect of Sex on the Data

The effect of sex on size at age was examined through analysis of covariance (ANCOVA) to evaluate if different somatic growth models were needed for each sex.

Estimation of Fecundity

The length to egg production relationship estimated in Section 7.5.3. was used to calculate individual fecundity.

$$Fecundity = 2.1023 * L - 2.3029$$

The fecundity relationship was constructed based on 55 individual females captured on several marine zones of the Irish and Celtic Seas. The individual reconstructed lengths were only translated into fertilities if a spawning mark (SM) was identified for that individual on that year (Table 7.6.5). The final population recreated life history table is a stacked list of the recreated annual life history events for every individual (Table 7.6.5), with estimated back calculated lengths and associated fecundities, which allows estimating the number of individuals spawning and the eggs produced every year based on our sample.

Table 7.6.5 Extract of the recreated life history table for five individuals from the River CURRANE.

Id	Year	Stage	Total age (years)	Length (mm)	Fecundity
I-CURR-10-037	2006	FW	0	211	0
I-CURR-10-037	2007	FW	1	306	0
I-CURR-10-037	2008	FW	2	397	0
I-CURR-10-037	2009	IM	3	485	0
I-CURR-10-037	2010	SM1	4	570	3096
I-CURR-10-037	2011	dead	5	651	0
I-CURR-10-038	2007	FW	0	184	0
I-CURR-10-038	2008	FW	1	268	0
I-CURR-10-038	2009	IM	2	348	0
I-CURR-10-038	2010	SM1	3	425	1670
I-CURR-10-038	2011	dead	4	499	0
I-CURR-10-039	2003	FW	0	186	0
I-CURR-10-039	2004	FW	1	270	0
I-CURR-10-039	2005	FW	2	350	0
I-CURR-10-039	2006	SM1	3	428	1695
I-CURR-10-039	2007	SM2	4	503	2377
I-CURR-10-039	2008	SM3	5	574	3147
I-CURR-10-039	2009	SM4	6	644	3996
I-CURR-10-039	2010	SM5	7	710	4912
I-CURR-10-039	2011	dead	8	774	0
I-CURR-10-040	2007	FW	0	204	0
I-CURR-10-040	2008	FW	1	296	0
I-CURR-10-040	2009	IM	2	385	0
I-CURR-10-040	2010	SM1	3	470	2064
I-CURR-10-040	2011	dead	4	552	0
I-CURR-10-043	2004	FW	0	185	0
I-CURR-10-043	2005	FW	1	268	0
I-CURR-10-043	2006	FW	2	348	0
I-CURR-10-043	2007	IM	3	426	0
I-CURR-10-043	2008	SM1	4	500	2349
I-CURR-10-043	2009	SM2	5	571	3111
I-CURR-10-043	2010	SM3	6	640	3949

In the above table (Table 7.6.5), the first individual, I-CURR-10-037, was captured in 2010 as a 3.1IM+ returning to spawn for the first time with a length of 57cm. The first six records on the table refer to such individual, and indicate the stage, back calculated length and associated fecundity in 2010 (the first time the individual was about to spawn), the projected final state of dead in 2011. Individual I-CURR-10-039 was captured as a 3.0+4SM+ in 2010, hence it has 5 years where this individual spawned, the 4 previous to capture and the one it was captured on (2010 = SM5).

Construction of Population Specific Transition Matrices

Construction of the transition matrices and analysis of the population demographics was done with the analysis package *popbio* (Stubben & Milligan 2007) for R (R Development Core Team 2014). Transition (Table 7.6.6) and fecundity (Table 7.6.7) matrices were constructed based on the recreated life histories using *popbio*. Each matrix values is estimated based on the proportion of individuals in stage *a* (indicated along the top of the matrix) entering stage *b* (indicated on the left of the matrix) recorded on the recreated life history tables. Thus transition values indicates the probability of an individual being in one stage going to another, while fecundity values indicate the numbers of new recruits generated on average by every individual in a particular stage.

Table 7.6.6 : Transition matrix from the River ESKB without mortality modifiers

$T	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.500	0	0	0	0	0	0	0
SW	0.352	0.029	0	0	0	0	0	0
IM	0.061	0.077	0.082	0	0	0	0	0
SM1	0.087	0.894	0.918	0	0	0	0	0
SM2	0	0	0	0.148	0	0	0	0
SM3	0	0	0	0	0.179	0	0	0
SM4	0	0	0	0	0	0.200	0	0
dead	0	0	0	0.852	0.821	0.800	1.000	0

Table 7.6.7: Fecundity matrix from the River ESKB without egg mortality modifiers

$F	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0	0	0	1663	2242	2573	3546	0
SW	0	0	0	0	0	0	0	0
IM	0	0	0	0	0	0	0	0
SM1	0	0	0	0	0	0	0	0
SM2	0	0	0	0	0	0	0	0
SM3	0	0	0	0	0	0	0	0
SM4	0	0	0	0	0	0	0	0
dead	0	0	0	0	0	0	0	0

Mortality cannot be estimated for all stages before first return of sea trout (FW, SW, IM) from the data available here, and thus a mortality modifier needs to be applied to the transition matrix. A standard annual mortality of 0.7 in fresh water and 0.95 at sea was applied to transition matrices of all rivers. Individuals which have returned to fresh water more than once can be used to estimate survival from one spawning event to another (i.e. transition rate from SM1 to SM2 based on all individuals who survived to SM2 compared to those present in SM1). The difference in the number of individuals who survived to SM2 compared to those present in SM1, can be obtained by adding an extra final stage (dead) to all individual life histories. Such final stage has no transition rates to any other stages. A modifier of 0.01 was applied to the fecundity matrix transition values to simulate the probability of egg survival to FW stage (1%). Such approach produces a matrix ready for demographic analysis through matrix projection using *popbio* (Table 7.6.8).

Table 7.6.8: Combined transition and fecundity matrix for the river ESKB with mortality modifiers

	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.150	0.000	0.000	16.594	22.189	25.273	35.455	0.000
SW	0.106	0.001	0.000	0.000	0.000	0.000	0.000	0.000
IM	0.018	0.004	0.004	0.000	0.000	0.000	0.000	0.000
SM1	0.026	0.045	0.046	0.000	0.000	0.000	0.000	0.000
SM2	0.000	0.000	0.000	0.148	0.000	0.000	0.000	0.000
SM3	0.000	0.000	0.000	0.000	0.179	0.000	0.000	0.000
SM4	0.000	0.000	0.000	0.000	0.000	0.200	0.000	0.000
dead	0.700	0.950	0.950	0.852	0.821	0.800	1.000	0.000

An introduction to measures of population growth

Many models of population growth are described for organisms (Gotelli 2008) and all are approximations of reality, as no model can really aim to explain the biology of a population exactly.

A basic outline of a differential equation is that that over a year the population size (N) changes by a combination of annual birth rate (b) and death rate (d), such that $dN/dt = (b - d)N$. Let $(b - d) = r$, r being a constant called the instantaneous rate of increase or intrinsic rate of increase, then $dN/dt = rN$. This is normally written as $N_t = N_0\, e^{rt}$, where t = time. If $r = 0$ the population will remain constant, if $r > 0$ it will increase to infinity, if $r < 0$ it will decline to extinction. For discrete time steps, $N_{t+1} = N_t + rN_t$, which rearranged gives $N_{t+1} = N_t(1 + r)$.

Let $\lambda = (1 + r)$, the population rate of increase, then $N_{t+1} = \lambda N_t$.

λ is a positive dimensionless (because it is a ratio) number that measures the proportional change in population size from one time step to the next (frequently measured in years). Thus, to find the population size in the following year (N_{t+1}) from that of the current year (N_t), simply multiply N_t by λ. It can be seen that if $\lambda = 1.0$ the population remains constant, if $\lambda < 0$ it will decrease and if $\lambda > 0$ the population will increase. For completeness, note that λ and r are related by $e^r = \lambda$.

A further important variable of population dynamics is R_0, the net reproductive rate, which can be interpreted as the mean number of female offspring by which a female will be replaced by the end of its life. Its units are number of offspring and intuitively if $R_0 = 1.0$ there is no population growth, because it exactly replaced itself, if $R_0 < 1.0$ the population decreases, and if $R_0 > 1.0$ then it increases. R_0 is positively related to λ, ($\lambda^{Gen.T} = R_0$, where $Gen.T$ is generation time), but they are intrinsically different: λ indicates the population growth per year, while R_0 the population growth per generation. R_0, and λ are often used as indices of population "fitness", the ability of the population to recover from perturbations and in turn related to population features of stability and resilience (Caswell 2001).

Population Demographics Modelling

Among the results of the matrix projection analysis, some of the most valuable information obtainable are the age-specific survival and the likelihood of reaching and staying in each stage.

These parameters are tabulated in the *fundamental matrix*, which was calculated from the projection matrix.

Eigen analysis of the transition matrices was used to estimate several population parameters:

- the **population growth rate** (λ), which is the dominant eigenvalue of the population transition matrix, and the **net reproductive rate**, (R_0). Two sources of uncertainty around λ values were evaluated: that due to which individuals are included in the estimation and that due to the number of individuals included in the estimation. 1) The variance in the life history of individuals included the modelling of population dynamics could have an effect on the estimated values of λ, hence 95% confidence intervals around values of λ were constructed based on bootstraps (n=1000) of the individual transitions included in the transition matrix (i.e. to evaluate the impact of not including all sampled transitions in each population). The number of transitions to be sampled was set to equal the number of transitions available for the population being analysed. 2) There was strong variance in the number of individuals per population, thus, to evaluate the effect of the variance among rivers in the number of individuals on the estimated λ, a second bootstrapping exercise (n=1000) was undertaken where the number of transitions resampled was fixed to 200, approximately 40 individuals with an average 5 transitions through their life time.

- The **generation time**, which can be interpreted as either the time needed for the population to increase by a factor of R_0, or the mean age of the parents of the offspring produced by a cohort over its life time.

- The **stable stage distribution**, which is the right eigenvector associated with λ, indicates the proportion of each stage in a population at equilibrium.

- The **stage specific reproductive value**, which is the left eigenvector associated with λ, indicates the potential reproductive contribution (mean number of offspring to be produced in its remaining lifetime) of an individual in a particular class.

- The **damping ratio** (ρ), which describes the relationship between the dominant eigenvalue (λ_1), and the second largest eigenvalue (λ_2) as $\rho = \lambda_1/|\lambda_2|$, and can be interpreted as the rate of convergence to the stable stage distribution. The larger λ_1 is compared to λ_2 (i.e. the higher the ρ value), the more rapid the convergence to stable stage distribution will be.

- Different life stage transitions have varying influences on population growth rate (λ), it may thus be interesting to know the impact on λ of augmenting each transition parameter (A_{ij}). Analysis of the **sensitivities of $\boldsymbol{\lambda}$** to additive perturbations of transition parameters (A_{ij} = survival, growth, and fecundity transitions) allows evaluation of the relative importance of each transition (A_{ij}) and how sensitive they are to additive perturbations.

- The **elasticity of $\boldsymbol{\lambda}$** measures the proportionality of the response of λ to proportional perturbations of transition parameters (A_{ij}). In other words, how tied is the response of λ to perturbations of a transition parameter (A_{ij}). It can also be interpreted as the transition's (A_{ij}) contribution to λ, as elasticities always add up to one. The elasticities of λ to transition parameters can be added by columns or rows to know the elasticity of λ to a particular stage. To evaluate the dependence of a population on the most basic life history strategy (FW -> SM1 -> FW, i.e. a 2.0+ whitling returning to spawn for the first time), the elasticities of the FW to FW, FW to SM1, and SM1 to FW were added up

(*E.minLH*). The remainder up to 1 was considered as the dependence of the population on alternative life histories (*E.altLH*), or as a measure of the complexity of life histories contributing to λ. To evaluate the elasticity of λ in each population to particular life history strategies of sea trout, we calculated the *elasticity of λ to the fresh water phase*; *the elasticity of λ to whitling* (the elasticities to the FW to SM1 transition); the *elasticity of λ to the sea winter phase* (sum of elasticities of λ to transitions involving SW and IM as start or final stage); *the elasticity for first time spawners* (elasticity of SM1 fecundity) and the *elasticity of λ to repeat spawners* (sum of elasticities of all repeat spawners). These five elasticities add to 1 as they include all transitions in the projection matrix. The relative importance of the summed elasticities of λ to perturbations in the whitling, sea winter phase, and repeat spawners is illustrated on ternary plots (triangular plots). Ternary plots allow depicting on a two dimensional space the contributions of three variables, each on one axis from 0 to 100%. The positioning of each dot (representing the sea trout population of a river) is determined by the percentage of summed elasticities of λ of each phase and can be understood as the relative contribution of whitling, sea winter phase, and repeat spawners to population growth rate. The plots have been focused on the range of values encountered in this study (*E.Whitling*= 30-100%, *E.SeaWinter*=0-70%, *E.RepSpawn*= 0-70%). For the among river comparative analysis, populations-specific traits such as population growth rate (λ), generation time, and damping ratio (ρ) were overlaid to understand the relationship between the frequency of alternative life strategies and population dynamics.

7.6.5.3 Results

The cleaned up dataset (N=4710) included individuals from 42 rivers and marine zones for which there were estimates of age, life history and somatic growth. However, the distribution of individuals among locations was heterogeneous (Table 7.6.9). Among the sea trout captured in rivers (N=3755), there were 87 different life history patterns Section 7.3.2 and Appendix A7.8, although the three most common life histories (2.0+, 2.1+, and 2.0+1IM) were found in 2338 individuals (62.3% of river caught sea trout).

Although the provenance of marine caught trout could be inferred through genetic and microchemistry assignment to river of origin, the marine samples were not included in the population dynamics assessment due to the uncertainty of whether they would remain at sea or spawn the following spawning season. Thus only sea trout caught within rivers were employed in the population dynamics assessment. Of the 25 rivers, 22 had at least 40 individuals sampled. Such a low number of individuals may not be enough to sample all the possible life history patterns that exist in a population, but should provide an indication of which type of life history strategy (sea winters, whitling, repeat spawners) dominate the population. To provide guidance on the confidence of the population dynamic modelling exercise, the samples sizes are indicated on the river specific summary plates.

The total age and age after year of smolting (sea age), was heterogeneous among rivers (Figure 7.6.14). For some rivers, like the BAND and CAST, the oldest fish only had a maximum sea age of two years, while in other rivers like the CURR and TYWI there was a great diversity of life histories including individuals with sea ages up to 8 years.

Table 7.6.9 Samples sizes by River and Marine zones

River	N		Marine Zone	N
CURRANE	346		MZ04	32
ARGIDEEN	223		MZ05	105
BANDON	44		MZ06	167
SLANEY	126		MZ07	64
DARGLE	66		MZ08	74
BOYNE	205		MZ09	69
DEE (Ireland)	217		MZ10	107
CASTLETOWN	54		MZ11	18
SHIMNA	181		MZ12	114
Isle of Man Rivers	59		MZ13	28
LUCE	205		MZ14	33
FLEET	95		MZ15	7
NITH	204		MZ16	15
ESK (Border)	378		MZ18	5
EHEN	20		MZ23	33
LUNE	319		MZ29	14
RIBBLE	72		MZ30	44
DEE (Wales)	117			
CLWY	65			
CONWY	64			
DYFI	236			
TEIFI	103			
TYWI	357			
LOUG	1			
TAWE	32			

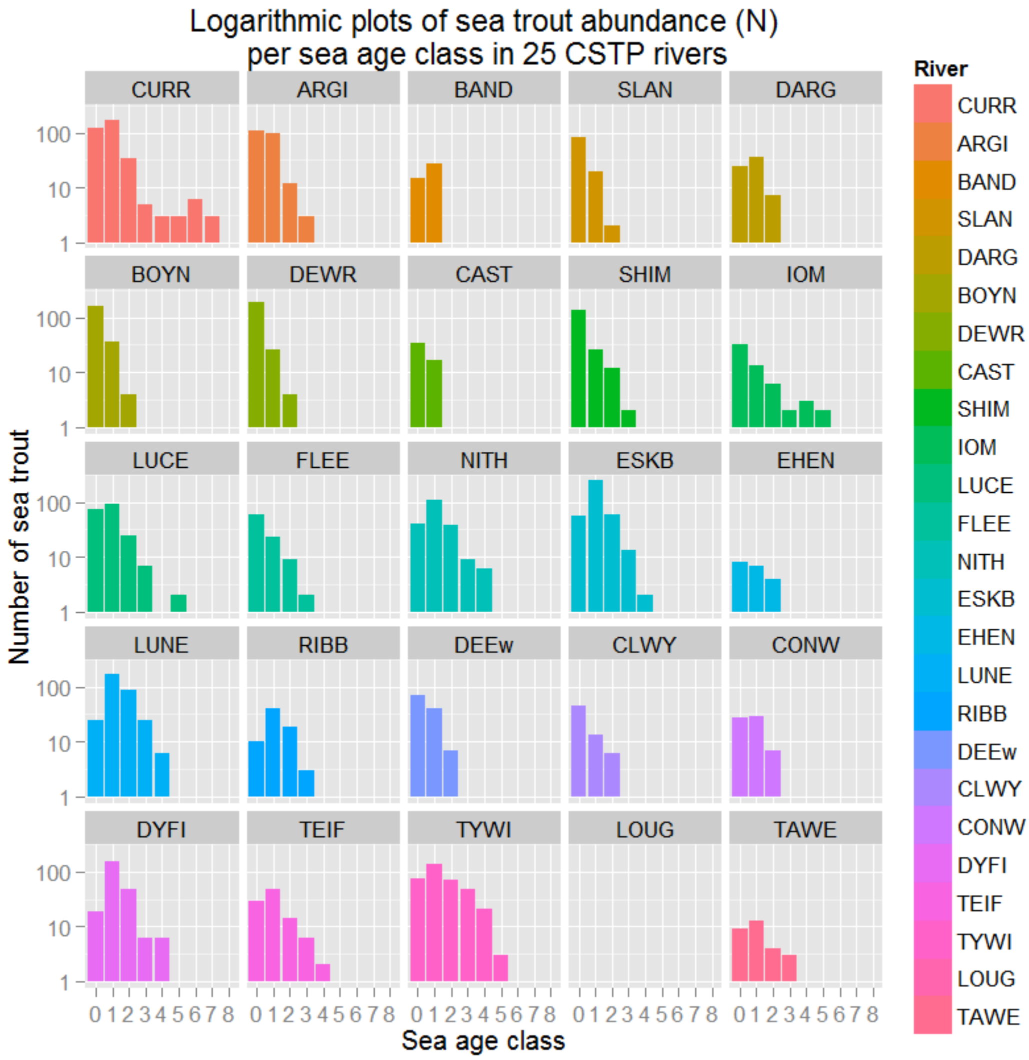


Figure 7.6.14 Logarithmic plots of sea trout abundance (N) per sea age class in 25 CSTP rivers

Effect of Sex on the Data

Of the individuals captured in rivers, there were 1697 females, and 598 males (Table 7.6.10). The remainder were of indeterminate sex or not examined. Analysis of the slopes of the overall relationship of length and weight at age indicated that the slopes are not significantly different for females and males (ANCOVA: p(L)=0.078; p(W)=0.829; Figure 7.6.15). However, variance in sex proportion by month and by river can have confounding effects on relationship of size at age (Figure 7.6.16 & Figure 7.6.17).

Table 7.6.10 Number of females, males, and non-sexed sea trout

Female	Male	Indeterminate	Not Examined
1692	598	726	734

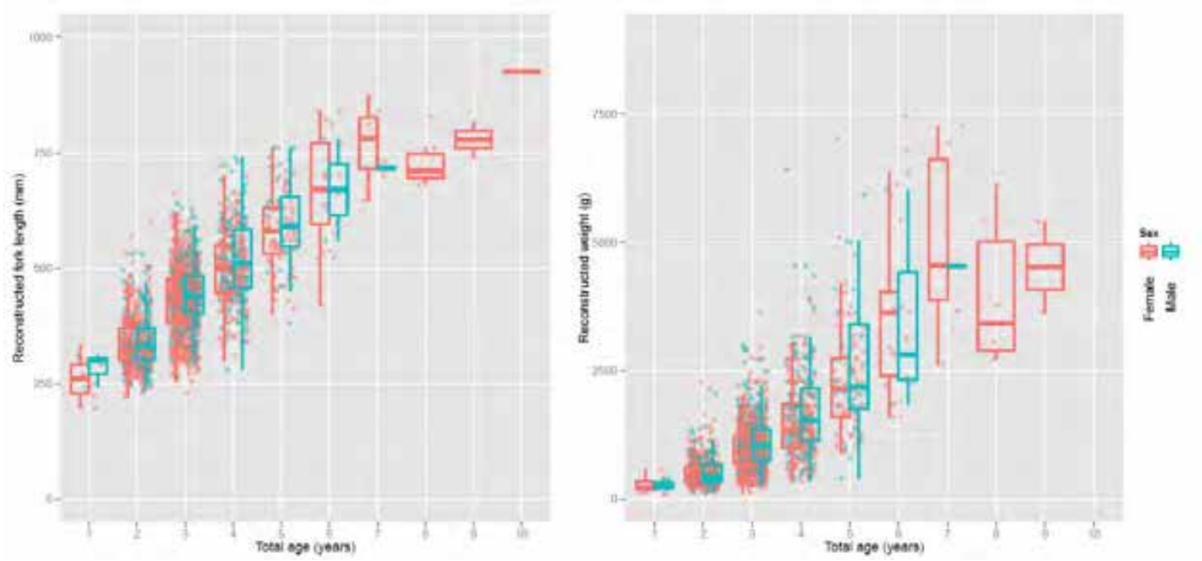


Figure 7.6.15 Reconstructed length and weight by age class for male and female sea trout

Only females, and their fecundity, are normally modelled in population dynamics studies as the spermatozoids of males are unlikely to be a limiting factor in the production of offspring. Females represented 73.9% of all sexed individuals, and in all our samples, females represented over 50% of the sexed individuals (Table 7.6.11).

Table 7.6.11 Sample size and proportion of females by river

River	N	%Fem
CURR	345	69.2
ARGI	221	80.3
BAND	44	85.7
SLAN	106	82.8
DARG	66	82.1
BOYN	204	69
DEWR	217	100
CAST	54	79.4
SHIM	177	88.9
IOM	59	91.7
LUCE	204	73.2
FLEE	95	53.3
NITH	199	89.6
ESKB	378	66.8
EHEN	20	60
LUNE	318	71.3
RIBB	72	65.1
DEEw	117	65.7
CLWY	64	67.4
CONW	64	77.1
DYFI	236	79.3
TEIF	102	61.6
TYWI	356	67.5
LOUG	1	100
TAWE	31	61.9

A possible approach would be to model the population dynamics exclusively with the sexed females. However, as there are no significant differences in length at age between sexes, the male proportion of the population can be assumed to be representative of the variance in size classes, size at age relationship, and life histories of the female proportion of the population. Hence, to augment the sample size of the individuals included in the population modelling, all individuals (females, males, and unsexed) are considered as reproductive females.

Such an assumption augments the number of females used in the modelling, but as the sampling has not included every individual in the population, males and unsexed individuals can be considered representative of unsampled females. Furthermore, the absolute number of individual females used in the modelling does not affect the outcome of the modelling, although the more individuals that are included, the more realistic the estimates of the transition and fecundity terms.

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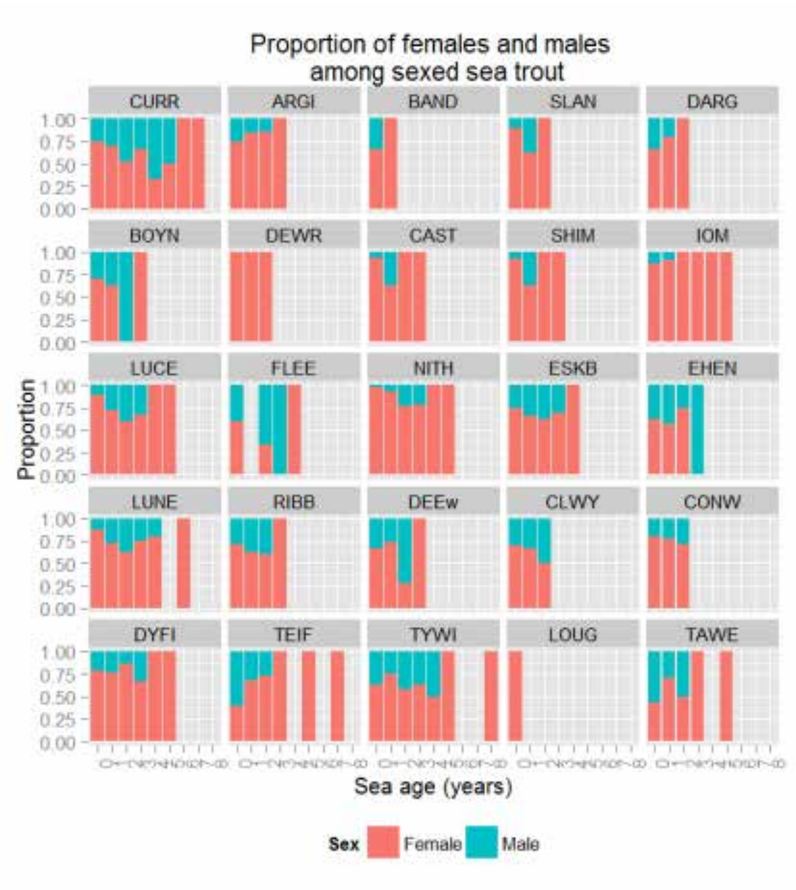


Figure 7.6.16 Proportion of females and males by sea age among sexed sea trout by river

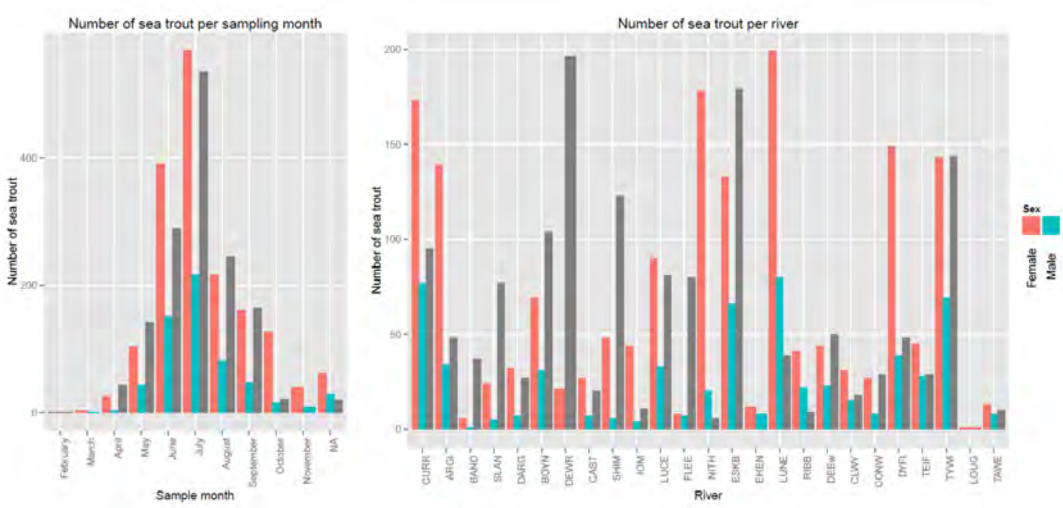


Figure 7.6.17 Number of females (red) and males (blue) sea trout by sampling month and by river**.** Grey represents individuals not examined.

Re-creation of Life History

Size at age of sea trout varied considerably among rivers, which resulted in a diverse range of somatic growth models (Figure 7.6.18). Trout from rivers in south Wales had the fastest somatic growth rates, while those in the north east of Ireland grew at the slowest rates.

	River	Linf	K	t0
1	CURR	2163.465	0.039	-2.084
2	ARGI	1300.875	0.059	-2.382
3	BAND	371.625	1.489	0.481
4	SLAN	713.801	0.096	-3.047
5	DARG	1373.885	0.062	-2.048
6	BOYN	1106.296	0.051	-4.289
7	DEWR	1275.143	0.043	-3.830
8	CAST	733.923	0.104	-3.762
9	SHIM	2963.568	0.028	-1.654
10	IOM	840.864	0.275	0.109
11	LUCE	893.931	0.182	-0.340
12	FLEE	1185.795	0.125	-0.231
13	NITH	1449.801	0.079	-1.399
14	ESKB	667.201	0.220	-1.639
15	EHEN	841.084	0.190	-0.452
16	LUNE	765.081	0.253	-0.330
17	RIBB	648.805	0.366	-0.073
18	DEEw	1283.557	0.126	-0.479
19	CLWY	536.851	0.905	0.886
20	CONW	769.076	0.191	-1.521
21	DYFI	2075.772	0.050	-2.280
22	TEIF	754.531	0.428	0.491
23	TYWI	892.770	0.311	0.229
24	LOUG	1000.115	0.169	-0.541
25	TAWE	2099.471	0.052	-2.410

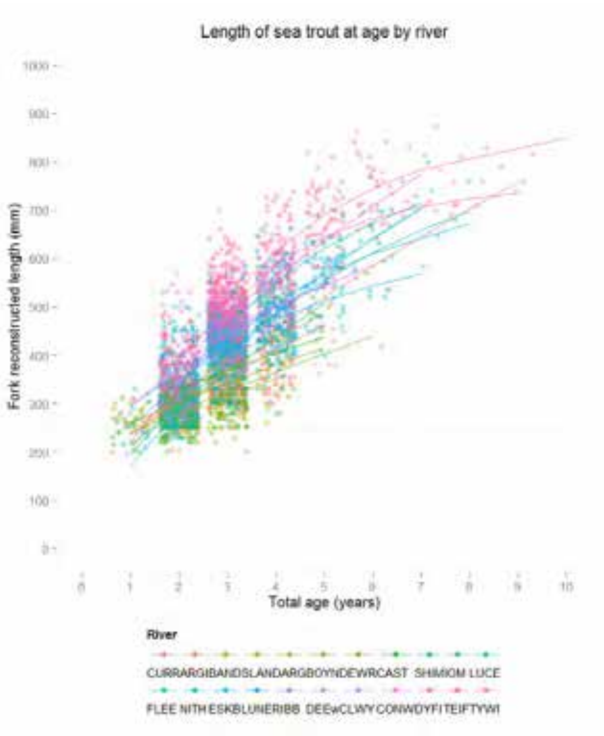


Figure 7.6.18 Length at age relationship for sea trout for all rivers and estimates of von Bertalanffy model parameters by river

These river-specific somatic growth models are based exclusively on returning sea trout, which in some rivers included some very rare 1.0+ aged trout captured late in the year (October, November). These unusual fish skewed the somatic growth models so that reconstructed lengths at age 1 seemed unrealistic. However, such bias does not affect the reconstructed fecundity as the vast majority of sea trout do not reproduce until at least 2 years of age.

As stated in the methods, the data collected here do not allow the estimation of egg, FW, SW and IM mortality, and thus, identical values were imposed on all populations. The imposed values may not be necessarily close to reality, but by being equal, they allow comparison among rivers of the impact of the sea trout contingent on each rivers trout population. The survival from one spawning event to the next was obtained from the frequency of repeat spawners present in each river dataset. The estimated survival estimated from this method varied widely among rivers (Figure 7.6.19). For most rivers, survival between spawning events is relatively low (<0.3) and individuals with more than SM3 mark are very rare (Figure 7.6.19). However, for a few rivers like the Currane, Isle of Man, Luce, Fleet, Dyfi, Teifi and Tywi, once a sea trout had survived from SM1 to SM2, stage specific survival increased (up to 0.8 for SM4 at the Currane and Isle of Man) before decreasing to zero.

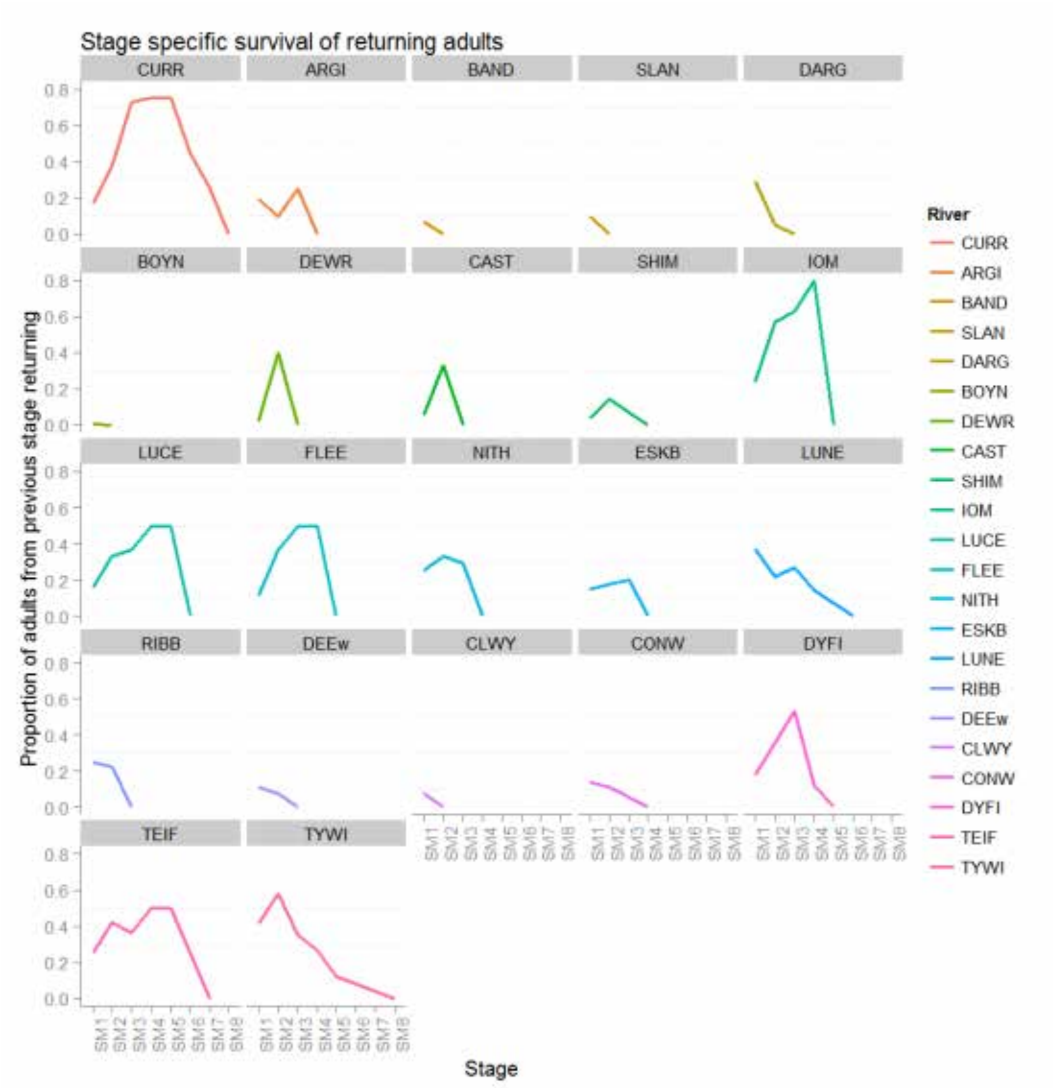


Figure 7.6.19 Stage specific survival of returning adult sea trout by river

Population Dynamics

Transition matrices were constructed for all rivers with at least 40 individuals (n=22). Results of the Eigen analysis of the transition matrix of each river are illustrated in river specific plates. Although there are commonalities, sea trout populations from rivers draining into the Celtic and Irish Seas were heterogeneous and followed different population dynamics patterns (Table 7.6.12).

Table 7.6.12 Population dynamics summary statistics by river.

N= number of individuals; *lambda* (λ) = population growth rate; *NetRepRate* = net reproductive rate; *GenTime* = generation time; *DampR* (ρ)= damping ratio; *E.FW*= elasticity of λ to fresh water phase; *E.Whitling* = elasticity of λ to whitling; *E.SeaWinter*= elasticity of λ to the sea winter phase;

	River	N	Lambda	NetRepRate	GenTime	DampR	E.FW	E.Whitling	E.SeaWinter	E.FirstSpawn	E.RepSpawn
1	CURR	345	1.180	1.707	3.225	1.824	0.058	0.315	0.034	0.222	0.370
2	ARGI	221	1.163	1.451	2.460	1.724	0.062	0.403	0.019	0.325	0.191
3	BAND	44	0.996	0.991	2.277	1.375	0.064	0.410	0.058	0.410	0.058
4	SLAN	106	1.094	1.231	2.308	1.409	0.075	0.433	0.006	0.386	0.100
5	DARG	66	1.204	1.596	2.519	2.398	0.073	0.393	0.023	0.301	0.211
6	BOYN	204	1.113	1.265	2.191	1.185	0.075	0.455	0.009	0.456	0.006
7	DEWR	217	1.110	1.268	2.276	1.223	0.072	0.440	0.006	0.414	0.068
8	CAST	54	1.200	1.525	2.313	1.272	0.063	0.431	0.016	0.397	0.093
9	SHIM	177	1.183	1.479	2.330	1.320	0.066	0.432	0.008	0.393	0.101
10	IOM	59	1.537	3.700	3.043	1.514	0.040	0.360	0.012	0.241	0.347
11	LUCE	204	1.171	1.540	2.732	1.723	0.057	0.359	0.039	0.276	0.270
12	FLEE	95	1.243	1.788	2.673	1.475	0.052	0.383	0.015	0.295	0.255
13	NITH	204	1.106	1.329	2.824	2.204	0.057	0.322	0.077	0.234	0.310
14	ESKB	378	0.909	0.778	2.638	2.543	0.074	0.303	0.143	0.291	0.189
15	LUNE	318	0.952	0.860	3.033	2.180	0.061	0.242	0.170	0.186	0.341
16	RIBB	72	0.970	0.920	2.746	2.699	0.063	0.293	0.140	0.246	0.259
17	DEEw	117	1.352	2.030	2.349	1.379	0.052	0.427	0.017	0.374	0.130
18	CLWY	64	1.340	1.949	2.279	1.316	0.056	0.440	0.013	0.403	0.088
19	CONW	64	1.262	1.768	2.445	1.617	0.054	0.401	0.037	0.348	0.161
20	DYFI	236	1.001	1.002	2.951	2.211	0.059	0.265	0.149	0.230	0.297
21	TEIF	102	1.379	2.526	2.885	1.650	0.045	0.356	0.038	0.258	0.303
22	TYWI	356	1.512	3.532	3.051	2.037	0.040	0.338	0.038	0.209	0.376

Population Growth Rate

Population growth rate (λ) ranged from slightly negative values in rivers on the North East of the Irish Sea ($\lambda_{ESKB} = 0.909, \lambda_{LUNE} = 0.952, \lambda_{RIBB} = 0.970$) to strongly positive values for most rivers in Wales ($\lambda_{DEEW} = 1.352, \lambda_{TEIF} = 1.379, \lambda_{TIWY} = 1.512$). The strongest population growth rate was found in the Isle of Man($\lambda_{IOM} = 1.537$). The IOM was a composite sample of three Manx rivers ($N_{SULB} = 1; N_{GLSS} = 2; N_{NEB} = 54$), where long lived repeat spawners (i.e. 2.0+4SM+) were particularly prevalent, leading to the strong population growth rate.

Estimations of λ, and all subsequent analysis were performed on sea trout populations from rivers with at least 40 individuals. To evaluate the effect of the number of individuals per sample on the estimated λ, bootstraps (n=1000) of 200 transitions (approximately 40 individuals) were drawn from every dataset. For most rivers, at smaller sampling rates (i.e. 40 individuals) the 95%CI become quite large (~0.5), however the estimated values from whole samples are centred among the bootstrapped values, indicating that values collected from smaller samples would be similar to these estimated from whole samples (Figure 7.6.20).

There is one notable exception, the river ESKB, for which the value estimated from the whole sample was at the edge of the 95%CI. The ESKB was the largest sample in terms of size (n=378), and had the lowest population growth rate ($\lambda_{ESKB} = 0.909$); however, subsamples of the transitions led to even lower λ values (mean $\lambda_{ESKB''} = 0.717$), indicating that a few transitions present in the real dataset have critical importance in maintaining λ around 1.

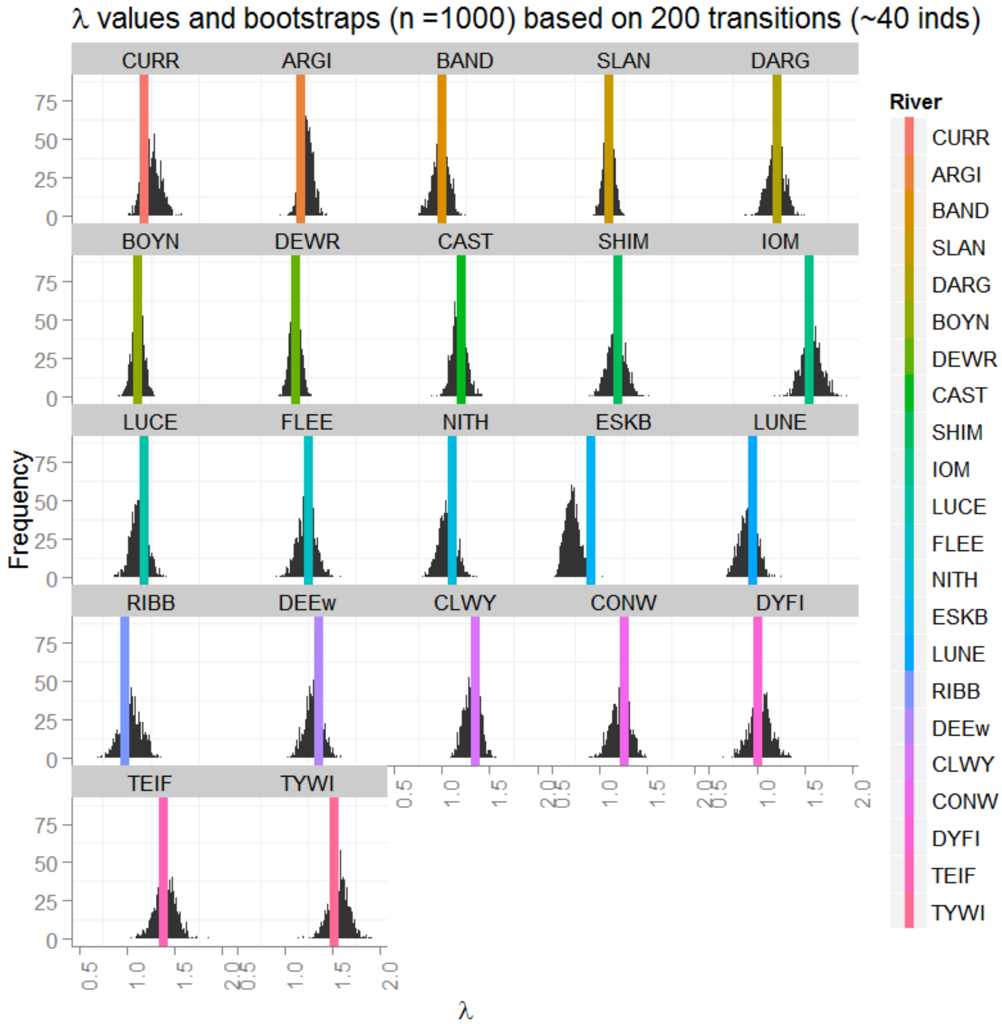


Figure 7.6.20 Population specific λ values and bootstraps (n=1000) based on 200 transitions (~40 inds).

Generation Time

Generation time varied from 2.19 years for sea trout from the BOYN, which showed the highest elasticity of λ to whitling (0.459), to 3.23 years for those from the CURR (Table 7.6.12), characterised by high frequency of repeat spawners and highest elasticity of λ to repeat spawners (0.259). The variance in generation time highlights the time required by the population to grow by a factor of R_0 ($R_{0\,BOYN} = 1.27; R_{O\,CURR} = 1.71$). It can also be understood as the average age of the parents of a cohort.

Stable Stage Distribution

Stable stage distributions are the constant proportions of each stage in a population at equilibrium. Stable stage distributions for sea trout populations from all rivers were strongly dominated by the FW stage, which always composed over half of the stable stage population (Table 7.6.13, Figure 7.6.21). SM1 were the next most common stage in all Irish rivers (except the CURR), the IOM, and the LUCE, FLEE, DEEw, CLWY and CONW in Great Britain. Conversely SW was the second most common stage in the NITH, ESKB, LUNE, RIBB, DYFI, TEIF, and TYWI. The stable stage distribution allows the identification of which rivers are more likely to be dominated by SW, whitling, or repeat spawners.

Table 7.6.13 River-specific stable stage distributions of 22 sea trout populations around the Celtic and Irish Seas.

	River	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	SM9	SM10
1	CURR	0.556	0.004	0.030	0.026	0.004	0.001	0.001	0.000	0.000	0.000	0.000		
2	ARGI	0.539	0.001	0.024	0.045	0.008	0.001	0.000						
3	BAND	0.485	0.015	0.035	0.037	0.003								
4	SLAN	0.529	0.003	0.006	0.059	0.005								
5	DARG	0.564	0.008	0.015	0.032	0.008	0.000							
6	BOYN	0.533	0.003	0.011	0.056	0.000								
7	DEWR	0.531	0.004	0.005	0.061	0.001	0.000							
8	CAST	0.551	0.003	0.019	0.048	0.002	0.001							
9	SHIM	0.549	0.006	0.008	0.054	0.002	0.000	0.000						
10	IOM	0.615	0.014	0.007	0.039	0.006	0.002	0.001	0.000					
11	LUCE	0.543	0.025	0.014	0.030	0.004	0.001	0.000	0.000	0.000				
12	FLEE	0.557	0.021	0.004	0.045	0.004	0.001	0.000	0.000					
13	NITH	0.525	0.037	0.016	0.020	0.005	0.001	0.000						
14	ESKB	0.469	0.055	0.010	0.017	0.003	0.001	0.000						
15	LUNE	0.480	0.048	0.019	0.013	0.005	0.001	0.000	0.000	0.000				
16	RIBB	0.484	0.039	0.026	0.016	0.004	0.001							
17	DEEw	0.580	0.013	0.011	0.044	0.004	0.000							
18	CLWY	0.581	0.008	0.011	0.046	0.003								
19	CONW	0.560	0.027	0.011	0.033	0.004	0.000	0.000						
20	DYFI	0.496	0.051	0.014	0.013	0.002	0.001	0.000	0.000					
21	TEIF	0.586	0.025	0.014	0.026	0.005	0.001	0.000	0.000	0.000	0.000			
22	TYWI	0.611	0.033	0.006	0.022	0.006	0.002	0.001	0.000	0.000	0.000	0.000		

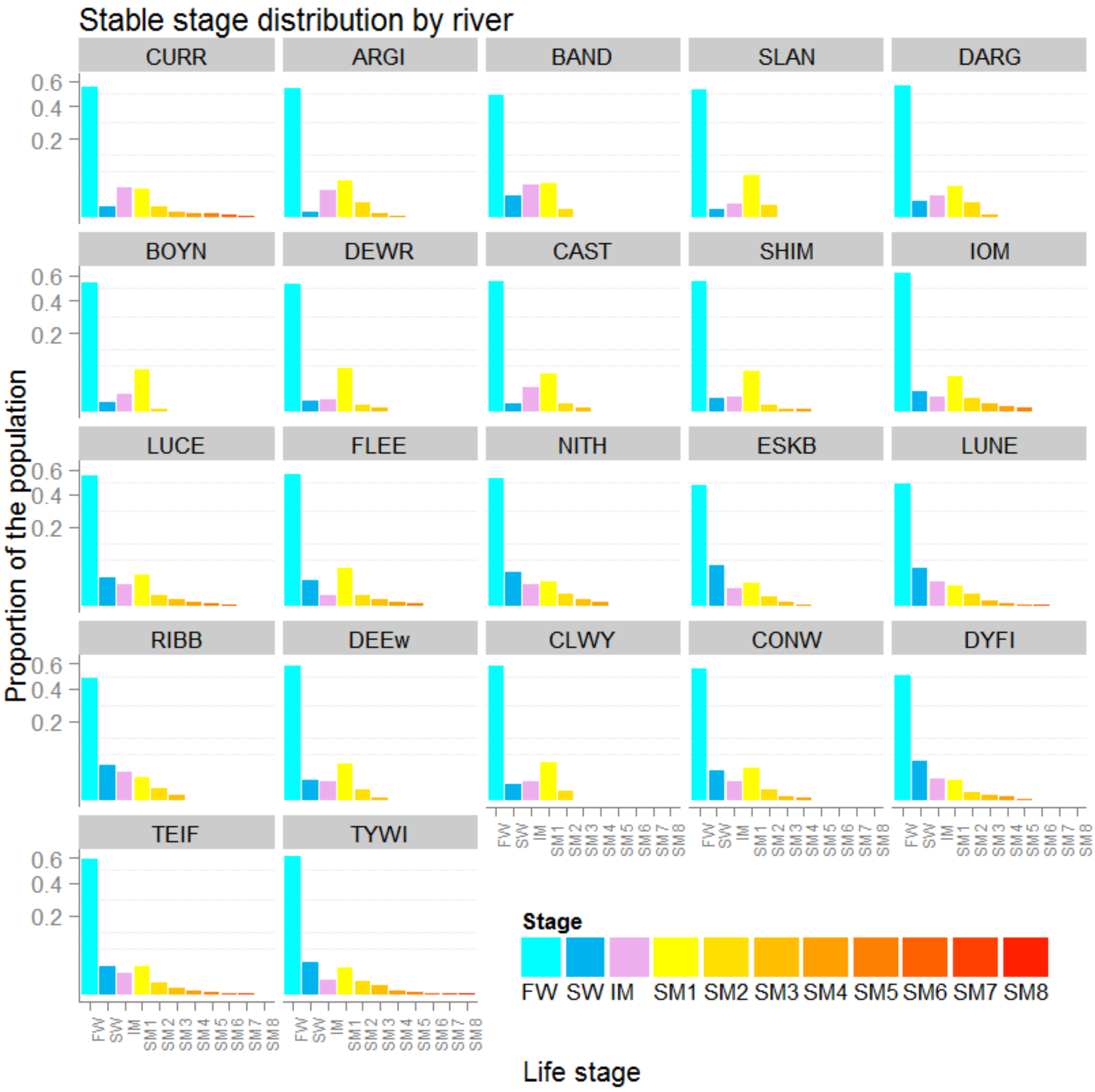


Figure 7.6.21 Stable stage distribution of sea trout populations from 22 rivers around the Irish and Celtic Seas.

Stage Specific Reproductive Value

The variance in somatic growth rates among sea trout from different rivers was translated into variance in individual egg production at stage (Figure 7.6.22). For example, the egg production of sea trout at SM2 in the river TYWI (n=3409 eggs) is three times that of SM2 sea trout from the river BAND (n=1105 eggs) (Table 7.6.14). The maximum number of eggs is achieved at the SM8 stage for trout in the TYWI (N=8567 eggs) (Table 7.6.14). The stage specific reproductive values which indicates the potential reproductive contribution of an individual in a particular class, also increases initially with older stages. However, as stage specific survival reduces and individuals in the oldest stages become rarer, the stage specific reproductive value for the later stages diminishes (Figure 7.6.22).

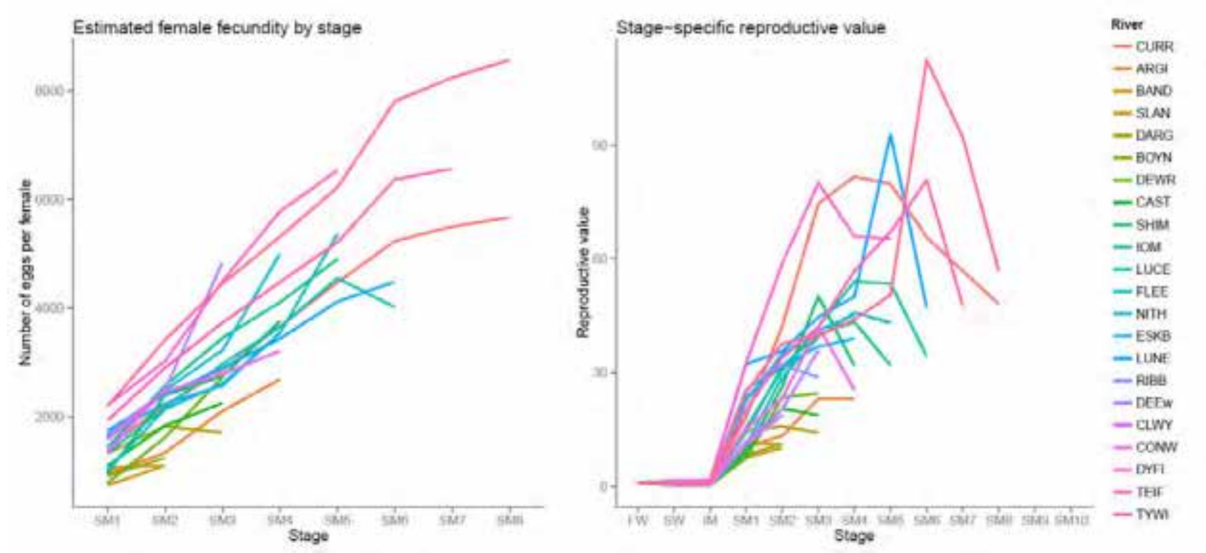


Figure 7.6.22 Number of eggs per female and stage specific reproductive value by river

Table 7.6.14 Reconstructed average number of eggs per female by stage and river

	River	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8
1	CURR				1442.316	2207.186	2856.136	3664.250	4475.500	5233.000	5500.750	5668.000
2	ARGI				953.860	1337.047	2106.000	2688.000				
3	BAND				1063.568	1105.000						
4	SLAN				737.491	1105.900						
5	DARG				1324.545	1827.211	1712.000					
6	BOYN				910.240	1248.000						
7	DEWR				780.046	1619.200	2723.000					
8	CAST				1099.963	1835.667	2253.000					
9	SHIM				949.051	2397.429	2746.000	3757.000				
10	IOM				1436.203	2570.286	3447.625	4105.600	4901.500			
11	LUCE				1326.500	2164.758	2971.182	3652.750	4552.500	4015.000		
12	FLEE				1024.653	2140.545	2610.750	3539.000	5359.000			
13	NITH				1623.583	2489.451	3220.706	4994.200				
14	ESKB				1662.881	2242.304	2572.700	3545.500				
15	LUNE				1741.258	2407.703	2898.308	3437.143	4119.000	4486.000		
16	RIBB				1678.958	2470.167	2794.250					
17	DEEw				1378.641	2494.077	4840.000					
18	CLWY				1343.766	2511.400						
19	CONW				1580.859	2462.556	2784.000	3211.000				
20	DYFI				2210.572	3021.024	4490.067	5776.875	6531.000			
21	TEIF				1927.696	2900.115	3729.273	4476.250	5210.000	6368.000	6565.000	
22	TYWI				2194.466	3409.082	4448.812	5311.833	6219.875	7805.000	8240.000	8567.000

Although juveniles may not reproduce while they are juveniles, they have the potential to grow to the spawning stages and reproduce, and thus every stage has a reproductive value (Figure 7.6.22; Table 7.6.15). For the BAND the maximum stage specific reproductive value was at SM1. For the SLAN, DARG, BOYN, CAST, RIBB, and CLWY the maximum stage specific reproductive value was reached at SM2 despite the occurrence of SM3 in some of these rivers. SM3 gave the maximum stage specific reproductive value for DEWR, SHIM, DEEw, CONW, and DYFI. Maximum stage specific reproductive value was reached at SM4 for the two rivers in south west of Ireland (CURR and ARGI) and rivers draining in the north east of the Irish Sea (IOM, LUCE, FLEE, NITH, and ESKB); at SM5 in the LUNE and at SM6 for the two rivers in south Wales (TEIF and TYWI). Late maximum stage specific reproductive value was not related with low reproductive value at early stages, as sea trout from rivers in south west of Ireland, north east of the Irish Sea or south Wales had comparatively high stage specific reproductive values at early stages (SM1 and SM2).

Table 7.6.15 Stage specific reproductive value, the mean number of offspring to be produced in its remaining lifetime, by river and the stage at maximal reproductive value (StageMax).

	River	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	StageMax
1	CURR	1.000	0.717	0.726	18.339	42.239	74.515	81.666	79.670	65.711	56.773	48.019	SM4
2	ARGI	1.000	0.448	0.427	10.429	13.336	23.066	23.104	0.000				SM4
3	BAND	1.000	0.574	0.545	11.439	11.095	0.000						SM1
4	SLAN	1.000	0.348	0.348	7.611	10.106	0.000						SM2
5	DARG	1.000	0.555	0.614	14.780	15.799	14.220	0.000					SM2
6	BOYN	1.000	0.251	0.341	8.225	11.209	0.000						SM2
7	DEWR	1.000	0.339	0.304	7.515	23.431	24.534	0.000					SM3
8	CAST	1.000	0.421	0.396	10.115	20.510	18.773	0.000					SM2
9	SHIM	1.000	0.275	0.314	8.902	26.310	50.057	31.758	0.000				SM3
10	IOM	1.000	0.431	0.463	14.223	31.606	40.038	43.306	31.888	0.000			SM4
11	LUCE	1.000	0.599	0.650	15.537	30.481	42.149	54.036	53.510	34.283	0.000		SM4
12	FLEE	1.000	0.383	0.439	10.923	28.759	39.436	45.818	43.116	0.000			SM4
13	NITH	1.000	0.889	0.987	22.574	34.910	41.135	45.161	0.000				SM4
14	ESKB	1.000	1.161	1.190	23.483	31.898	36.867	38.989	0.000				SM4
15	LUNE	1.000	1.560	1.639	32.195	35.635	44.622	50.058	92.830	47.144	0.000		SM5
16	RIBB	1.000	1.189	1.270	25.574	32.066	28.807	0.000					SM2
17	DEEw	1.000	0.420	0.440	11.883	20.489	35.806	0.000					SM3
18	CLWY	1.000	0.365	0.415	11.119	18.739	0.000						SM2
19	CONW	1.000	0.575	0.598	15.110	23.222	42.204	25.437	0.000				SM3
20	DYFI	1.000	1.387	1.599	32.542	58.746	79.996	65.890	65.272	0.000			SM3
21	TEIF	1.000	0.642	0.705	20.256	33.934	42.030	56.792	67.069	80.730	47.619	0.000	SM6
22	TYWI	1.000	0.729	0.820	24.812	37.722	39.693	44.018	50.424	112.421	91.954	56.652	SM6

Fundamental matrix

The likelihoods that an individual from a particular stage will reach another are given in the fundamental matrix. Values along the diagonal must be at least 1, as any individual already in a stage must at least exist for one iteration at that stage. The values read by columns indicate the likelihood and mean time spent by individuals from that stage in all other stages. For example, in the fundamental matrix of ESKB in Figure 7.6.23 an individual in fresh water stays on average in the fresh water stage for 1.176 iterations, such a value above 1 reflects the likelihood that some individuals remain in the fresh water stage. Although most individuals alive have stayed in fresh water for two years, the fundamental value does not reach two iterations due to the mortality exerted in fresh water (0.7 per year). Other individuals in the FW stage grow into other stages: the same individual in FW will remain in the sea winter stage for an average of 0.124 iterations, in indeterminate mark stage for 0.022 iterations, and as first spawner 0.037 iterations, highlighting the low likelihood that an individual in the FW stage will reach the spawning stages. Once an individual has reached the first spawning stage (SM1), it is relatively likely that it will return for at least another season (SM2 0.148 iterations), but the likelihood of returning a third (SM3) or fourth (SM4) reduces (0. 026 and 0.005 respectively). Conversely for the river CURR (Figure 7.6.24), the likelihood of a whitling returning a second time is still low (0.171), but successive likelihoods for SM2 to SM3, SM3 to SM4 , SM4 to SM5 increase (0.373, 0.727, 0.75 respectively) before decreasing for SM6 to SM7, and SM7 to SM8 (0.444, 0.250 respectively) (Figure 7.6.24).

C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	1.178	0	0	0	0	0	0	0
SW	0.124	1.001	0	0	0	0	0	0
IM	0.022	0.004	1.004	0	0	0	0	0
SM1	0.037	0.045	0.046	1	0	0	0	0
SM2	0.006	0.007	0.007	0.148	1	0	0	0
SM3	0.001	0.001	0.001	0.026	0.179	1	0	0
SM4	0	0	0	0.005	0.036	0.2	1	0
dead	1	1	1	1	1	1	1	1

Figure 7.6.23 Fundamental matrix of sea trout population of the river ESKB

C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	dead
FW	1.214	0	0	0	0	0	0	0	0	0	0	0
SW	0.01	1.002	0	0	0	0	0	0	0	0	0	0
IM	0.077	0.002	1.003	0	0	0	0	0	0	0	0	0
SM1	0.067	0.046	0.047	1	0	0	0	0	0	0	0	0
SM2	0.011	0.008	0.008	0.171	1	0	0	0	0	0	0	0
SM3	0.004	0.003	0.003	0.064	0.373	1	0	0	0	0	0	0
SM4	0.003	0.002	0.002	0.046	0.271	0.727	1	0	0	0	0	0
SM5	0.002	0.002	0.002	0.035	0.203	0.545	0.75	1	0	0	0	0
SM6	0.002	0.001	0.001	0.026	0.153	0.409	0.562	0.75	1	0	0	0
SM7	0.001	0.001	0.001	0.012	0.068	0.182	0.25	0.333	0.444	1	0	0
SM8	0	0	0	0.003	0.017	0.045	0.062	0.083	0.111	0.25	1	0
dead	1	1	1	1	1	1	1	1	1	1	1	1

Figure 7.6.24 Fundamental matrix of sea trout population of the river CURR

FW retention fundamental values were similar across all rivers (Figure 7.6.25). The likelihood of FW individuals returning as SM1 was, however, different among rivers: rivers along the east coast of Ireland (SLAN, BOYN, DEWR, CAST, and SHIM), had particularly high likelihoods of returning as SM1 (~0.14), while the opposite was true for ESKB, NITH, RIBB, and TYWI (~0.4), which were far more likely to go through a sea winter phase (SW/IM) (Figure 7.6.25).

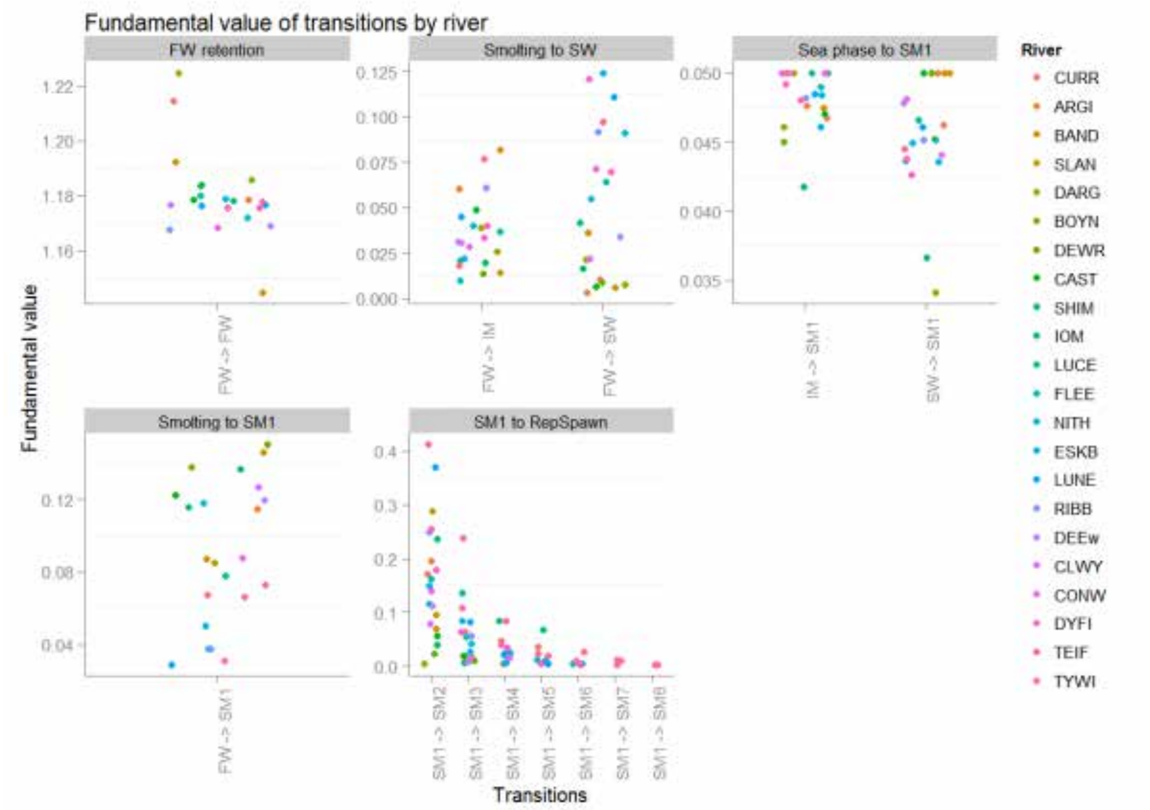


Figure 7.6.25 Comparison of fundamental value of transitions among rivers grouped by transition type (retention in freshwater, smolting to sea winter stage, freshwater to first reproduction, sea winter to first reproduction, and first reproduction to repeat spawner).

Sensitivity Analysis

The values of the sensitivity matrix (S_{ij}) for each transition (A_{ij}) can be interpreted as the increase in λ ($\Delta\lambda$) associated with an additive increase (ΔA_{ij}) for that transition:

$$\Delta\lambda = S_{ij} * \Delta A_{ij}$$

For example, if the survival of SM1 to SM2 on the river ESKB were to increase from 0.148 to 0.248 ($\Delta A_{ij} = 0.1$), the population growth rate would increase from $\lambda_{ESKB} = 0.909$ to $\lambda_{ESKB'} = 0.960$ ($\lambda' = \lambda + \Delta\lambda$; where $\Delta\lambda = 0.508 * 0.1$). Sensitivities can be calculated for all possible transition parameters, for example from FW to SM8. However, the utility of sensitivities for transitions other than non-zero transitions is questionable, so here we highlight only those transitions which are found in the population. Trout populations from all rivers were similar in that additive perturbations to the FW to SM1 transition had the largest impact on λ (Figure 7.6.26) while additive perturbations to fertilities have relatively little impact. Therefore, in general enhancing or blocking the productions of SM1 will have the greatest impact in terms of sea trout population control, while increases in individual fecundity have negligible impact. The sensitivity of λ to the FW to SM1 transition was particularly high for some rivers, namely CURR, NITH, ESKB, LUNE, RIBB, DYFI, CONW, TEIF, and TYWI, indicating that the sea trout populations from these rivers would respond very positively to environmental management practices protecting the transition from FW to SM1. These rivers were also characterised by low fundamental values for the FW to SM1 transition, indicating the low likelihood of a FW to return as a SM1 without spending at least a winter at sea. The trout populations from four rivers, the DEWR, SHIM, LUCE, and FLEE, were characterised by low sensitivities to the FW to SM1 transition while the SM1 to SM2 transition had particularly high sensitivities (>1). For these populations protection of whitling may not be enough to insure positive population growth rates, and protection of young repeat spawners in these rivers should be encouraged if increased population growth is desired.

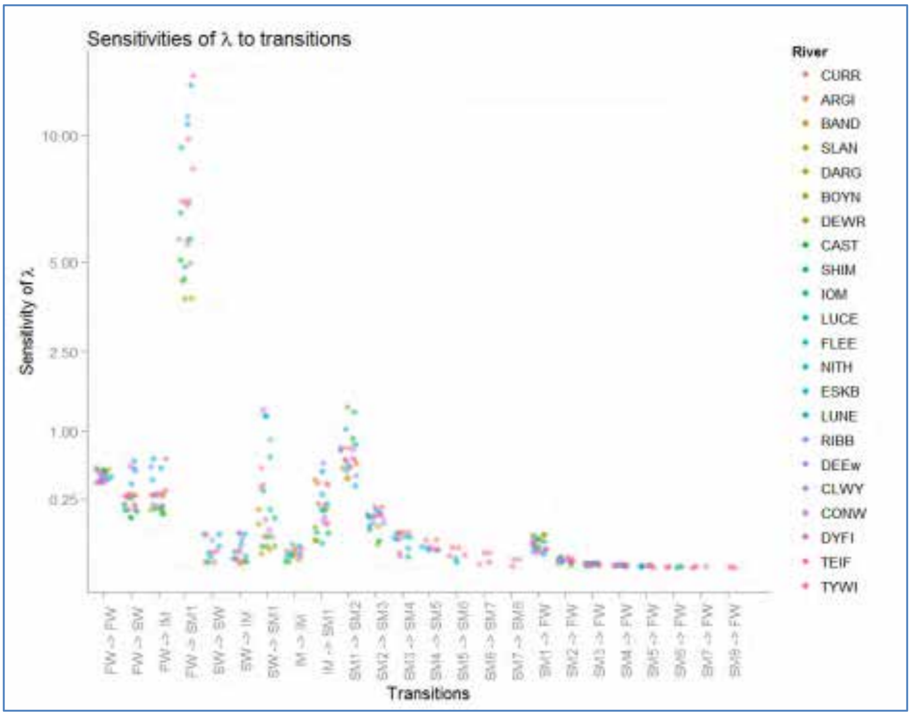


Figure 7.6.26 Sensitivities of λ to transitions by river.

Elasticity Analysis

Complementary to the fundamental values and the sensitivity of λ to transition perturbations, the elasticity of λ to transition perturbations measures the *proportionality* of the change in λ to a change in a transition value. High elasticity of λ to a certain transition A_{ij} suggests high proportionality between $\Delta\lambda$ and ΔA_{ij}. The elasticities of a transition matrix always add up to one, so they represent the transition's relative importance to λ. Elasticities can be added by rows, columns, or groups of transitions, to estimate the relative importance of such groups. If examined by rows, elasticities highlight the importance of transitions entering a stage, while if examined by columns, elasticities reveal the importance of transitions leaving a stage. For example, FW are, by far, the most important source of SM1 (whitling life history pattern as opposed to .1+ and .2+ maidens), while the most important contribution of SM1 is its fecundity rather than the production of repeat spawners. For all rivers it can be observed that the elasticities of λ to transitions FW to FW, FW to SM1, and SM1 fecundity, contribute over 0.5 to λ, highlighting the importance of whittling for maintaining the all populations of sea trout (Table 7.6.16). These transitions (FW -> FW, FW -> SM1, and SM1 -> FW; *i.e.* a 2.0+ whitling returning to spawn for the first time) compose the shortest life history strategy an individual can take to contribute to the next generation, which is defined here as the *minimum life history* (minLH). The dependency of a population on the minimum life history strategy was calculated by adding the elasticity of λ to the FW to FW, FW to SM1, and SM1 to FW transitions (*E.minLH*). Such dependency varied widely among sea trout populations from different rivers: in some rivers, such as the BAND, SLAN, BOYN, DEWR, CAST, SHIM, and CLWY, the combined elasticities of λ to the minimum life history (*E.minLH*) added up to close to 0.9, showcasing the dependence of these populations on a very short life cycle with little diversity of life strategies. In the BOYN, this value added up to 0.99, indicating no role of alternative strategies in the dynamics of the population. The sum of the elasticities of all other transitions not included in the minLH, can be interpreted as the dependency on alternative life histories (*E.altLH*), such as those with sea winters (SW and IM) and repeat spawners (SM2, SM3…). The elasticities of alternative life strategies summed to around 0.4 in sea trout populations in the CURR, NITH, LUNE, RIBB, DYFI, and TYWI highlighting the importance to population growth rate of the diversity of life strategies found in these rivers. Alternative life strategies can play an important role in the stability of a population, as populations highly dependent on the minimum life history could be strongly affected by stochastic events preventing spawning one year.

Table 7.6.16 Elasticities of λ to the minimum life history strategy (E.MinLH) and to alternative life history strategies (E.AltLH) by river

	River	E.MinLH	E.AltLH
1	CURR	0.595	0.405
2	ARGI	0.790	0.210
3	BAND	0.884	0.116
4	SLAN	0.895	0.105
5	DARG	0.766	0.234
6	BOYN	0.986	0.014
7	DEWR	0.926	0.074
8	CAST	0.892	0.108
9	SHIM	0.891	0.109
10	IOM	0.641	0.359
11	LUCE	0.691	0.309
12	FLEE	0.730	0.270
13	NITH	0.614	0.386
14	ESKB	0.669	0.331
15	LUNE	0.488	0.512
16	RIBB	0.601	0.399
17	DEEw	0.853	0.147
18	CLWY	0.899	0.101
19	CONW	0.802	0.198
20	DYFI	0.554	0.446
21	TEIF	0.660	0.340
22	TYWI	0.586	0.414

Elasticities of λ to fresh water, whitling, sea winters, first time spawners, and repeat spawner phases were calculated (Table 7.6.12). Low estimated population λ was associated with higher elasticities of λ to the sea winter phase (Figure 7.6.27), indicating that populations where sea winters are a common life history stage (such as ESKB, LUNE, RIBB, and DYFI) had slower population growth rates and that the increased fecundity gained during sea winters does not compensate for the delay in first spawning.

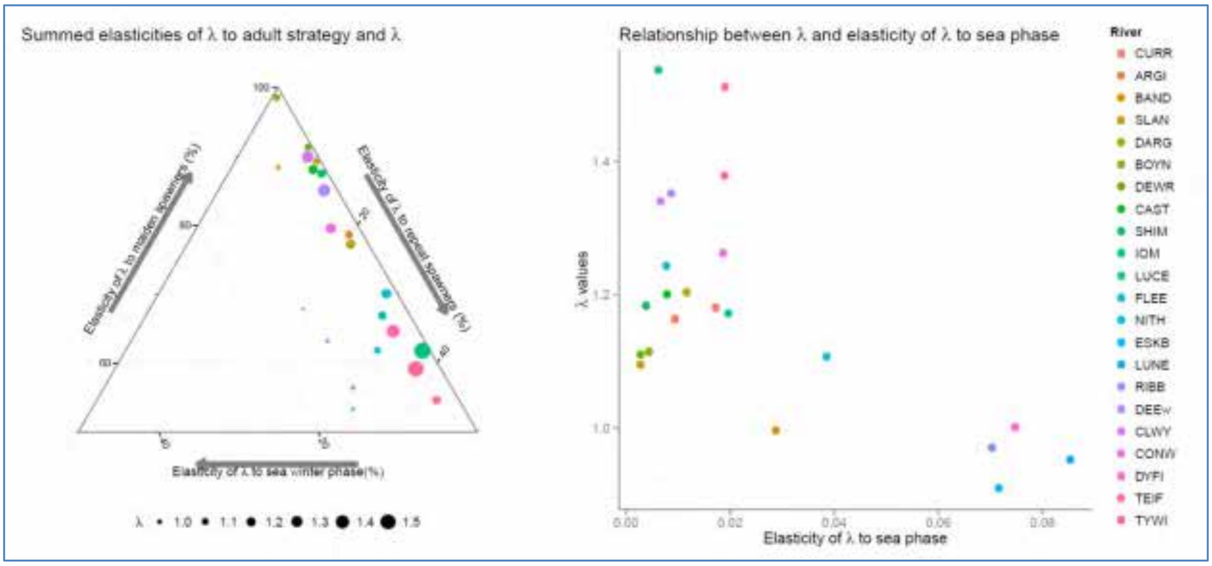


Figure 7.6.27 Summed elasticities of λ to different phases of the adult life history strategy and relationship betweeen λ and elasticity of λ to sea winter phase.

Longer generation times were associated with high elasticities of λ to repeat spawners (Figure 7.6.28), showing the impact of repeat spawners on the time needed to increase the population size by a factor of R_0.

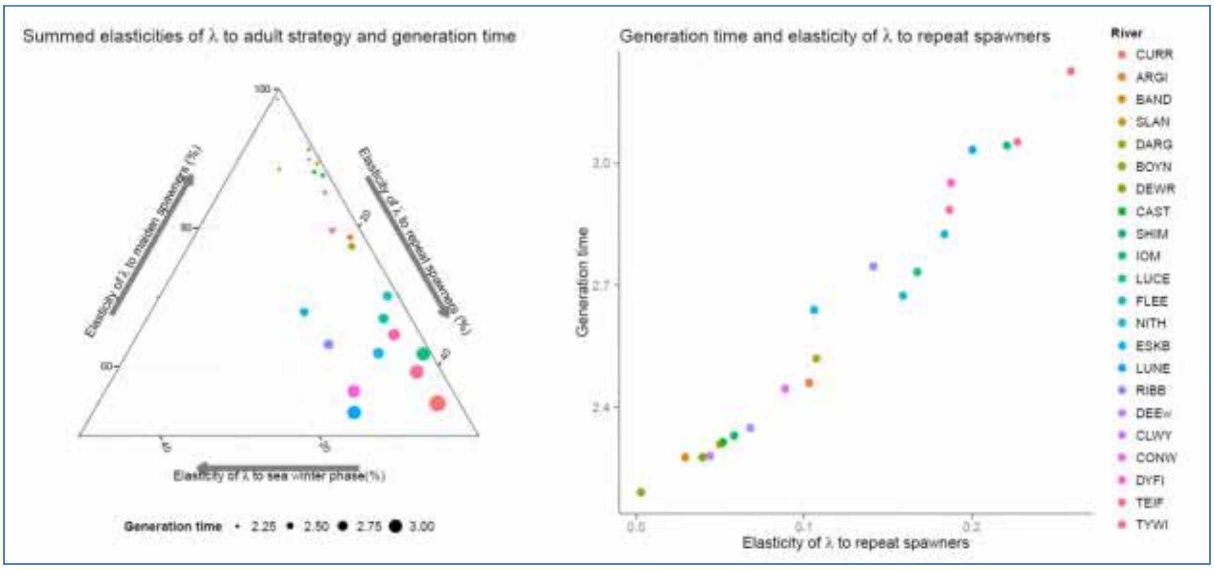


Figure 7.6.28 Summed elasticities of λ to different phases of adult life history strategy and relationship between λ and elasticity of λ to repeat spawners.

Higher damping ratios were associated with high elasticity of λ to sea winters (Figure 7.6.29), illustrating how the distrution of reproductive effort across many stages, such as the inclusion of sea winters, improves the population capacity of converge to stable stage distribution.

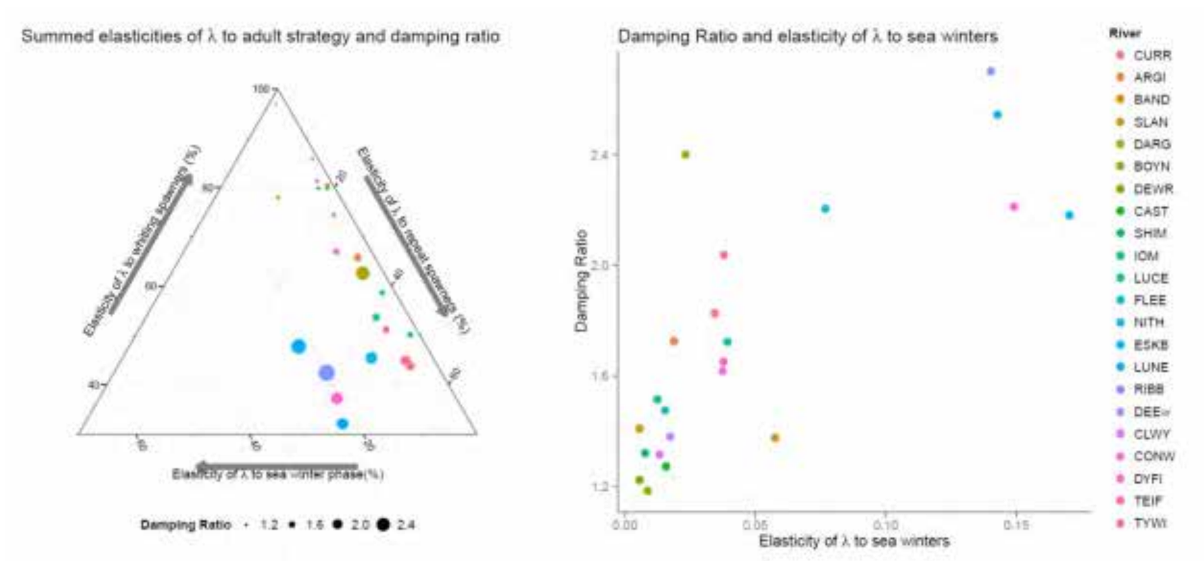


Figure 7.6.29 Summed elasticities of λ to different phases of adult life history strategy and relationship between λ and elasticity of λ to sea winters

River specific sea trout population dynamics analysis summary plates

The outcomes of the population dynamics analysis of the sea trout population of each of 22 rivers have been summarized into individual river plates (Appendix 7.7). The abbreviated name of the river and the number of individuals (n) for which there was age, life history and length and weight is indicated.

a) Relationship between total length (mm) and total age (years) for all individuals collected for the river. The number of sea winters recorded for each individual is indicated by the shape of the point: circles of whitling returns, triangles for 1 sea winter, squares for 2 sea winters, and so on; The colour of the last stage before capture recorded for each individual is indicated by the colour of the point: cyan for fresh water (FW), blue for sea winter (SW), pink for indeterminate marks (IM), and a range from yellow to red for increasing number of spawning marks (SM); The von Bertanlanffy model best describing the data is written in the form of an equation, $L_t = L_\infty\left[1 - e^{-K(t-t_0)}\right]$, where L_t is the estimated length, L_∞ is the asymptotic length at which growth is zero, K is Brody's growth coefficient (the rate at which the asymptote is approached) , and $t0$ is a scaling factor of no biological significance. The trajectory of the model from the river under study is depicted as a line on the plot in the river specific colour (River Legend). The trajectories of the other 21 rivers analyses are depicted as thin grey lines for comparison among rivers.

b) The transition and fertility values estimated from the recreated life histories are indicated in the transition matrix, which are the probability of an individual in one stage (columns) moving to another stage (rows).

c) The fundamental matrix indicates the likelihood of an individual from a particular stage (columns) reaching another stage (rows) during their lifetime. The values have been colour coded for ease of interpretation from low (light blue) to high (dark blue).

d) The sensitivities of λ to additive perturbations of the transition matrix are indicated in the Sensitivities matrix. Sensitivities can be calculated for all transitions in a matrix, however, some transitions are not found in populations (i.e. FW to SM4) and do not make sense in most cases, these values have been indicated in grey. Transitions found in the population are in black font, and the values have been colour coded for ease of interpretation from low (light blue) to hight (dark blue).

e) The elasticities of λ to proportional perturbations of the transition matrix are indicated in the sensitivity matrix. The values have been colour coded for ease of interpretation from low (light blue) to hight (dark blue).

f) Stable stage distribution. The relative proportions of each stage (colour coded) on the stable stage distribution of a population at equilibrium.

g) The river specific sea trout population growth rate (λ) is indicated with a thick line in the river specific colour (River colour legend). The λ values of 1,000 bootstraps of the data and of the same size as the data (i.e. 284 individuals) are plotted as a black histogram. 95%CI of estimated λ values are indicated as black dotted lines. The λ values of the other 21 rivers analysed are also plotted for comparison of the river under study with other rivers.

h) Evolution of stage-specific reproductive value with stage for river under study (thick line in river specific colour). The evolution of stage-specific reproductive values of 21 other rivers is also plotted for comparison with other rivers.

i) Ternary plot of the summed elasticities of λ of each of the phases in differing life history strategies (sea winters, whitling, and repeat spawners). The river under study is depicted by a larger circle of the river-specific colour (River colour legend). The other 21 rivers have also been plotted for comparison among rivers. The positioning of each dot is determined by the percentage of summed elasticities of λ of each phase and can be understood as the relative contribution of sea winter phase, whitling, and repeat spawners to population growth rate. The plots have been focused on the range of values encountered in this study (E.whitling= 30-100%, E.winter=0-80%, E.RepSpawn= 0-80%).

7.6.5.4 Discussion

It is important to recognise that a number of caveats limit the power of the population dynamics analysis of the current dataset: the variance in sampling efforts among rivers (from 44 in the BAND to 378 in the ESKB) may have led to variance in the certainty of estimated population parameters, and thus interpretation of these parameters from low confidence populations must be done with caution. The average life history of returning sea trout varies strongly over the months, where older sea trout return earlier in the year than whitling. If sampling in certain rivers is biased to early or late months, then the estimated population parameters will not be representative of the whole population inhabiting the river. For example, the BOYN has a rather high proportion of August and September caught individuals (Figure 7.6.10) which are frequently whitling, and shows the highest dependence on the minimum life history strategy (2.0+). If the sampling is biased because there was no sampling in earlier months, rather than a true biological feature (no sea trout returning in earlier months), then the high dependence on the minimum life history (2.0+) would be a spurious result. However, other rivers in the area (DARG, DEWR, CAST and SHIM) also have high proportions of late returning fish, and are characterised by relatively high dependency on such short life history strategy, giving weight to a regional tendency of sea trout populations towards simplified life history strategies.

The survival transitions for repeat spawners (e.g. SM2 -> SM3, SM3 -> SM4…) were estimated based on the transitions reported in the whole data available for each river (i.e. combining all sampling years together). Hence, these transition estimates assume that populations are at stable stage distribution, which is unlikely to be true. For rivers with large sample sizes, future analysis should evaluate the temporal stability of the estimated parameters to assess the confidence on the estimated values.

The fecundity of each individual sea trout was not empirically known, and thus it was estimated based on individual length using a relationship based on 55 sampled individuals (CSTP Report) collected from marine zones between July and October. With the data available, it was not possible to produce river specific fecundity relationships, which may have an important impact on population dynamics. If possible, an evaluation of the variance of river specific fecundity values would improve the estimates of population dynamics parameters.

As indicated in the introduction, sometimes post-smolting winter marks are indeterminate in that some erosion of the scale is present but not enough to clearly state a return of the individual to fresh water to spawn. These winter marks were recorded as indeterminate marks (IM), and were modelled identically as sea winters (SW), i.e. they had no fecundity values associated with them. Without further information on the true nature of these IMs, it is difficult to judge on the impact on the model of inclusion of IMs as spawners. First spawners are by far the highest contributors to the next generation and thus if all IMs are spawners, they would have a significant impact on the estimated parameters. If data were collected that would allow estimating the number of true spawners among the IM, then that proportion could be easily included in the matrix model by multiplying that proportion by the SM1 fecundity. Such evaluation could have important effect on rivers with a relatively high proportion of IMs, such as the rivers in the south west of Ireland, England, and mid Wales.

The matrix population models were constructed solely on returning individuals on their way back to their spawning grounds, and hence no river specific empirical information on the life cycle before first reproduction (fresh water survival and sea winter survival) was available. This means that the inter-river variance in those parameters has not been captured by the current sampling effort. Identical standardised parameters for the unsampled transition values (fresh water mortality =0.7, brown trout spawning=0, and sea winter mortality=0.95) were employed for all rivers, so all variance in estimated λ values is due to variance in inter-river post-first reproduction survival and fecundity. Hence, the absolute λ values cannot be interpreted as true population growth rate values, as among river variance in the unsampled transitions is likely to have major impacts on λ, but as the relative effects of the variance in post-first reproduction life-history on the population dynamics of trout populations. The available data allows us to estimate that, unless balanced by the unsampled transitions, the ESKB has a lower population growth rate than the TYWI, and that such difference may be explained by the relatively high frequency of individuals experiencing one or two winters at sea before first reproduction combined with a relatively low frequency of repeat spawners in the ESKB compared to the TYWI, a river whose sea trout population is characterised by high elasticity of λ to repeat spawners.

The current model also ignores the contribution of brown trout spawning to the population dynamics of trout on the studied rivers, as no empirical contemporary data was available on: 1) the river specific proportion of the population remaining as brown trout, 2) the somatic growth rate of such brown trout, and 3) the relationship between somatic size and fecundity for brown trout females. These parameters are likely to have major effects on the population dynamics of trout. If empirity data were available for all rivers, then a more complex version of the matrix models employed here as suggested by Pfister & Wang (2005) could be envisaged (Figure 7.6.30), where the two alternative life strategies (brown trout and sea trout) are included in the matrix, each with their own survival, growth, and fecundity transition values. However, parameterising such a model would require an extensive sampling of the fresh water phase of all rivers targeted.

$$\begin{bmatrix} s_{L,1}(1-g_{L,1})p_{LL,1} & s_{H,1}(1-g_{H,1})p_{HL,1} & F_{LL,2} & F_{HL,2} & F_{LL,3} & F_{HL,3} \\ s_{L,1}(1-g_{L,1})p_{LH,1} & s_{H,1}(1-g_{H,1})p_{HH,1} & F_{LH,2} & F_{HH,2} & F_{LH,3} & F_{HH,3} \\ s_{L,1}g_{L,1}p_{LL,1} & s_{H,1}g_{H,1}p_{HL,1} & s_{L,2}(1-g_{L,2})p_{LL,2} & s_{H,2}(1-g_{H,2})p_{HL,2} & 0 & 0 \\ s_{L,1}g_{L,1}p_{LH,1} & s_{H,1}g_{H,1}p_{HH,1} & s_{L,2}(1-g_{L,2})p_{LH,2} & s_{H,2}(1-g_{H,2})p_{HH,2} & 0 & 0 \\ 0 & 0 & s_{L,2}g_{L,2}p_{LL,2} & s_{H,2}g_{H,2}p_{HL,2} & s_{L,3}p_{LL,3} & s_{H,3}p_{HL,3} \\ 0 & 0 & s_{L,2}g_{L,2}p_{LH,2} & s_{H,2}g_{H,2}p_{HH,2} & s_{L,3}p_{LH,3} & s_{H,3}p_{HH,3} \end{bmatrix}$$

Figure 7.6.30 Example of matrix model with two alternative life strategies (H and L): S indicates survival; g indicates growth; p the probability of changing from one strategy to the other; and F indicates the fecundity towards each strategy. Reproduced from (Pfister & Wang, 2005).

Future work on the current dataset and results should aim to estimate the importance of environmental variables and population genetic structure on explaining the different population dynamic patterns encountered here. The relative importance of environmental variables such as fresh water productivity, temperature, river size, marine food availability, predation, fishing pressure, and population genetic structure on the elasticities of λ to certain transitions of life history patterns should be explored. Associations between environmental or genetic patterns and life history strategies would allow modelling the potential impact of changes on those patters on the population dynamics parameters of sea trout populations around the Celtic and Irish Seas.

The current models could be improved through integrated projection models (IPMs), in which several sources of data (e.g. scale reading data to estimate life history, fisheries data to estimate census size, mark-recapture data to estimate survival, and published data to estimate unsampled transitions) can be incorporated into a single model (Ellner & Rees 2006; Abadi *et al.* 2010; Schaub & Abadi 2011; Metcalf *et al.* 2013). All sources of uncertainty due to process variability and sampling error can also be included through state-space models (Buckland *et al.* 2004; Petris & Petrone 2011), and thus confidence on parameter estimate can be evaluated as well. The IPMpack (Metcalf *et al.* 2013) offers the possibility of constructing IPMs based on continuous demographic variables, such as weight, and allows the inclusion of complex life cycles and independent covariates, such as environment or genetic population membership. Future work on the dataset presented here should aim to produce IPMs where the different sources of data are incorporated and the uncertainty in each of the estimated parameters is reported.

7.6.6 Use of life history information to evaluate fisheries

Resourcing and time problems with delivering in full the modelling component of the Task prevented comprehensive demonstration of full life cycle models for management applications. This may be done in follow-up reports as resources permit. However, some basic principles emerged from the preliminary exploration of age-specific life tables based on data from Welsh rivers, which were more extensive than elsewhere.

High fecundity potentially maintains anadromy in partially migrating populations

Life tables were set up to represent separately migratory and resident contingents of a putative partially migrating sea trout population, and the two independently derived estimates of R_0, were summed to give an index of total eggs per generation. R_0 is defined as the net reproductive rate (e.g. Gotelli, 2008), the number of female eggs per female per generation, discounted for mortality. The tables are indicative only, but based on data for the river Dee, North Wales. Growth and survival were made to vary between the two contingents and for the residents to alternatives of fast and slow growing population were included. For the migratory fish survival, growth rate, maturation and proportions mature females were taken from the Dee trap data, pooled for the period 2003-2007. For the resident contingent the proportions mature were taken from a study of maturation in Welsh trout (Hoggarth, 1992); annual survival post 0+ was assumed to be constant at 40%; growth was taken from literature values of length at age in contrasting populations of fast and slow growth rate. Survivals, growth and fertilities of the contingents are shown in Figure 7.6.31. The proportions of females in migratory and resident were assumed constant at 0.8 and 0.5 respectively. Values of $R_0=\sum l_x m_x$ were calculated for each contingent, summed and the percentage of the sum from the migratory contingent plotted against P_a (Figure 7.6.32).

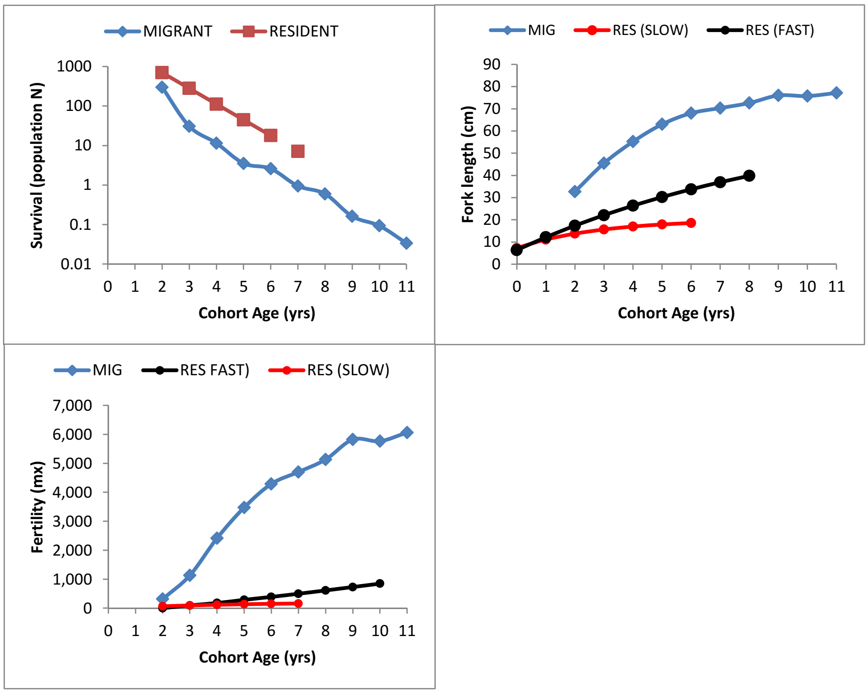


Figure 7.6.31 Age-specific survival growth and fertility (age specific fecundity x proportion mature) in trout migratory and anadromous contingents, assumed to apply for purposes of calculating relative reproductive contributions.

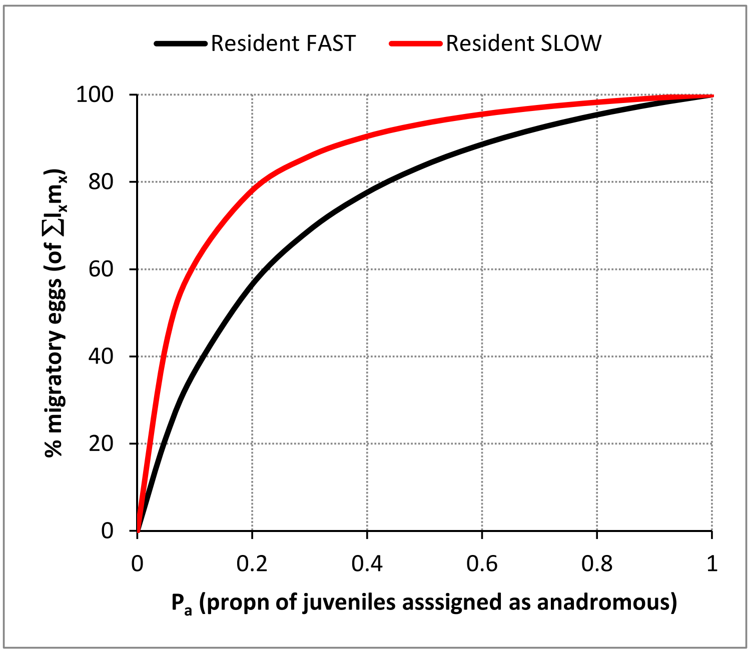


Figure 7.6.32 The simulated relationship between the proportion of migratory trout juveniles (P_a) assigned to a cohort and subsequent eggs of migratory parent origin, expressed as % of $\sum l_x m_x$. Lines for fast and slow growing residents are shown, see text.

Simple life table representation of partially migrating populations (part resident part anadromous) demonstrates that the sea trout females dominated egg deposition (Figure 7.6.32) even at low P_a values and therefore the proportion of juvenile trout that had migratory parents and might therefore be likely to be also anadromous. For example if 20% of juveniles were anadromous the percentage of eggs of migratory parents in the resulting cohort was 78%. This simplified calculation has no mechanism for adjusting P_a, in response to environmental factors between egg and smolt stages and results from the greater age-specific fertility of anadromous females. Anadromy of the progeny is therefore based only on the notion that there is some genetic basis to anadromy that, as a threshold quantitative trait (Ferguson, 2006), sensitises fish to whatever environmental factors might trigger smolting e.g. food supply and growth rate (Cucherousset *et al*., 2005; Olsson *et al.*, 2006; Wysujack *et al*., 2009; Dodson *et al*., 2013).

The implication of this result is that if, for a particular stream population, the anadromous habit is a favourable life history tactic, then it will tend towards the "sea trout" morph, and is self- reinforcing. Consequently, genuine sympatry (i.e. females living in the same meso-habitats) of the two morphs would be expected to be rare. In contrast to resident females, resident sympatric males are functionally part of "sea trout" populations and in that sense represent the non-migratory part of partially migrating populations. Anadromy has been shown to vary within catchments along environmental gradients in rainbow trout (*Onchorhynchus mykiss*) (Mills *et al*., 2012) Dolly Varden char (*Salvelinus malma*) (Koizumi *et al*. 2006) and in brown trout (Olsen and Greenberg, 2004; Cucherousset *et al*., 2005; Jonsson and Jonsson, 2006) and this gradation appears to be inconsistent with "all or nothing" anadromy. A further complexity is that resident females can produce anadromous offspring in rainbow trout, which has been suggested as a means to let anadromy persist in areas where anadromous fish abundance is low due to natural or anthropogenic influences (Courter *et al*., 2013). However, it would be useful to test if these populations comprise genuinely sympatric females. Anecdotal evidence suggests that partial migration *within a catchment as a whole* is common and not unexpected; because the spatial variation in environmental factors that might trigger anadromy can be considerable even within quite small catchments such as the River Conwy, North Wales (e.g. Milner *et al*., 1998). The suggested tendency towards "all or nothing" nature of most sea trout freshwater populations might therefore be an approximation i.e. some genuine partial migration (sympatry of resident and anadromous females) does occur. Nevertheless, if confirmed it would be important for monitoring and for life history modelling. This is because, while combined densities of males and females are still important for production and competition, the complexities of life history analysis of females might be ignored for practical assessment purposes.

Evaluating Impacts of Competing Fisheries

Fishery regulations for sea trout and salmon are set differently in the countries of the British Isles according to several criteria, which can include biological reference points such as Conservation Limits (for salmon). For sea trout decisions have to be made regarding the impacts of rod and net fisheries on returning runs and these are usually made on the numerical size of catches sometimes complemented by various arbitrary socio-economic considerations.

Catch numbers alone have shortcomings as indices of impacts if the fisheries are size-selective because the lifetime egg contributions of their catches will differ according to the size distribution of the catches. Life table approaches can offer some insight into these effects. A simple example of this is shown for the Afon Tywi in South Wales. Rod and net catches (coracles and seine nets) were available for the year 2010 and illustrate the size selective nature of the fisheries (Figure 7.6.33); with the nets taking higher proportions of the larger fish and the rod catch dominated by whitling.

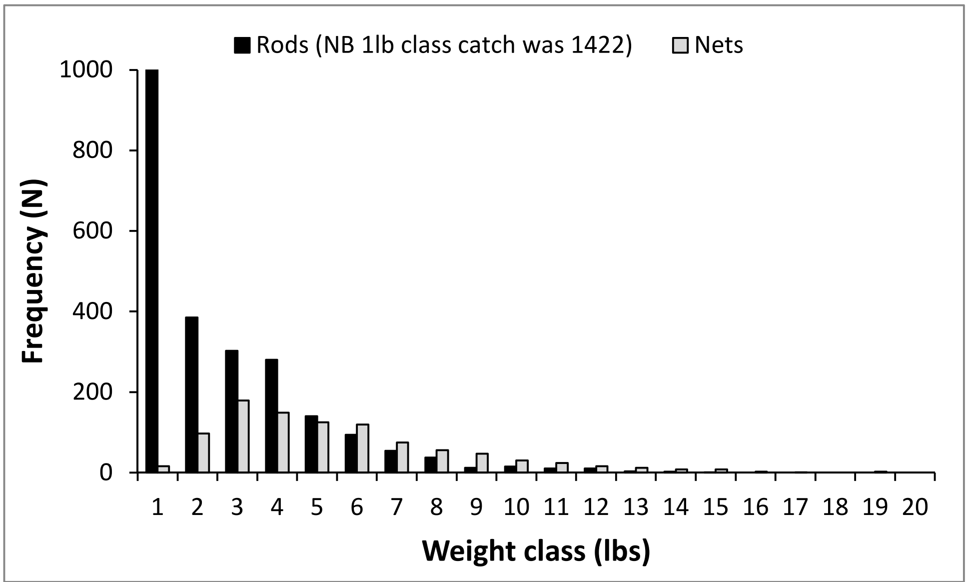


Figure 7.6.33 Size-frequency distributions of rod and net (seines plus coracles) catches, Afon Tywi, 2010. NB the scale does not include the <1lb group catch which was 1,422. Nets are combined data for coracle and seine net fisheries.

Population indices were based on previous, more extensive size frequency data from the rod catches pooled for 2003-2007 to give 5 yr average values of size frequency. These were transformed to age frequency data ($N_{x,}$ where x is the sea age,Table 7.6.17) by a weight-age key derived from the River Dee trap catches for the same period.

A partial life table was constructed (Figure 7.6.34) from which overall average annual survival (S) was estimated by regression of ln(N_x) against sea age, as done in Section 7.6.2. S was estimated as 42.5%. Individual year annual survival ($P_x = N_{(x+1)}/ N_x$) was also calculated for the Twyi (Table 7.6.17), but this appeared to be influenced by the comparatively small sample sizes. A better data set for estimating P_x, suitable for this illustrative purpose was from the Dee trap where a larger and less biased sample was available for 2003-2007 (Table 7.6.17). Fecundity (eggs/female) was derived from Solomon (1997); proportions or females and maturity at age were based on River Dee data. Fertility (m_x) is the eggs per female at sea age x, adjusting for the proportion and maturity of the females.

Table 7.6.17 Basic life table data for the rivers Tywi and Dee, Wales. Nx values are abundances at age as 5 year means 2003-2007, indexed by rod catch (Tywi) and trap RSE estimate (Dee). P_x is the proportional annual survival from year x to year x+1.

	Afon Tywi rod data								River Dee trap data	
sea age (yrs), x	N_x (5yrmean)	P_x	Wt (kg)	Length (cm)	Fecundity	Propn female	Propn mature	Fertility (m_x)	N_x (5yrmean)	P_x
0	1806	0.47	0.42	32.7	711	0.6	0.55	117	9484.04	0.10
1	852	0.53	1.14	45.5	1,767	0.72	0.8	509	972.48	0.37
2	453	0.31	2.05	55.2	3,017	0.8	1	1207	363.81	0.31
3	139	0.47	3.05	63.0	4,343	1	1	2171	111.81	0.73
4	66	0.29	3.84	68.0	5,362	1	1	2681	82.18	0.36
5	19	1.00	4.24	70.3	5,877	1	1	2939	29.94	0.63
6	19	0.21	4.67	72.6	6,414	1	1	3207	18.92	0.27
7	4	0.25	5.36	76.0	7,278	1	1	3639	5.10	0.58
8	1	1.00	5.30	75.8	7,206	1	1	3603	2.94	0.36
9	1	0.00	5.60	77.2	7,580	1	1	3790	1.06	0.00

Using this composite table the future remaining life time egg depositions for females was estimated for fish of each age x using two ways of deriving P_x: (1) assuming constant S (=constant P_x) over sea lifetime (the regression method) and (2) calculating individual P_x annually (using the Dee data).

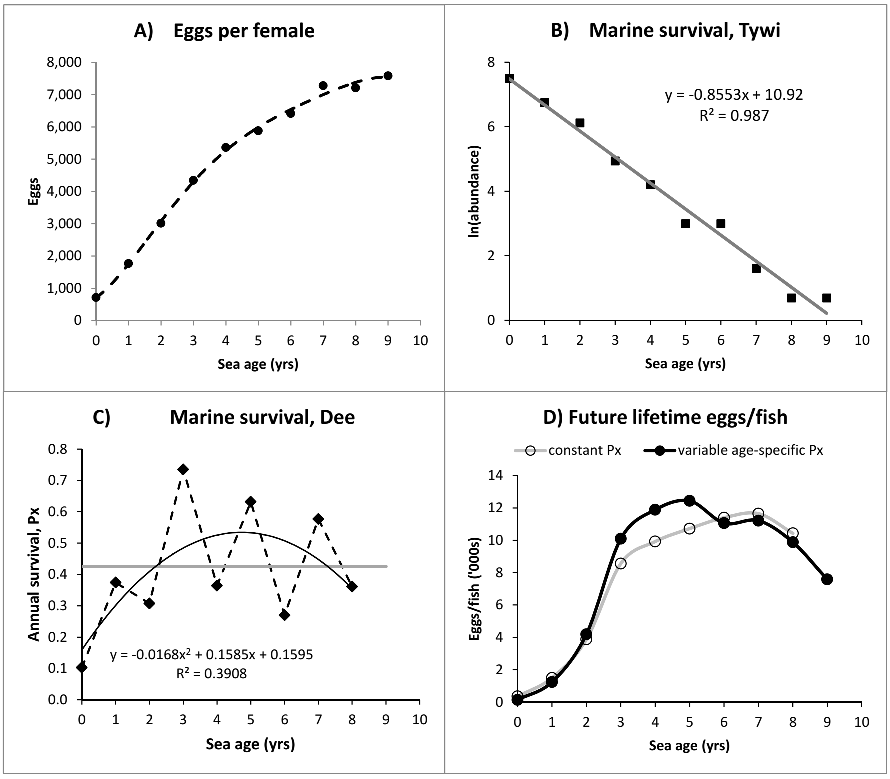


Figure 7.6.34 Life table variables and derivation of future life time eggs per fish at sea ages 0 to 9. A) fecundity at age (Tywi), B) adult survival with constant P_x (Tywi), C) adult survival with P_x varying with age (from the Dee, polynomial curve fitted to the black diamonds), D) Eggs per fish caught (male and female combined) for the two ways to derive annual survival (open circles - constant Px black filled circles - polynomial,).

Future lifetime eggs produced per fish caught (males and females combined) peaked at different time depending on the alternative assumptions of constant or fluctuating P_x: future eggs peaked at around 5 year and 7 years respectively (Figure 7.6.34). Several alternative metrics can now be calculated and compared for the relative impacts of the fisheries' catches details are in Appendix7.10 and are summarised in Table 7.6.18.

Table 7.6.18 Comparison of metrics for the impacts on sea trout stock "health" of annual rod and net catches from the Afon Tywi, 2010.

Metric	Rods	Coracles	Seines	Nets combined	Total
total Numbers (catch)	2,764	653	311	964	3735
%	74	18	8	26	
total wt (lbs)	6,721	3,747	1,524	5,271	12,035
%	56	31	13	44	
Eggs in year	1,802,761	1,042,608	419,688	1,462,296	3,265,057
%	55	32	13	45	
Future (constant Px)	5,936,339	3,664,586	1,440,401	5,104,987	11,041,325
%	54	33	13	46	
Future (variable Px)	5,947,986	4,046,467	1,556,860	5,603,328	11,551,314
%	51	35	13	49	

On the basis of fish catch numbers, the rods comprise 74% of the fishery "impact". However, in terms of the future life time eggs, of the current year and beyond, the rod fishery impacts was 51%-54% assuming variable and constant P_x respectively. The impact of the combined net fisheries was comparatively low in terms of fish numbers (26%), but 46%-49% in terms of future eggs. In terms of weight of catch alone the rod and net fisheries took were 56% and 44% respectively, close to the future egg depositions attributed to each fishery.

7.6.7 Commentary on modelling

The fisheries comparison example suggested that catch weight is a good surrogate for egg production (because of the dominance of females in the run and the fecundity size relationship) and an improvement on numbers as an index of the reproductive impact of catch. There appeared to be little benefit in incorporating proportional annual (P_x), which is imprecise given the variability and uncertainty of catch data. However, the true pattern of change in annual survival with age may be more important when life tables are taken up into projection models for future population size.

As noted above the evidence on age-specific survival is conflicting. Instantaneous mortality is rarely constant throughout life (Type II mortality, e.g. Krebs, 2013). More likely, survival might be expected to be low in the first post-smolt year, to increase somewhat as size advantages arise and to decrease again in the oldest classes if senescence becomes a factor in survival. Close inspection of Dee data (which are regarded as the most reliable, the others being based on rod catches) gives some support to this, but these were inconsistent.

Peaking of eggs per fish at intermediate ages (or weights, the calculations can be simply transposed to weight categories using an age /size key); might be taken to imply that fish either side of the peak have less fitness "value". In terms of egg production alone that is true, but caution is needed before taking this to mean less exploitation regulation on these groups, or even the adoption of slot limits. Size-selective fishing crops different parts of the collective genome, or genetic diversity of the population. Because the overall fitness potentials are unknown it is hard to judge the impact of the loss of any particular component. It could be argued that the largest fish have particular value because, if spawning site fidelity applies, they are adapted to spawn in main stem channels and in larger gravel sizes than smaller fish. Small channels are, by their hydro-morphology, more prone to environmental variation (e.g. flow and temperature); therefore it makes evolutionary sense to spread reproductive effort around the diversity of stream types in a catchment. This raises a question about adaptation and homing. If sea trout do home tightly to their natal areas and if smaller fish preferentially use smaller gravel sizes in small channels (Crisp, 2000), where does this leave those of their progeny which survive to large size? Would they therefore be less well adapted to spawning in their natal gravels? The converse applies also: small (whitling) progeny of large spawners (depositing eggs in large gravels) would be apparently maladapted to spawn in their natal gravels. Either there is in practice only loose attachment to spawning sites, or there is a strong genetic inheritance of age (=size) of return. The precautionary approach would be to avoid or minimise selective exploitation and use these reproductive based metrics to compare between fisheries rather than to promote selective exploitation.

7.7 Hydrodynamic Modelling of Sea Trout Movements In The Irish And Celtic Seas

7.7.1 Summary

Hydrodynamic modelling was undertaken to describe the possible pattern of movements of sea trout from different rivers/regions in the Irish and Celtic Seas and to estimate the environmental conditions that may be experienced by these fish during the marine phase of their life-cycles. The patterns of currents in the Irish and Celtic seas are complex; they vary significantly between summer and winter periods and are strongly influenced by weather conditions. The hydrodynamics were therefore modelled for specific years using the three-dimensional General Estuarine Transport Model (GETM), which simulates the most important hydrodynamic and thermodynamic processes in natural waters. A particle tracking module within this model was used to evaluate scenarios for the possible movements of sea trout post-smolts during the first year in the sea. These scenarios were compared with information on the distribution of sea trout in the Irish and Celtic Seas derived from the genetic assignment of fish sampled at sea back to their region of origin. The results indicate that a significant proportion of the fish remain relatively close to their river of origin. This behaviour was simulated by proposing that fish tend to hold position when at or close to a preferred depth (a depth of 20m was selected) and swim more actively in a random direction as they move away from that depth. Where fish undertook longer distance migrations, these appeared to be strongly influenced by the prevailing currents. The simulated tracks were also used to estimate the temperature conditions that may have been experienced by fish from different rivers. This confirmed that fish from rivers in the north of the study area (e.g. River Luce) are likely to experience about 10% fewer degree-days over a given period in the first year at sea than fish from the southern rivers (e.g. River Twyi). However, stocks from rivers in the south and south-east of Ireland, particularly the River Argideen, probabaly experience cooler conditions than those from Welsh rivers at the same latitude.

7.7.2 Introduction

The work described in this section formed part of Task 7 of the EU Celtic Sea Trout Project, the objectives of which were "*to enhance and support the sustainable use, protection and management of sea trout resources through the description of marine phase ecology and the development of a process-based, spatially structured, practical model of life history variation and responses to environmental pressures in the Celtic seas, using historical and contemporary biological material, and building on existing knowledge of ecological processes in sea trout* ". This Task therefore aimed to investigate and describe the linkages between biological traits such as river and sea age, anadromy, growth and maturation and environmental variables both in the sea and freshwater. These relationships were explored in an attempt to explain the basis of temporal and spatial patterns in sea trout life histories and abundance and the implications for fisheries management.

A key element of this work was to investigate factors affecting the movements of sea trout in the marine environment, the conditions they experience and the potential effects on the life history variation both within and between river stocks. The hydrodynamic modelling had two principal purposes:

- to describe the possible distribution and pattern of movements of sea trout from different rivers/regions in the Irish and Celtic Seas; and
- to estimate the environmental conditions that may be experienced by fish from these rivers during the marine phase of their life-cycles.

The first phase required the development and running of a three-dimensional General Estuarine Transport Model (GETM) to model the currents, temperatures and salinity throughout the Irish and Celtic Seas for given periods. The second phase used the outputs of this model in a particle tracking module to simulate possible migration trajectories for sea trout from different rivers/regions. Data could then be extracted on the conditions (e.g. temperature and salinity) that would have been experienced by each simulated fish during its migration in order to assess differences in growth opportunities for the fish originating from different rivers and possible consequences for population growth and structuring.

7.7.2.1 Hydrodynamics and Particle Tracking Model

Hydrography of the Irish and Celtic Seas

The main topographical features of the Irish Sea are a deep channel in the west, with shallower embayments to the east of the Isle of Man (the Eastern Irish Sea and Cardigan Bay). The channel is open-ended, forming part of a loop which is connected to the Atlantic Ocean at both ends, in the south via the St. George's Channel and the Celtic Sea and in the north, via the North Channel and the Malin Shelf Sea (Howarth, 1984). The channel is about 300 km long and 30 – 50 km wide, with a depth generally ranging from 90 – 110 m but with a maximum exceeding 275 m in the North Channel. The Celtic Sea is an embayment opening out from St George's channel, with depth range between 30 to 120 m (Carrillo, *et al*, 2005). Its bottom topography is characterized by an elongated basin, the Celtic Deep, which is about 100-110 m deep and extends roughly south-west from St. George's Channel towards the centre of the Celtic Sea. The tidal pattern takes the form of a standing wave with its velocity node in the centre of the Western Irish Sea. Thus tides here are weak (< 25 cms^{-1}) as is the vertical mixing, whereas in the North and St Georges Channel tides are strong (> 100 cms^{-1}) and vertical mixing is strong (Robinson 1979).

Residual current patterns in the Celtic and Irish Seas are complex. Ramster and Hill (1969) deduced, from seabed drifter returns and moored current meters, that there was a general northward transport across the Irish Sea basin with a mean flow of 1 - 2 km d^{-1}. Bowden (1980), however, highlighted the importance of wind to the northward flux through the Irish Sea and in forcing water through the North Channel. Modelling studies and high frequency observations have since shown the extent to which the residual flow in Irish Sea is strongly dominated by wind driven transport in the winter, when flushing of the Celtic-Irish Sea system can occur rapidly (Young *et al*., 2001).

In the summer, the establishment of thermal stratification in the Celtic Sea and a strong thermal front in the St Georges results in little or no transfer of water into the Irish Sea at depth and relatively little surface exchange (Hill *et al*., 2008). This also limits the net movement of water out of the Irish Sea through the North Channel, although there are weak northerly currents on the eastern side and southerly currents on the western side. The thermal stratification in the Celtic Sea and similar stratification in the western Irish Sea largely eliminate flows between these and neighbouring areas and result in anticlockwise gyres developing at depth, although surface currents are also affected by eddies and wind.

7.7.2.2 Hydrodynamic Model of the Irish and Celtic Seas

The hydrodynamics of the Irish and Celtic seas were simulated for specific years using the three-dimensional General Estuarine Transport Model (GETM) (www.getm.eu, Burchard & Bolding, 2002). The GETM simulates the most important hydrodynamic and thermodynamic processes in natural waters (van der Molan *et al*, 2007). The model solves the three-dimensional shallow-water equations, which mathematically describe the water motion in coastal seas and also solves advection-diffusion equations to model seasonal changes in temperature and salinity.

The resolution of the hydrodynamic model is approximately 3.5 km in the horizontal direction, and the water column is divided into 25 non-equidistant layers, which are organised to enhance resolution near the surface and the seabed. The results of the hydrodynamic computation are stored at hourly intervals and are then used, in a post-processing mode, to drive a separate behavioural and particle-tracking model for the development and transport of eggs, larvae or fish (see below).

The GETM was run on a spherical grid and the Irish Sea model domain extended from Latitude 9.65°W to 2.82°W and Longitude 51.0°N to 56.9°N. The model was forced with realistic winds, temperature and humidity data derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) operational reanalysis obtained through the British Atmospheric Data Centre (badc.nerc.ac.uk). The open boundaries were forced with tidal elevations and depth-averaged velocities derived from a barotropic shelf-wide model setup using Flather boundary conditions (Flather, 1976; Carter & Merrifield, 2007). The shelf-wide model was forced with tidal elevations derived from gridded harmonic constituents based on Topex Poseidon satellite altimetry. In addition, the open boundaries were forced with depth-resolved climatological boundary conditions for temperature and salinity based on the World Ocean Database (www.nodc.noaa.gov). Fresh water was introduced into the model at river mouth locations based on observations. UK data was processed from raw data provided by the Environment Agency (England and Wales, contains Natural Resources Wales information © Natural Resources Wales), the Scottish Environment Protection Agency (Scotland), the Rivers Agency (Northern Ireland) and the National River Flow Archive. Irish flow data was provided by Hydrodata and the Environment Protection Agency (Hydronet). The model was run on the Cefas High Performance computing cluster at Cefas, Lowestoft.

7.7.2.3 Particle Tracking Model

The General Individuals Tracking Model (GITM) is an Individual Behaviour Model integrated as a module within the hydrodynamic model, GETM. When the GETM hydrodynamic model is run, the three-dimensional flow fields are stored every hour; these are then used off-line by the GITM to calculate particle advection and diffusion taking account of biological development and behaviour of the simulated fish. The advection-diffusion elements of the GITM were based on a re-coded version (Nagai *et al*., 2003) of the Lagrangean advection-diffusion method developed by Wolk (2003). The method uses a semi-analytical advection method, which ensures that particles follow stream lines exactly, and a random walk method with advective correction (Visser, 1997) to simulate diffusion (Hunter *et al*., 1993), which uses a constant diffusion coefficient in the horizontal and a variable diffusion coefficient in the vertical that is based on the vertical diffusivity obtained from the turbulence closure model in the GETM.

The biological development and behaviour module of the GITM allows particles (i.e. the fish being simulated) to progress through a user-defined number of development stages (eggs, larvae, etc). Development can include various states, from ‘passive’ (no behaviour or growth) to ‘active’ (with behaviour and growth); development of and between each state can be linear, temperature-dependent or, for the active states, size-dependent. For each stage, particles are subject to a growth rule that defines their progression to the next stage, potentially using local environmental characteristics derived from the hydrodynamic model (e.g. water temperature). Mortality can also be introduced as a constant daily rate or a temperature-dependent rate.

The particles can display various forms of vertical migration behaviour (e.g. constant buoyancy, diel or tidally cued vertical migration), which affects their horizontal dispersion. The speed of horizontal migration can be related to environmental parameters (e.g. swimming faster in deeper water or warmer temperature) while the horizontal direction of migration can be purely random or oriented with or against the current direction. Finally, particles can display various forms of settling behaviour based on local physical conditions (e.g., temperature, salinity) or user-defined spatially varying parameters (e.g. sedimentary environment, depth, adult distributions).

As part of this project, two new behaviours were introduced in the particle tracking model. The first permits the model to generate movements in a random direction, while the second mimics any tendency of the fish to remain close to the shore rather than moving offshore. This latter behaviour was simulated by relating swimming speed to the water depth, leading to a particle tending to remain close to areas of a chosen depth.

7.7.2.4 Validation and Testing of Hydrodynamic Model

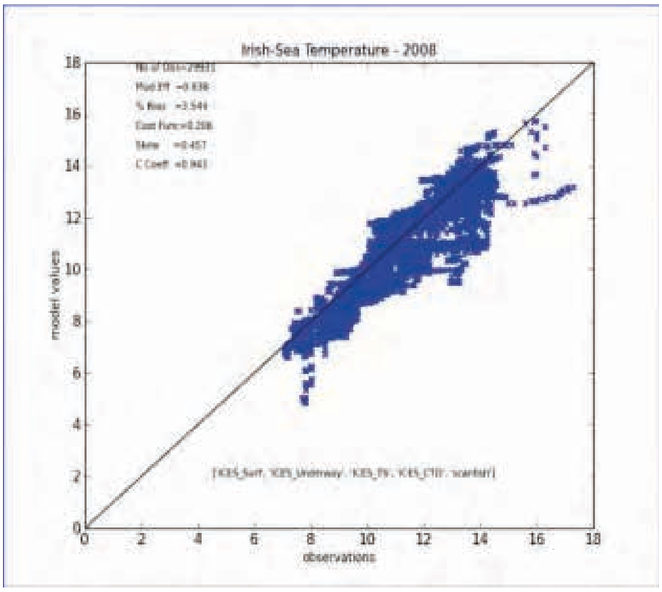
The use of multivariate data from a three-dimensional density-resolving model such as the GETM necessitates a validation procedure to gain a quantitative measure of the model's performance against quality checked and accredited observations. The validation gives confidence in the performance of the model in respect of advection of temperature and salinity. The performance of the GETM model over the Irish Sea domain was checked for the year 2008. Observations to validate model performance were taken from the ICES databases for ICES 'Surface', 'Underway', 'Temperature and Salinity' and 'CTD' data (www.ices.dk/marine-data/Pages/default.aspx); and observational data collected during Cefas cruise deployments. Each observation within the spatial and temporal limits of the 2008 GETM model, was matched with its corresponding modelled point at the nearest node (lat and long position) and layer (depth) of the modelled area.

A suite of statistical tests was used to compare the model data against observational data. Tests for the Nash Sutcliffe model efficiency, percentage model bias, cost function, skewness and correlation were evaluated, and the validation criteria were as described in Allen *et al.* (2007). The expected limits for three of the parameters are shown in Table 7.7.1; skewness and correlation are considered in the results section below.

The hydrodynamic model performs differently with respect to temperature and salinity. Using almost 30,000 temperature observations in the domain area matched with corresponding model values (Figure 7.100), a high overall correlation was achieved (R^2 = 0.943). The model efficiency, bias and cost function all fall in the 'excellent' categories from the application of the validation criteria (Allen *et al.* 2007). The skew of the dataset, however, is adjudged to be significant, with a value greater than 0.15. The positive skew of 0.457 determines that the model tends to make more underestimations than overestimations.

Table 7.7.1 Model Validation Procedure - Classification limits for three parameters used in comparison on observed and modelled hydrodynamic data (from Alan et al., 2007).

Parameter	Excellent	Very Good	Good	Poor
% Efficiency	> 0.65	0.65 - 0.5	0.5 - 0.2	< 0.2
Model Bias %	< 10	10 – 20	20 – 40	> 40
Cost Function	< 1	1 – 2	2 – 5	> 5



No of Points 29,931

Model test	Test result	Class'n
% Efficiency	0.838	Excellent
% Bias	3.544	Excellent
Cost Func	0.206	Excellent
Skew	0.457	
Correlation R^2	0.943	

Figure 7.7.1 Irish Sea Model Validation – Temperature

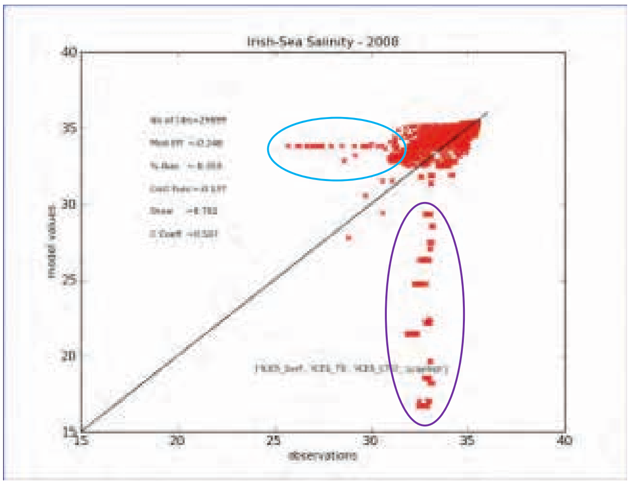
For salinity, the results have greater variance and some distinct areas of outliers are apparent (Figure 7.7.2). The performance of the model remains classified as 'excellent' in respect of model efficiency, bias and cost function, but the dataset is further skewed as a result of the outliers and the overall correlation value is reduced (R^2 = 0.507).

The outliers fall into two categories:

- where modelled values were significantly less than those observed; and
- where observations were significantly less than those modelled.

In these terms the outliers are categorised as significant if the observed value differs from the modelled value by more than two standard deviations. The two sets of outliers are ringed on Figure 7.7.2 in magenta and blue respectively.

There were 74 outlier positions in the first category, where modelled values were significantly less than those observed; with data collected at different water depths, this gave a total of 204 data points, 0.68% of the total test sample of 29,231 points. These points are located adjacent to the Isle of Mull (Figure 7.7.3) where modelled salinity is affected by input from freshwater catchments in the Western Highlands. This is outside the main CSTP study area, and this error is unlikely to affect the results.



No of points	**29,899**	
Model test	**Test result**	**Class'n**
% Efficiency	-0.248	Good
% Bias	-0.359	Excellent
Cost Func	-0.137	Excellent
Skew	8.72	
Correlation R2	0.507	

Figure 7.7.2 Irish Sea Model Validation – Salinity

Figure 7.7.3 Points where modelled salinity was significantly less than observed values.

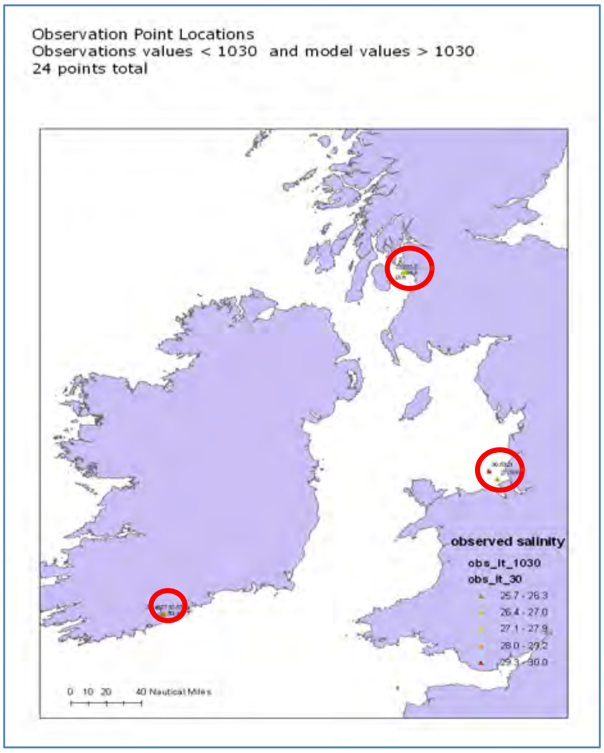


Figure 7.7.4 Points where observed salinity was significantly less than modelled values.

The second category of outliers is attributed to 24 shipboard observations recorded in Liverpool bay, Cork harbour and the Firth of Clyde where salinity was observed to be lower than the modelled result (Figure 7.7.4). This represents only 0.08% of the tested points and the affected locations are mainly outside the main CSTP study area.

It should be noted that predictions of density are likely to be unreliable near the open boundaries of the model, because a combination of climatological open-boundary conditions for temperature and salinity and hind-cast wind and temperature are used. Also, the model cannot reproduce the density structures in areas such as Liverpool Bay in detail; as such conditions still represent a major challenge to physical models.

7.7.2.5 Use of the Hydrodynamic Model

Once run for a specific year, the hydrodynamic model can provide estimates of the temperature and salinity at any point in the Irish Sea region, at any depth and at hourly intervals through the year. Figure 7.7.5 shows temperature profiles from the Irish Sea model at locations in Dublin Bay and Cardigan Bay derived from the 2008 run of the Irish Sea model. This demonstrates the model's representation of temperature stratification during the spring and summer months off Dublin Bay whereas a fully mixed water column is retained throughout the annual cycle in Cardigan Bay.

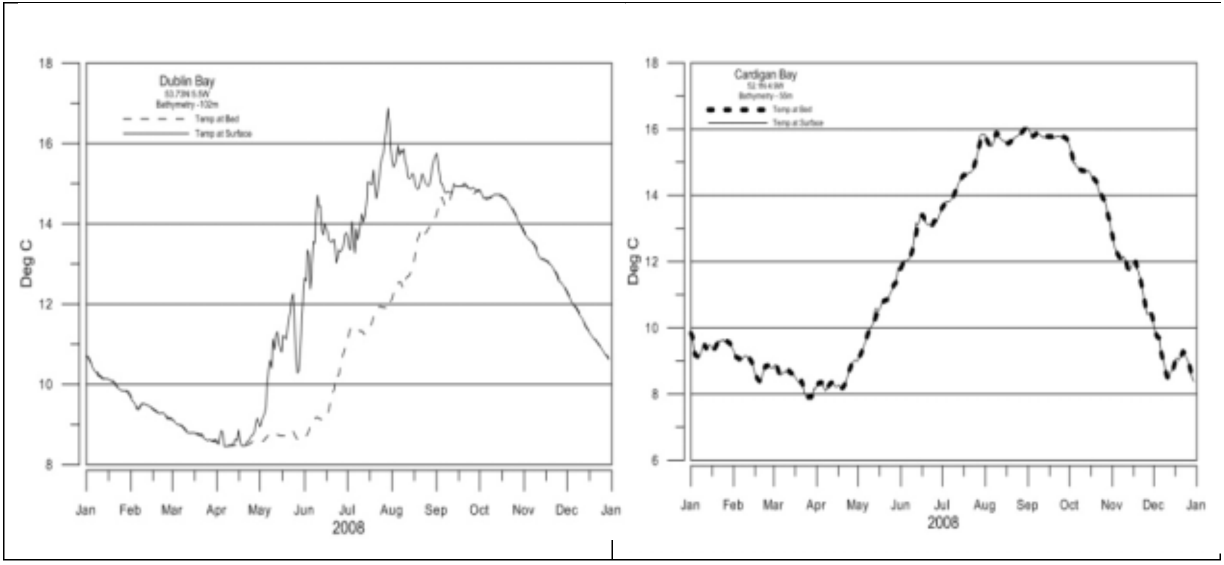


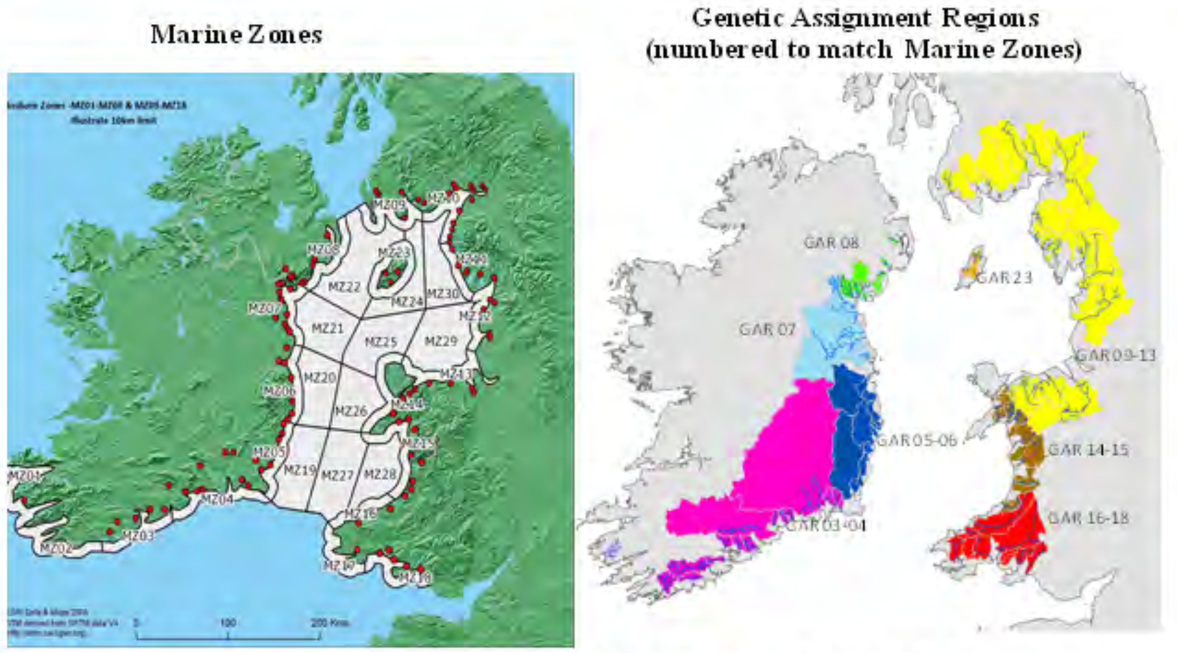
Figure 7.7.5 Estimated mean daily temperature in Dublin Bay (LH panel) and Cardigan Bay (RH panel) at the surface (solid lines) and sea bed (dashed lines) from January 2008 to January 2009 derived from the GETM hydrodynamic model.

Biological and Genetic Data

7.7.2.6 Biological Sampling

Survey programmes were undertaken to sample post-smolt and adult sea trout in various 'marine zones' around the Irish Sea (Figure 7.7.6) using a variety of different fishing methods. Full details of the sampling are provided under Task 3. The biological and genetic data derived from these programmes provide a means to develop a crude picture of the migration patterns of fish originating from different regions against which simulated tracks can be compared.

Scale samples were taken from all fish sampled at sea and were read to estimate the river age, sea age and spawning experience of the fish. Full details of the scale reading work are provided under Section 7.3.1. Length and weight measurements were taken either from fresh samples or samples that had been frozen and then thawed. The process of freezing and thawing tends to result in fish getting both shorter and lighter. Samples that had been measured both fresh and thawed were therefore used to develop a conversion factor for the thawed fish lengths [Fresh length (mm) = 1.02 x thawed length + 3.2579 ($r2 = 0.9825$)]. All subsequent analysis of lengths in this section is based on the fresh lengths or, where these were not available, the converted thawed length, and the values are all referred to as 'lengths'.



Key to Genetic Assignment Regions (GAR):

GAR 03-04	Ireland – South	GAR 09-13	Solway/Morecambe
GAR 05-06	Ireland – South-east	GAR14-15	Wales - West
GAR 07	Ireland – North	GAR16-18	Wales - South
GAR 08	Ireland – North-east	GAR23	Isle of Man

Figure 7.7.6 Marine Zones for sampling of sea trout at sea (LH panel) and Genetic Assignment Regions.

7.7.2.7 Genetic Assignment Analysis

The genetic analysis used a baseline dataset of over 5500 genetic samples collected from over 100 rivers around the CSTP area. Analysis of the baseline dataset also identified regional groupings, based on genetic differences and geographic areas (Figure 7.7.6 RH panel). Tissue samples were taken from all fish sampled at sea and were used for genetic assignment analysis to assess their likely river and region of origin, by comparison with the baseline dataset. Full details of this analysis are provided under Task 4.

The river assignments represent the best assignment for the marine caught fish to one of the rivers/regions in the baseline genetic dataset. Assignment scores were provided using the principal assignment methods, Geneclass and ONCOR (see Task 4). Geneclass is based on the likelihood of a genotype occurring in a particular river sample, i.e. that genotype has a higher probability that it belongs or is a better match to the sample of population 'A' rather than the sample of population 'B'. ONCOR is similar, however it attempts to learn from the mixture proportions in a given sample and corrects accordingly, the idea being that fish are not moving alone but in some biologically relevant aggregation. The accuracy of Geneclass and ONCOR assignment scores depend ultimately on the quality of the baseline, measured in terms of how well it reflects all the 'true' populations which are contributing to the mixture. For example, samples taken from brown trout rather than sea trout would not be true populations as they would not be contributing to fish in the sea. However, there are no unique markers, and it is possible for such assignments to provide misleading results because some fish will inevitably be misassigned. In addition, fish originating from rivers that are not in the baseline dataset will also be assigned to the most likely river in the baseline.

The results must therefore be interpreted with care. Assignments to regions may be expected to be more reliable than to rivers, and since they provide a convenient way to group the data, have been used in the subsequent analyses in this section. It is not possible to determine which of the Geneclass or ONCOR assignments are more reliable. However out of the 1212 assignments undertaken, 184 were assigned to different regions by the two methods. These have therefore been excluded from the subsequent analyses.

7.7.2.8 Scale Reading Data

When combined with the scale reading data, the genetic assignments can provide a crude picture of the distribution of fish originating from different regions over the months after they leave freshwater. The scale reading results are first required to identify fish that have not returned to freshwater between emigrating as smolts and their capture in the sampling programme (i.e. maiden fish) by excluding fish with spawning marks on their scales. Nearly all the fish recorded as having spawning marks (or possible marks) had fork lengths over 300 mm, indicating that most smaller fish were identified as maidens. This provides some confidence in the identification of spawning marks. A total of 460 maiden fish were identified in this way.

A sequential picture of the distribution of fish in the sea can then be obtained if all fish are assumed to have emigrated in the same year and the time at sea is estimated from the month of sampling plus the sea age in months (where sea age 0 = 0 months, sea age 1 = 12 months, etc); this is referred to as a 'lagged capture date'. (NB: smolt emigration occurs between months 2 and 5). However, applying the above approach revealed some anomalies in the scale reading results. Significant numbers of fish sampled between January and May were read as sea age 0 or 0+, despite having lengths over 300 mm, and some fish with lengths less than 200 mm were read as sea age 1 or 1+ (Figure 7.7.6). Both scenarios are likely to reflect errors in measurement or aging, and as the latter is more difficult and subjective it was assumed to be the source of the likely error. An alternative approach was therefore used to separate the 0/0+ and 1/1+ groups, using the *mixdist* package in R (R Development Core Team, 2008; Macdonald & Green 1988), which calculates parameter values and their standard errors for each distribution in a mixed population. This analysis was applied to the length frequency distributions for each month, or for groups of months when there were few samples (Table 7.7.2 and Figure 7.7.7); the function was seeded with starting values for the means lengths and standard deviations for 0/0+ and 1/1+ age groups of 300± 50 mm and 400±50 mm respectively. In five of the seven periods, the analysis identified a fairly clear split between 0/0+ and 1/1+ age groups, suggesting that dividing the groups in this way should provide few errors; in the other two months there was more overlap, although there were still relatively few samples in the overlapping zone. It was not possible to identify a third length group (i.e. sea age 2/2+ fish) using this approach, probably indicating that there were few, if any, maiden fish of this age in the samples.

These length splits derived from this analysis (Table 7.7.2) were used to re-assign the maiden sea trout into sea age 0 and 1 groups and revise the 'lagged capture date' values (Figure 7.7.8).

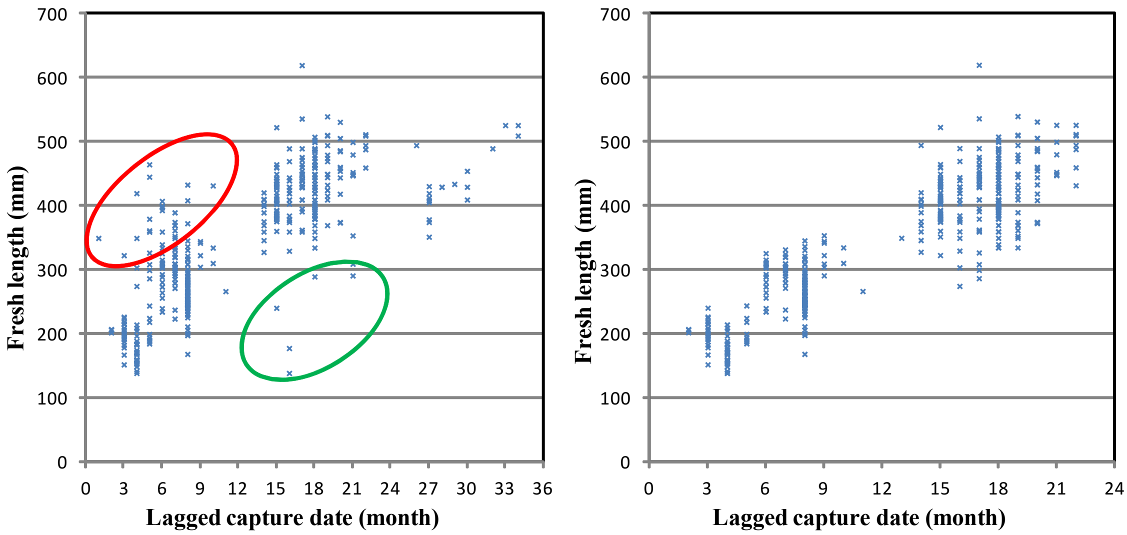


Figure 7.7.7 Fresh length of sea trout sampled in the sea against lagged capture date based on scale reading (LH plot) and on mixed distribution analysis (RH plot).

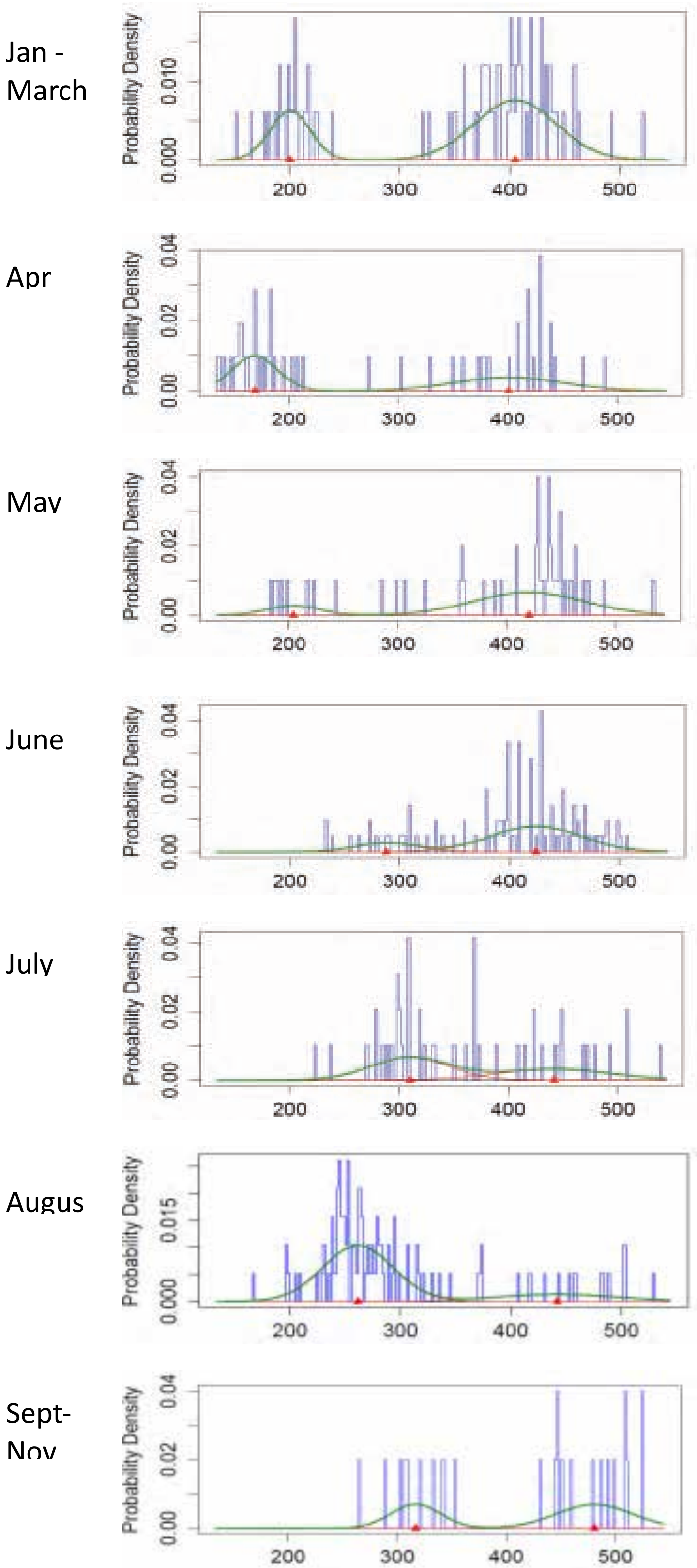


Figure 7.7.8 Mixed distribution analysis of monthly frequency distributions of maiden 0+ and 1+ sea trout caught in the Irish Sea.

Table 7.7.2 Estimated parameters for length distributions for monthly samples of sea age 0 and 1 maiden post-smolt sea trout and length splits based on mixed distribution analysis.

Month	Total number samples	Putative 0+ fish				Putative 1+ fish				Optimal length split
		prop'n of samples	mean	s.d.	Est' number	prop'n of samples	mean	s.d.	Est' number	
Jan-Mar	83	0.289	200.3	18.5	24.0	0.711	405.1	37.4	59.0	273.9
Aril	52	0.519	168.8	21.0	27.0	0.481	400.5	49.9	25.0	247.8
May	50	0.161	204.0	24.3	8.1	0.839	420.2	50.1	42.0	269.6
June	105	0.189	287.7	27.6	19.8	0.811	424.0	40.7	85.2	333.9
July	48	0.590	310.0	36.0	28.3	0.410	441.9	51.3	19.7	373.0
August	96	0.824	261.6	31.8	79.1	0.175	442.0	53.7	16.8	347.0
Sep-Nov	25	0.400	316.9	22.8	10.0	0.600	480.6	34.5	15.0	384.3

7.7.2.9 Distributions Based on Genetic Assignments

This section is based on a preliminary interpretation of the genetic data undertaken under CSTP Task 4 [Genetic Stock Identificiation] which may be subject to change with subsequent analysis.

There were 384 maiden sea trout in the marine samples which had the same genetic assignments by the Geneclass and ONCHOR methods; 140 of these were estimated to be 0/0+ and 244 were 1/1+. The genetic assignments provide the estimated origin of the sea trout sampled at sea, and the capture locations (Marine Zones) indicate where they had migrated to at the time of sampling. In order to make it easier to match the regions to which fish were assigned (Genetic Assignment Regions (GAR)) with the marine zones in which the sampling was undertaken, the GARs have been given the appropriate numbered code; thus GAR03-04 covers approximately the same area as Marine Zones 03 and 04, etc (Figure 7.7.6). When tabulated for successive periods, these results give an indication of the progressive migration or distribution of the fish over time (Table 7.7.3). A small number of fish that were genetically assigned to parts of England outside the CSTP area, probably the south-west, were omitted from the table.

The uneven distribution of sampling in both space and time and relatively small numbers of samples make it difficult to detect clear patterns of movement. However, out of the 140 sea age 0/0+ post-smolts, 70 (52%) were caught in the same area to which they were genetically assigned, 54 (40%) were caught to the north of their assignment area, 10 (7%) were caught to the south and 8 (6%) were caught at approximately the same latitude on the opposite side of the Irish Sea (Table 7.7.4). This pattern was similar for each of the three 3-month sampling periods during which 0/0+ fish were caught (1_Feb-Apr; 2_May-Jul; 3_Aug-Oct). This is consistent with the majority of the fish tending to hold position in the location of their river of origin or being transported with the residual tidal currents. However, a small number of fish appeared to have migrated quite long distances very quickly; for example, some fish caught in Morecambe Bay during the smolt emigration period (February-April) were genetically assigned to the south coast of Ireland and south west England. While such migrations are possible, to cover these distances it would probably be necessary for post-smolts of around 200 mm to swim in a directed fashion from the time they left freshwater. Given the distribution of the remaining fish, this seems unlikely and these may be misassignments.

Table 7.7.3 Numbers of samples caught in each Marine Zone assigned to different regions based on genetic analysis for 3 month periods; periods '1_Feb-Apr' to '3_Aug-Oct' are in the year of smolt emigration and periods '5_Feb-Apr' to '7_Aug-Oct' are in the following year. Green cells indicate where the Genetic Assignment Region and the Marine Zone are approximately the same. Red cells indicate movement across the Irish Sea.

Sampling period	Genetic Assignment Region	Marine sampling zone																		Grand Total	Samples with same MZ & GRA	
		MZ03	MZ04	MZ05	MZ06	MZ07	MZ08	MZ09	MZ10	MZ11	MZ12	MZ13	MZ14	MZ15	MZ16	MZ18	MZ23	MZ29	MZ30		No.	%
0+ fish																						
1_Feb-Apr	GA03-04										2		1							3		
	GA05-06										4									4		
	GA07										1									1		
	GA09-13				1						17		1							19		
	GA14-15										2									2		
	GA16-18										7									7		
	GA23												1							1		
	Total				1						34		3							37	17	46%
2_May-Jul	GA03-04			1				1												2		
	GA05-06			1	1			1	1											4		
	GA07			4			2													6		
	GA09-13		1					1		1	1									4		
	GA14-15									1		2								3		
	GA16-18							2							5					7		
	GA23			1							1						1			3		
	Total		1	7	1		2	5	1	2	3	2			5		1			29	11	38%
3_Aug-Oct	GA03-04		2			1		1										1	2	7		
	GA05-06					1						1	1				1		3	7		
	GA07					4												2	1	7		
	GA09-13					1			1			4	1					7	24	38		
	GA14-15		1					1				2						1	3	8		
	GA16-18									1		2						2	4	9		
	Total		3			7		2	1	1		11	2				1	14	37	76	42	55%
1+ fish																						
5_Feb-Apr	GA03-04		1		3		1				1						1			7		
	GA05-06		1		8								1				2			12		
	GA07				14	2	3													19		
	GA09-13		1	2	17	1							1				2			24		
	GA14-15				4															4		
	GA16-18		1		3															4		
	Total		4	2	50	3	4				1		3				5			70	11	16%
6_May-Jul	GA03-04		2	3	2			1	3	2		1								14		
	GA05-06	1		6	5	1			5			1			1					20		
	GA07			7	4	3	1		5		1	1					1			23		
	GA09-13			4	4			1	43	2	1			1	1					57		
	GA14-15			2	1				3											6		
	GA16-18		2	3	4			2	4				1		1	1	1			19		
	GA23																1			1		
	Total	1	4	26	20	4	1	4	65	4	2	3	1	1	3	1	3			140	66	47%
7_Aug-Oct	GA03-04					1	1													2		
	GA05-06					1	1							1						3		
	GA07					5	6	1												12		
	GA09-13						1			1		1	2							5		
	GA14-15		1					2				1								4		
	GA16-18					1														1		
	Total		1			8	9	3		1		2	2	1						27	7	26%

Table 7.7.4 **S**ummary of migratory behaviour of post-smolts estimated from the location of the marine zone (MZ) in which they were caught relative to their genetic assignment region (GAR). (Data from Table 7.7.3)

Fish stage	Sampling period	MZ relative to GAR				Total
		Same area	North	South	East/West	
0/0+ fish	1_Feb-Apr	17	16	3	1	37
		46%	43%	8%	3%	
	2_May-Jul	11	11	6	1	29
		38%	38%	21%	3%	
	3_Aug-Oct	42	27	1	6	76
		55%	36%	1%	8%	
	Total 0/0+	**70**	**54**	**10**	**8**	**134**
		52%	**40%**	**7%**	**6%**	
1/1+ fish	5_Feb-Apr	11	14	37	8	70
		16%	20%	53%	11%	
	6_May-Jul	66	47	21	6	140
		47%	34%	15%	4%	
	7_Aug-Oct	7	15	4	2	28
		25%	54%	14%	7%	
	Total 1/1+	**84**	**76**	**62**	**16**	**222**
		38%	**34%**	**28%**	**7%**	

The 244 sea age 1/1+ fish samples were split roughly equally between those that were caught in the same area (84 (38%)), those that had moved north (76 (34%)) and those that had moved south (62 (28%)). The results provide no clear evidence that sea trout from different regions migrate to particular areas within the Irish Sea to feed nor that they all follow similar migration paths. Rather, they appear to reflect more random or current driven distributions. The samples of sea age 1/1+ fish collected in most MZs in most periods were relatively small, but larger numbers of fish were caught in period 5 in MZ06 (50) and in period 6 in MZ05 (26), MZ06 (20) and MZ10 (65). For each of these samples, fish were genetically assigned to all GARs except GAR08 (Northern Ireland) and GAR23 (Isle of Man). This suggests that older sea trout may disperse more widely in the Irish Sea, but they again show no clear or consistent patterns of movement. Such wider distribution of the older fish compared with the 0/0+ fish may be expected because a 400 mm sea trout swimming at 0.5 Bl s^{-1} (see Section 4) can swim about 17 km per day, thus enabling it to cover the distance between any two points within the Irish and Celtic Seas (in a straight line) within a few weeks.

All these distributions are, of course, complicated by combining fish that are on their outward migration and those that are returning to freshwater to spawn. Little is known about how sea trout home to their river of origin and whether or not they return along their outward migratory route.

7.7.2.10 Particle tracking simulations

Parameter Selection

Eulerian[2] 3D hydrodynamic data were modelled from January until December 2011 from which the Lagrangian[3] tracks of individual particles could be simulated. The emigration of sea trout smolts to

[2] The **Eulerian** specification of a flow field is a way of looking at fluid motion that focuses on specific locations in the space through which the fluid flows as time passes

sea is simulated in the numerical model by releasing particles at a specified time and location and assigning the particles a size, growth rate and specific behaviour. Various parameters are therefore required to run the model, and ideally these should be based upon observations of wild populations. However, there have been relatively few detailed studies of sea trout migratory behaviour in the sea. While complex behaviour patterns might be proposed, it was considered appropriate to find the simplest behaviours that resulted in the general distribution of fish observed from the genetic assignment studies.

The following parameters are included in the model:

Release locations: Particles were released at the mouths of ten rivers around the Irish Sea to provide examples of the simulated tracks of emigrating smolts from each GAR (Table 7.7.5 & Figure 7.7.9)

Table 7.7.5 Release locations for particle tracks simulating the movements of sea trout smolts from ten rivers around the Irish and Celtic Seas

River	Lat	Long	Lat	Long
	Deg:min:sec		Decimal	
Tywi	51° 46' 15"	04°22'27"W	51.77083	-4.37417
Dyfi	52° 32' 40"	04°00'20"W	52.54444	-4.00556
Dee	53° 16' 38"	03°10'09"W	53.27722	-3.16917
Lune	53° 59' 17"	02°52'27"W	53.98806	-2.87417
Esk (Border)	54° 58' 07"	03°02'00"W	54.96861	-3.03333
Luce	54° 51' 50"	04°48'39"W	54.86389	-4.81083
Glass (IoM)	54° 05' 21"	04°35'27"W	54.08920	-4.59091
Shimna	54° 12' 37"	05°53'26"W	54.21028	-5.89056
Boyne	53° 43' 52"	06°15'38"W	53.72136	-6.21946
Slaney	52° 21' 37"	06°32'44"W	52.36028	-6.54556
Argideen	51° 38' 42"	08°45'48"W	51.64500	-8.76333

Release dates and times: Sea trout smolts in UK and Ireland generally emigrate between March and May, with the peak runs being associated with periods of increased river temperatures and elevated flows during April. The larger, older smolts tend to emigrate earlier than the smaller, younger fish. Moore *et al* (1998) tracked wild sea trout smolts emigrating from the River Conwy, North Wales and reported that emigration in freshwater was predominantly nocturnal but there were changes in this pattern in the lower reaches of the estuary with fish moving during both the day and night. All the smolts migrated seawards on an ebb tide, but migration in the lower portion of the estuary was indicative of active swimming and quickly became independent of the tide. More recent tracking studies in Poole Harbour (southern England) have also shown sea trout smolts emigrating at all states of the tide (Andy Moore, pers. comm.). Particles were therefore released at hourly intervals over a period from 1st to 28th April to cover all possible emigration behaviour and all stages of a lunar cycle.

[3] The **Lagrangian** specification of the flow field is a way of looking at fluid motion where the observer follows an individual fluid parcel as it moves through space and time

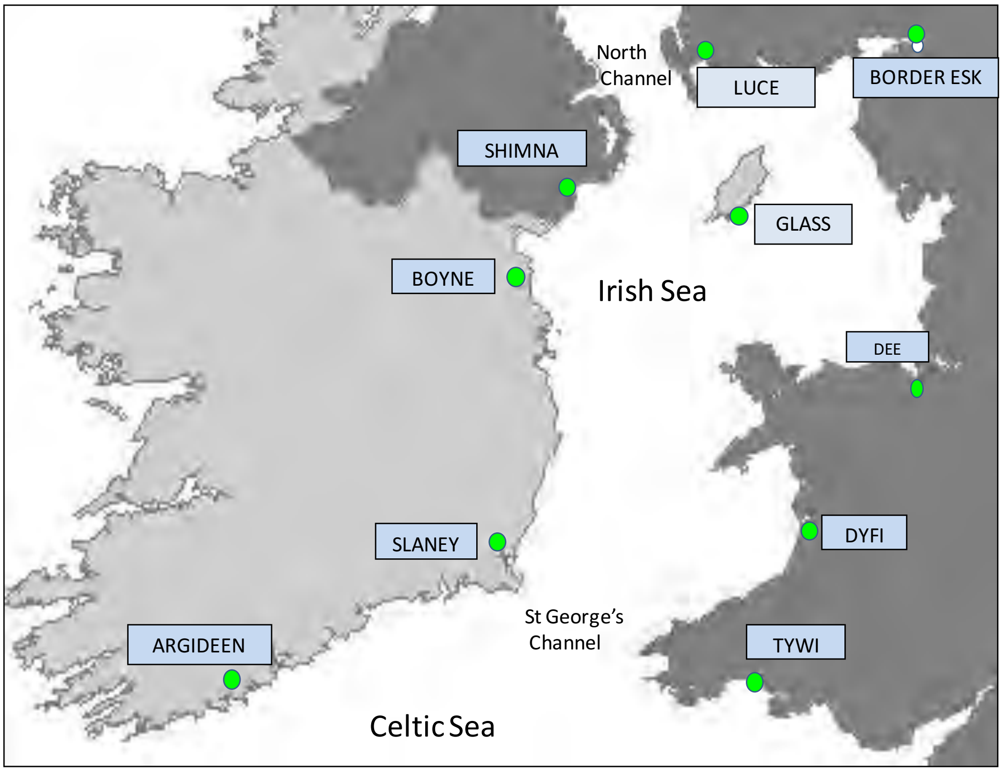


Figure 7.7.9 Rivers around the Irish and Celtic Seas used for particle tracks simulations of the movements of sea trout smolts.

Depth: Moore *et al* (1998) observed that emigrating smolts remained very close to the surface as they left the Conwy estuary. Johnstone *et al.* (1995), tracking the movements of sea trout post-smolts in Loch Ewe in the north-west of Scotland, found that in most cases fish swam in the top 10 m (in ca. 50 m of water), and Sturlaugsson and Johannsson (1998) reported that sea trout tagged with archival tags in the Grenlaekur River, SE Iceland, spent 91% of the time in the top 7 m during their marine migration. Post-smolts were also caught further offshore during the marine sampling programme using a surface trawl suggesting that even in deeper waters they remain relatively close to the surface. Rikardsen *et al.* (2007) reported that sea trout in their first 40 days at sea in Alta Fjord in north Norway, spent >50% of their time at depths between 1 and 2 m depth and >90% at less than 3 m. On the basis of these data, the particles were released at a depth of 2 m.

Vertical movements: Although vertical movements were reported by Moore *et al* (1998) for smolts passing through an estuary, this appeared to be associated with tidal transport on the ebbing tide, and the behaviour did not continue once the fish left the estuary. In the absence of any evidence of systematic vertical movements, these were not included in the simulations and the simulated fish were retained at a depth of 2 m.

Length: The mean length of emigrating smolts was estimated to be 180 mm, based on data provided from the sampling studies during the CSTP programme.

Growth: Growth is included in the model because swimming speed is expressed in relation to length. A growth rate of 0.5 mm per day was used based on estimates provided from the sampling programme.

Swimming speed: Many studies have been conducted on the swimming speeds of salmonids. Most of these have estimated critical and burst speeds as a basis for investigating movements around obstructions and through fish passes, but some authors have estimated the optimal and preferred swimming speeds of fish. Kawabe *et al.* (2003) used the relationship between tail beat frequency and swimming speed to estimate the 'preferred' swimming speed of trout to be between 0.48 and 0.58 body lengths per second (bl s^{-1}). Tudorache *et al.* (2011) estimated the preferred swimming speed of brook char to be between ~ 0.78 ± 0.02 bl s^{-1} and 0.95 ± 0.03 bl s^{-1}. Taylor *et al.* (1996) reported that the mean (± se) speeds recorded for maximal sustainable aerobic exercise were 0.52±0.02, 0.81±0.06 and 0.39±0.02 bl s^{-1} for rainbow trout swimming at their acclimatisation temperatures of 4, 11 and 18 °C, respectively. As this study is simulating the behaviour of free swimming sea trout that would be searching for food, a mean swimming speed of 0.5 bl s^{-1} was used.

Swimming behaviours: Very little information is available on the swimming behaviour of sea trout post-smolts in the marine environment. It is generally believed that sea trout smolts do not move offshore as quickly as salmon smolts, and a number of studies have suggested that they remain relatively local to their river of origin for extended periods (e.g. Finstad *et al*., 2005; Middlemas *et al*., 2009; Johnstone *et al*., 1995). While some of these studies have observed sea trout remaining very close to the shore, they were caught at greater distances offshore during the marine sampling in this programme (e.g. in MZ 29 and 30; Figure 7.7.6) and are also known to have been caught at least 10 km offshore on the English NE coast (Potter, unpublished data).

Thorstad *et al.* (2004) observed the movements of sea trout post-smolts in a Norwegian fjord system and found that they were random compared to the direction of the water current. Even with no swimming activity, simulated fish in most locations in the Irish Sea are widely dispersed by the currents. For example, Figure 7.7.10 shows the distribution of particles released at the mouth of the River Shimna, transported passively with the currents. Adding random or directed swimming behaviour to the current movements (unless it opposes the currents) increases the speed at which fish became more widely distributed.

The genetic assignment results in this programme, confirmed that many sea trout tended to remain in coastal waters relatively close to their river of origin, particularly during their first year at sea. It is not known what features these fish are responding to, but since they may be more than 10 km offshore, it seems more likely to be related to water depth than distance from the shore. In order to model this behaviour, an option was therefore included in the model which simulates a fish having a preference for a specific water depth, and introduces a new variable in the code, "depth experienced by particle", calculated from the bathymetry and the free surface elevation. The preferred water depth is entered as a mean and standard deviation. These parameters define a velocity coefficient which equals zero at the preferred depth and increases to one as the difference between the observed depth and the preferred depth increases (Figure 7.7.11); the fish swims randomly at a speed equal to the velocity coefficient multiplied by 0.5 bl s^{-1}. Thus if a fish is not at its preferred water depth, it will try to find other locations by swimming at a velocity equal to up to 0.5 bl s^{-1} in a random direction. If the fish finds its preferred water depth, it will slow its swimming speed but remain moving in a random direction. Fish swimming speed will thus range from 0 to 0.5 bl s^{-1}. Fish will also be transported by the prevailing currents.

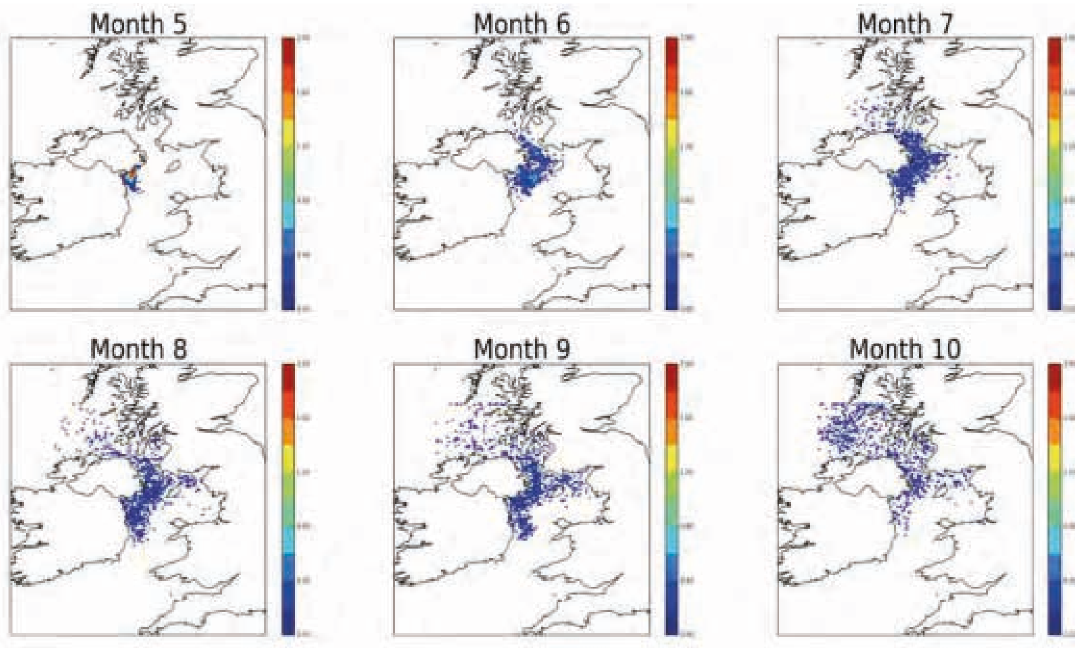


Figure 7.7.10 Distribution of 720 particles released at hourly intervals from 00:00 on 1st April 2011 in the River Shimna estuary and allowed to move passively with the tidal currents.

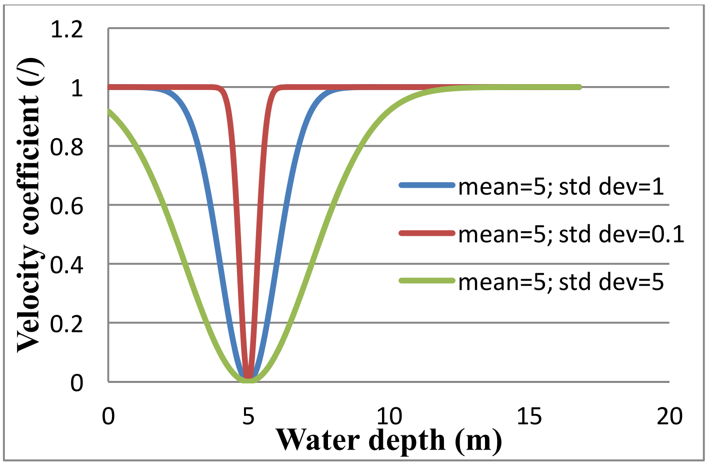


Figure 7.7.11 Examples of the velocity coefficient used in the depth related swimming behaviour where the preferred swimming depth is 5m with s.d. of 0.1m, 1m or 5m.

7.7.2.11 Simulated Tracks

Simulations were run for 'smolts' emigrating from the 10 rivers (Figure 7.7.9) using the parameter values specified above and the depth related swimming behaviour (with mean = 20 m; s.d. = 20 m). The simulated patterns of distribution for each month of the first year at sea, from April (Month 4) to December (Month 12) are shown in Figure 7.7.12 to Figure 7.7.21. For all rivers, the simulated fish remained relatively close to their river origin for at least two to three months (April to June). There were then different regional patterns of movement in the summer months (July to September), generally followed by strong northerly movements in the autumn (October to December).

The simulated fish from the River Argideen remained in the Celtic Sea until the end of the summer, spreading out from the Irish coast, and many of the tracks were 'lost' at the edge of the study area. Between October and December the remaining fish were transported northwards into the Irish Sea.

This is in marked contrast to the simulated fish from the River Slaney which moved progressively northwards throughout the year, with the majority remaining on the western side of the Irish Sea, but small numbers entering the eastern Irish Sea. Very few of the River Slaney fish went in a southerly direction, unlike the simulated fish from the Rivers Boyne and Shimna, the majority of which moved gradually southwards along the Irish coast between June and August before being transported northwards again later in the year, in October to December.

Simulated fish from the River Glass moved both to the southeast of the Isle of Man towards the English coast and northwest towards the North Channel, with some of the latter group then being transported southwards along the Irish coast. From September onwards there was a general northerly movement of these fish, although significant numbers remained close to the English coast. The tracks of fish from the River Luce showed a similar pattern of movement to those from the River Glass but with fewer fish moving into the eastern Irish Sea.

A large proportion of the simulated fish from the River Esk were retained in the shallow waters close to the Solway Firth. Fish moving out of the Solway Firth during the summer were then transported northwards through the North Channel or southwards along the English coast; no tracks crossed to the Irish coast. In a similar way, the majority of the simulated fish from the River Dee remained in Liverpool Bay, with those fish that moved away mainly being transported northwards along the English coast. The simulated fish from the River Dyfi dispersed more rapidly, with the majority moving northwards and spreading out widely in the eastern Irish Sea. Finally, the simulated fish from the River Tywi were mainly retained within the Bristol Channel until the summer; small numbers then moved out into the Irish Sea, spreading out as they moved northwards.

A large proportion of the simulated fish moved northwards out of the Irish in the autumn months. This suggested that the behaviour of the fish may change in the second and indicated that it would not be fruitful to continue these tracks into the second year in the sea.

7.7.2.12 Environmental Conditions Experienced by Post-Smolts

The GETM hydrodynamic model can be used to estimate the conditions (temperature and salinity) experienced by each simulated fish during its track. Figure 7.7.22 shows the median (and 25th and 75th percentiles) of the mean daily temperatures experienced by the simulated fish on each day between 1st May, when all fish had been released, and 31st December. This has been compared with the mean daily temperature at a fixed location 10 km off the mouth of the river at a depth of 2 m over the same period, also estimated from the hydrodynamic model (Figure 7.7.22).

The temperatures for the tracks are generally a little lower than the temperatures at the fixed locations in the early months and then higher than for the fixed locations after September; this may reflect the movement offshore over time. Thus the total degree days experienced by the simulated fish tends to be lower than that at the fixed locations for the period from May to August, but is more similar over the period from May to December (Table 7.7.6, Figure 7.7.23). The Argideen appears anomalous because the temperature of the simulated fish is significantly higher than at the fixed location, but the results are unclear because a large proportion of the simulated fish reach the edge of the area bounded by the model.

There is a general trend for degree days of both the simulated fish and at the fixed locations to decrease with latitude (Table 7.7.6, Figure 7.7.24), although the Argideen and Esk are outliers. Temperatures experienced by the simulated fish and at the fixed location are lower than expected for the latitude in the Argideen, and higher than expected in the Esk. This probably reflects the fact that the Argideen simulated tracks move offshore to the south, while a large proportion of the Esk fish were retained close to the Solway Firth.

The model also suggests that fish from some rivers may experience a much wider range of degree days than those from other rivers. Figure 7.7.25 shows examples for four sets of simulated post-smolt tracks (Rivers Tywi, Dyfi, Dee and Glass). In general the more widely dispersed the simulated tracks the greater the variation is in the number of degree days experienced by each individual.

Genetic Assignment Region 03-04 - River Argideen

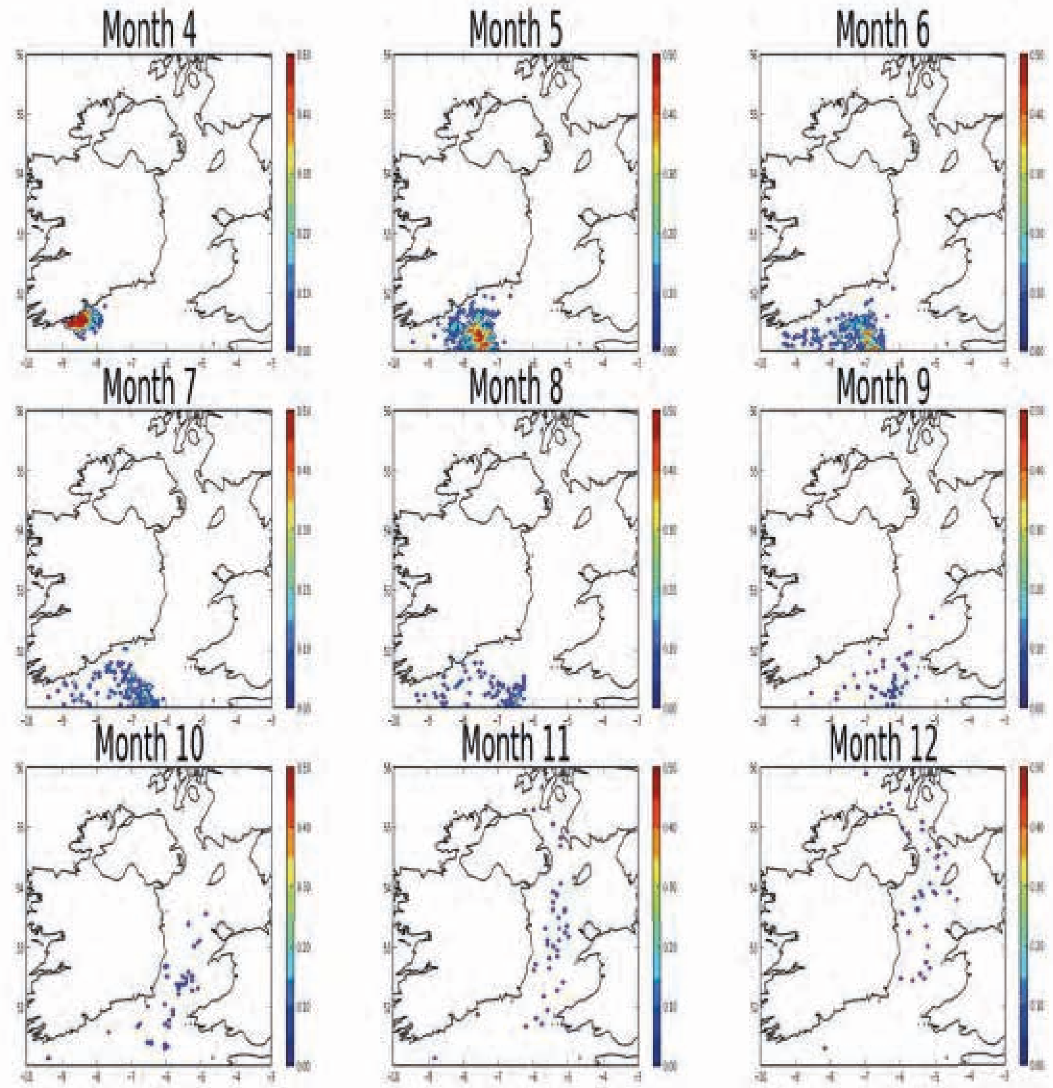


Figure 7.7.12 Simulated tracks of 672 sea trout smolts emigrating from the River Argideen, Ireland at hourly intervals from 00:00 on 1st April 2011 until 23:00 on 28th April. Panels show estimated positions at the end of each month from April to December 2011.

Genetic Assignment Region 05-06 - River Slaney

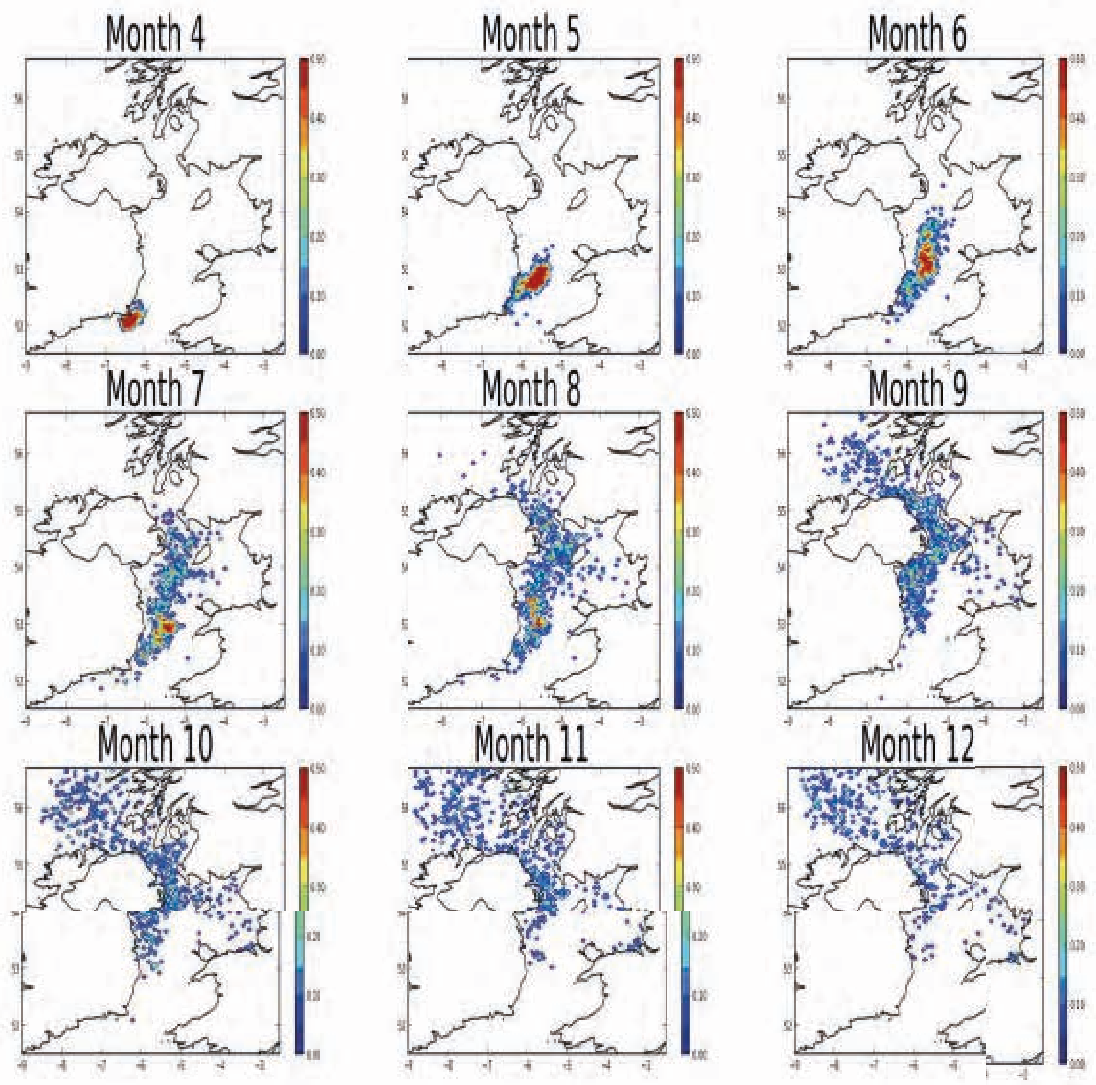


Figure 7.7.13 Simulated tracks of 672 sea trout smolts emigrating from the River Slaney, Ireland at hourly intervals from 00:00 on 1st April 2011 until 23:00 on 28th April. Panels show estimated positions at the end of each month from April to December 2011.

Genetic Assignment Region 07 River Boyne

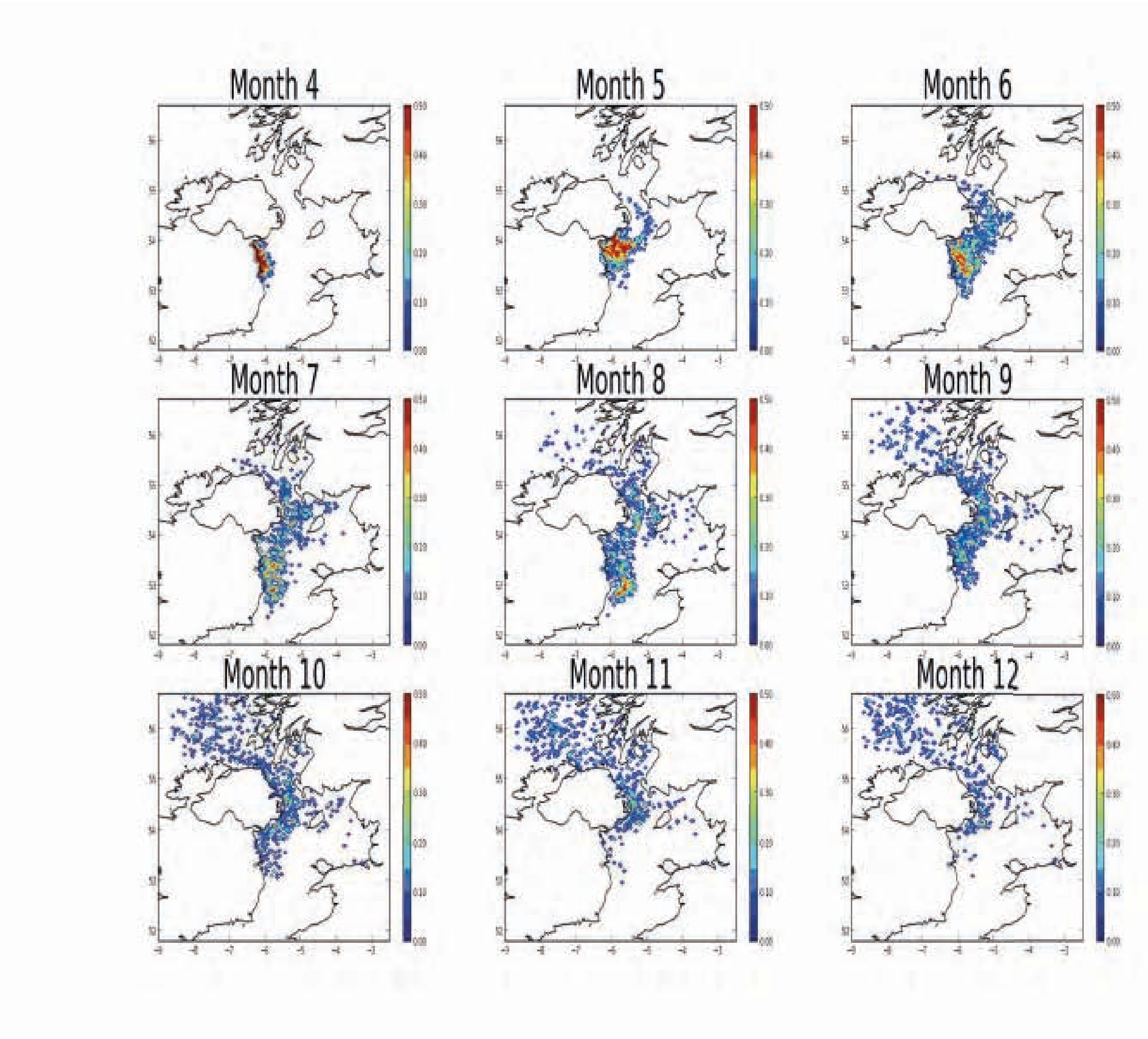


Figure 7.7.14 Simulated tracks of 672 sea trout smolts emigrating from the River Boyne, Ireland at hourly intervals from 00:00 on 1st April 2011 until 23:00 on 28th April. Panels show estimated positions at the end of each month from April to December 2011.

Genetic Assignment Region 08 - River Shimna

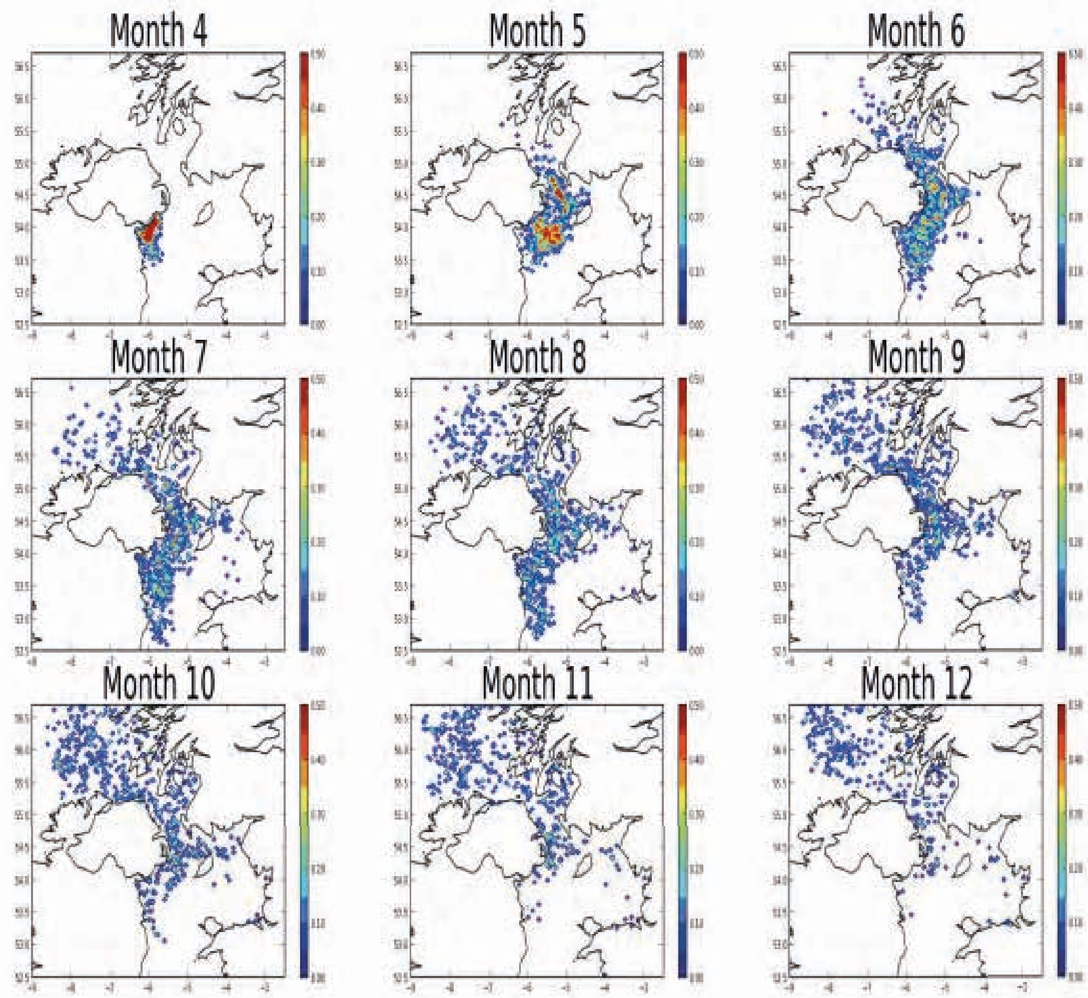


Figure 7.7.15 Simulated tracks of 672 sea trout smolts emigrating from the River Shimna, Northern Ireland at hourly intervals from 00:00 on 1st April 2011 until 23:00 on 28th April. Panels show estimated positions at the end of each month from April to December 2011.

Genetic Assignment Region 23 - River Glass, Isle of Man

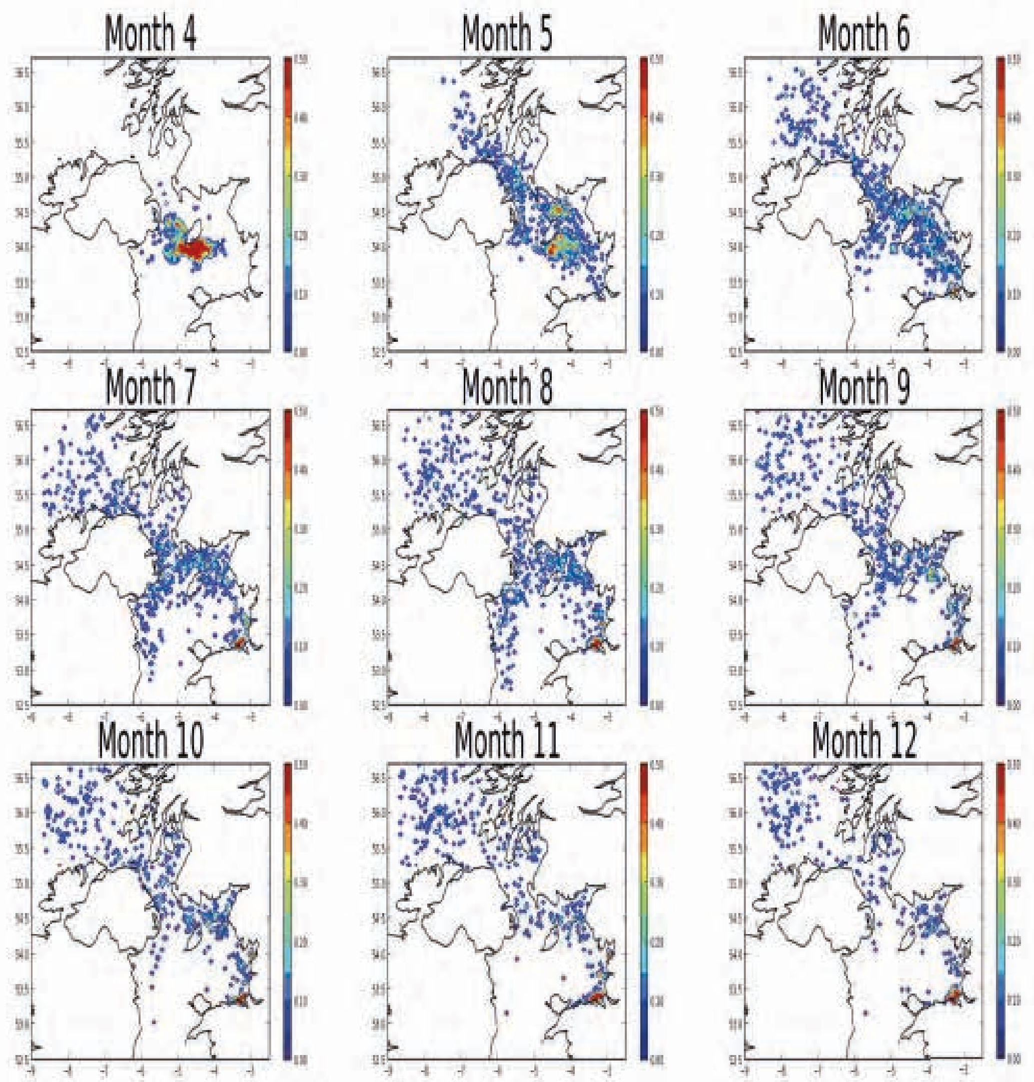


Figure 7.7.16 Simulated tracks of 672 sea trout smolts emigrating from the River Glass, Isle of Man at hourly intervals from 00:00 on 1st April 2011 until 23:00 on 28th April. Panels show estimated positions at the end of each month from April to December 2011.

Genetic Assignment Region 09-13 - River Luce

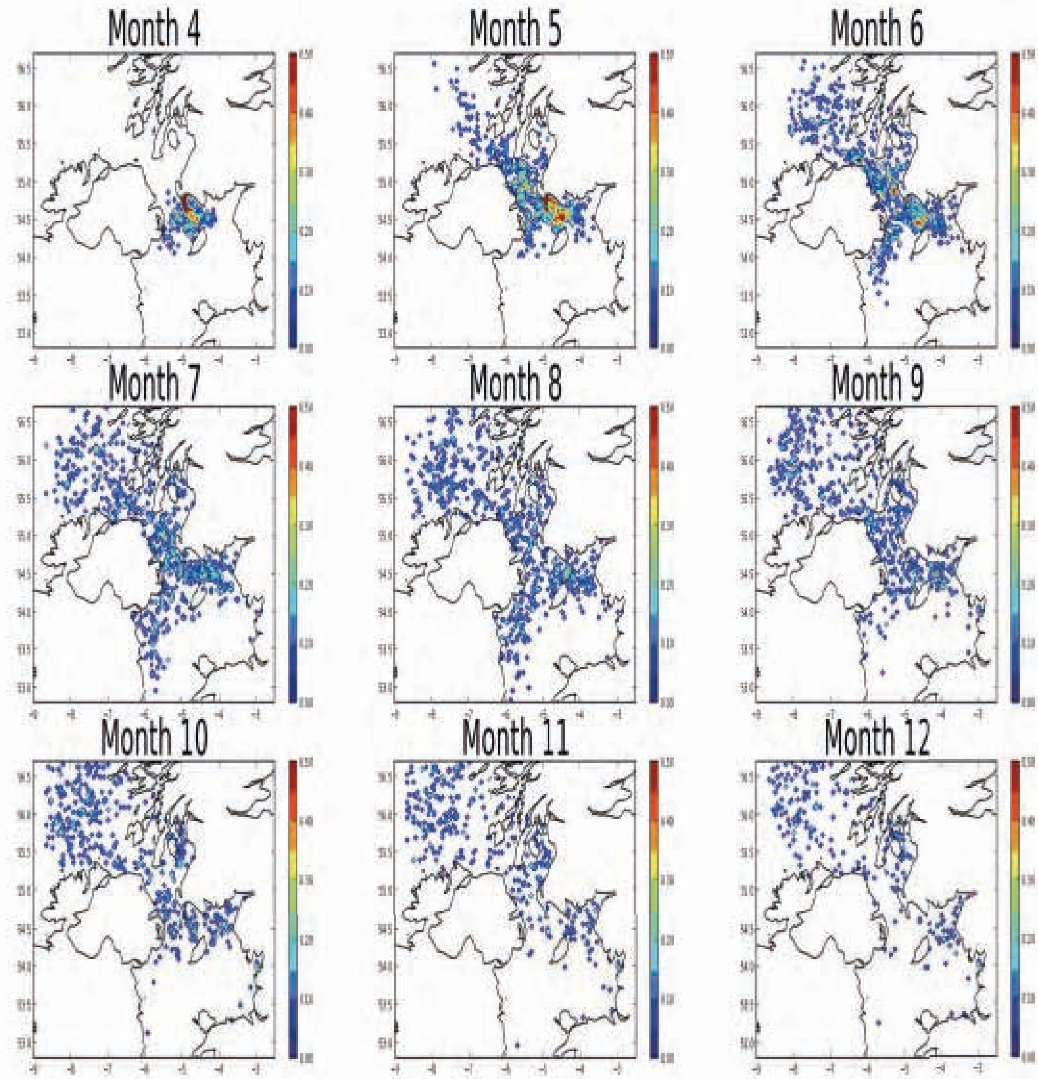


Figure 7.7.17 Simulated tracks of 672 sea trout smolts emigrating from the River Luce, Scotland at hourly intervals from 00:00 on 1st April 2011 until 23:00 on 28th April. Panels show estimated positions at the end of each month from April to December 2011.

Genetic Assignment Region 09-13 - River Esk (Border)

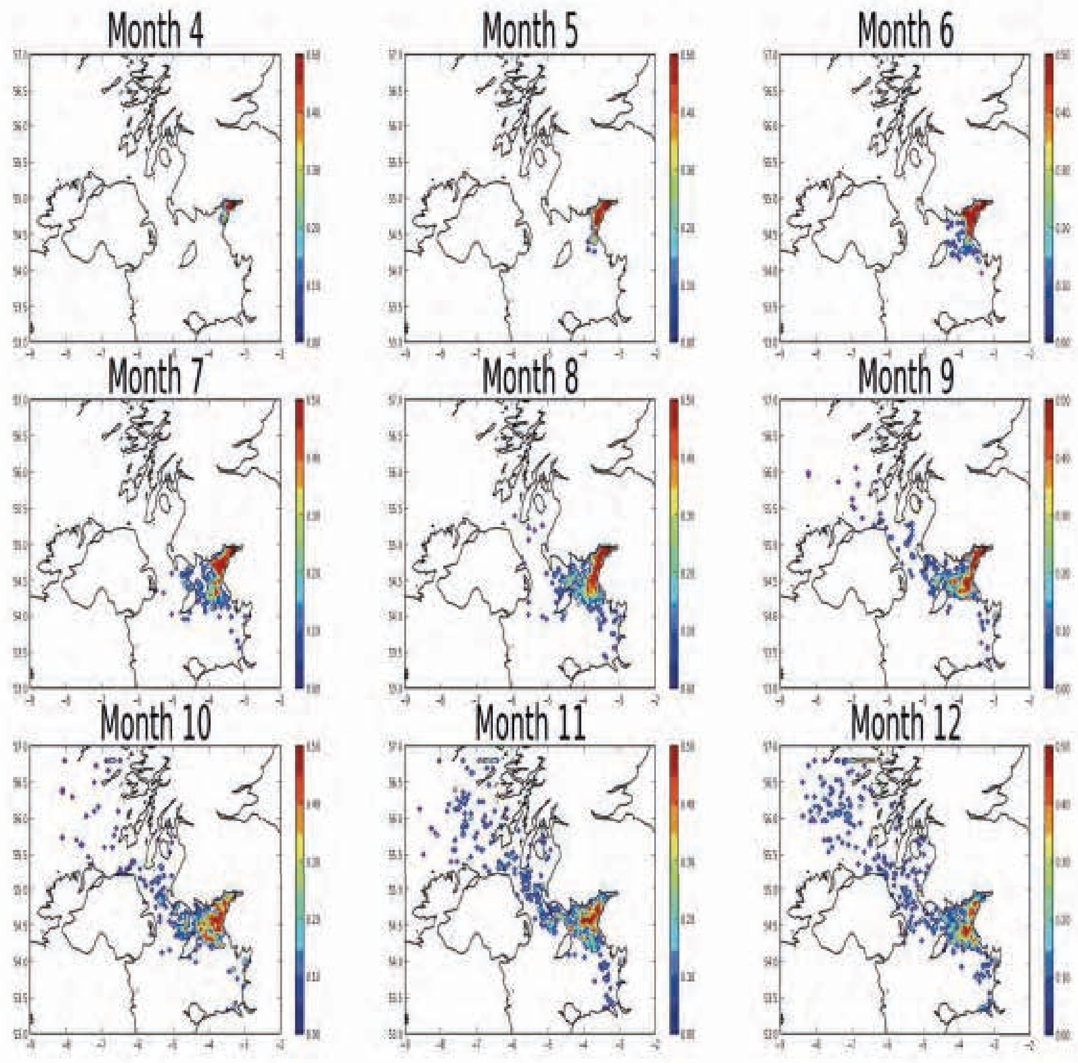


Figure 7.7.18 Simulated tracks of 672 sea trout smolts emigrating from the River Esk (Border), (between England and Scotland) at hourly intervals from 00:00 on 1st April 2011 until 23:00 on 28th April. Panels show estimated positions at the end of each month from April to December 2011.

Genetic Assignment Region 09-13 - River Dee

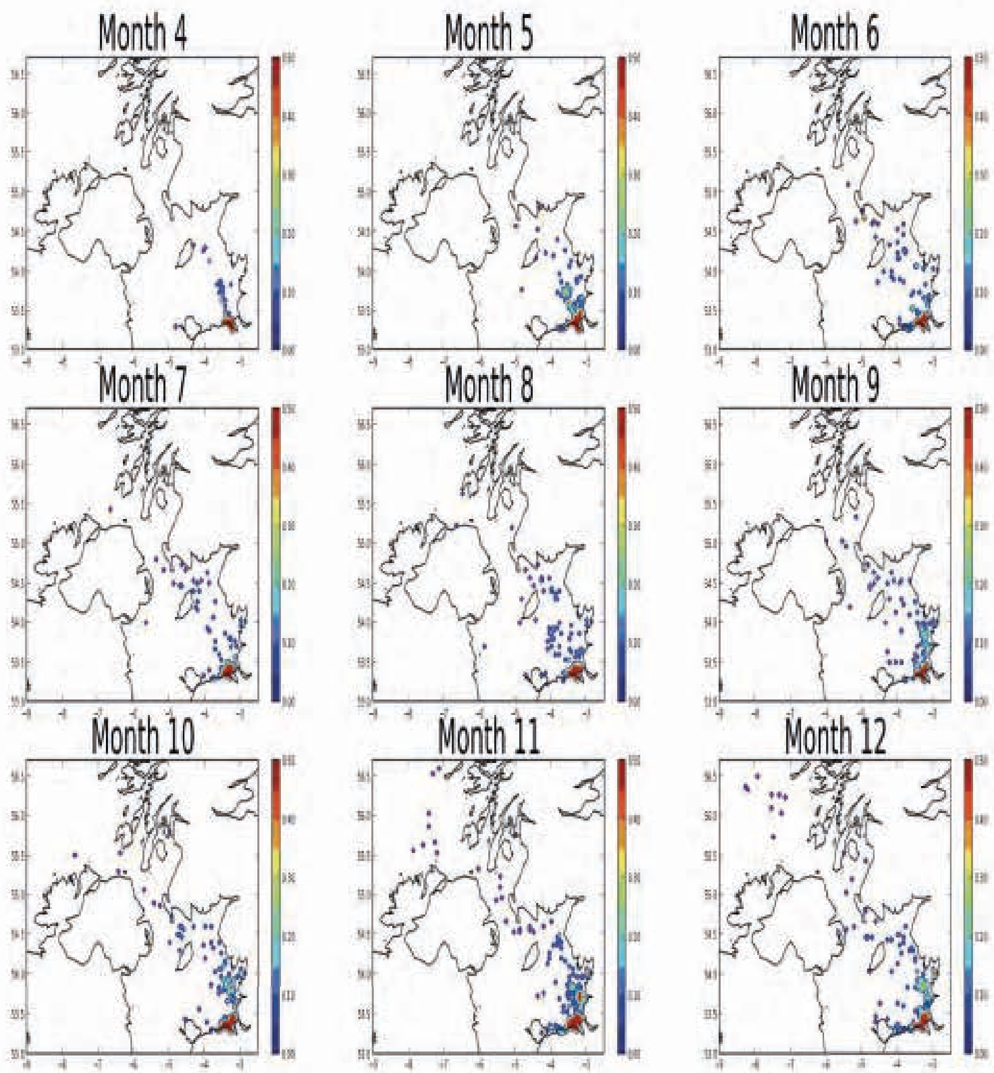


Figure 7.7.19 Simulated tracks of 672 sea trout smolts emigrating from the River Dee, Wales at hourly intervals from 00:00 on 1st April 2011 until 23:00 on 28th April. Panels show estimated positions at the end of each month from April to December 2011.

Genetic Assignment Region 14-15 - River Dyfi

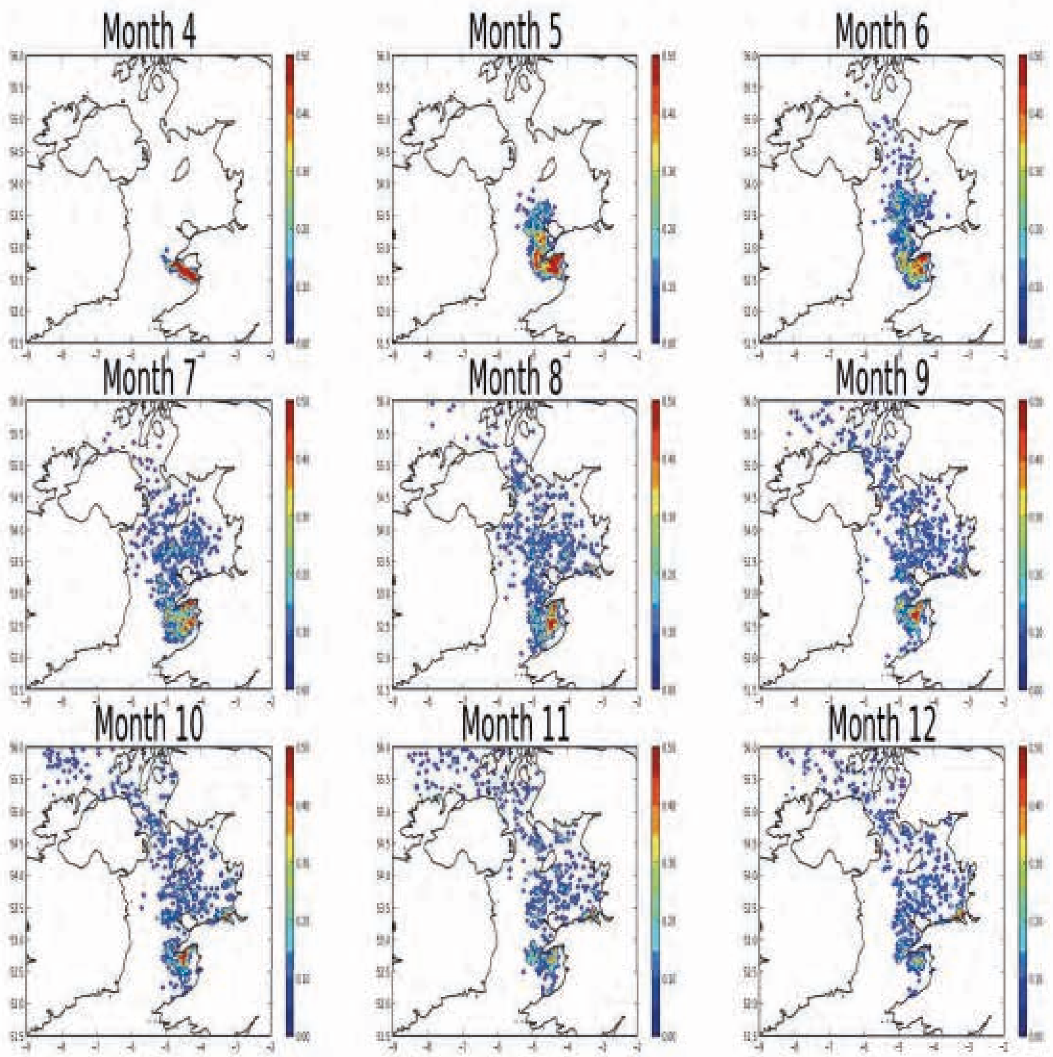


Figure 7.7.20 Simulated tracks of 672 sea trout smolts emigrating from the River Dyfi, Wales at hourly intervals from 00:00 on 1st April 2011 until 23:00 on 28th April. Panels show estimated positions at the end of each month from April to December 2011.

Genetic Assignment Region 16-18 - River Tywi

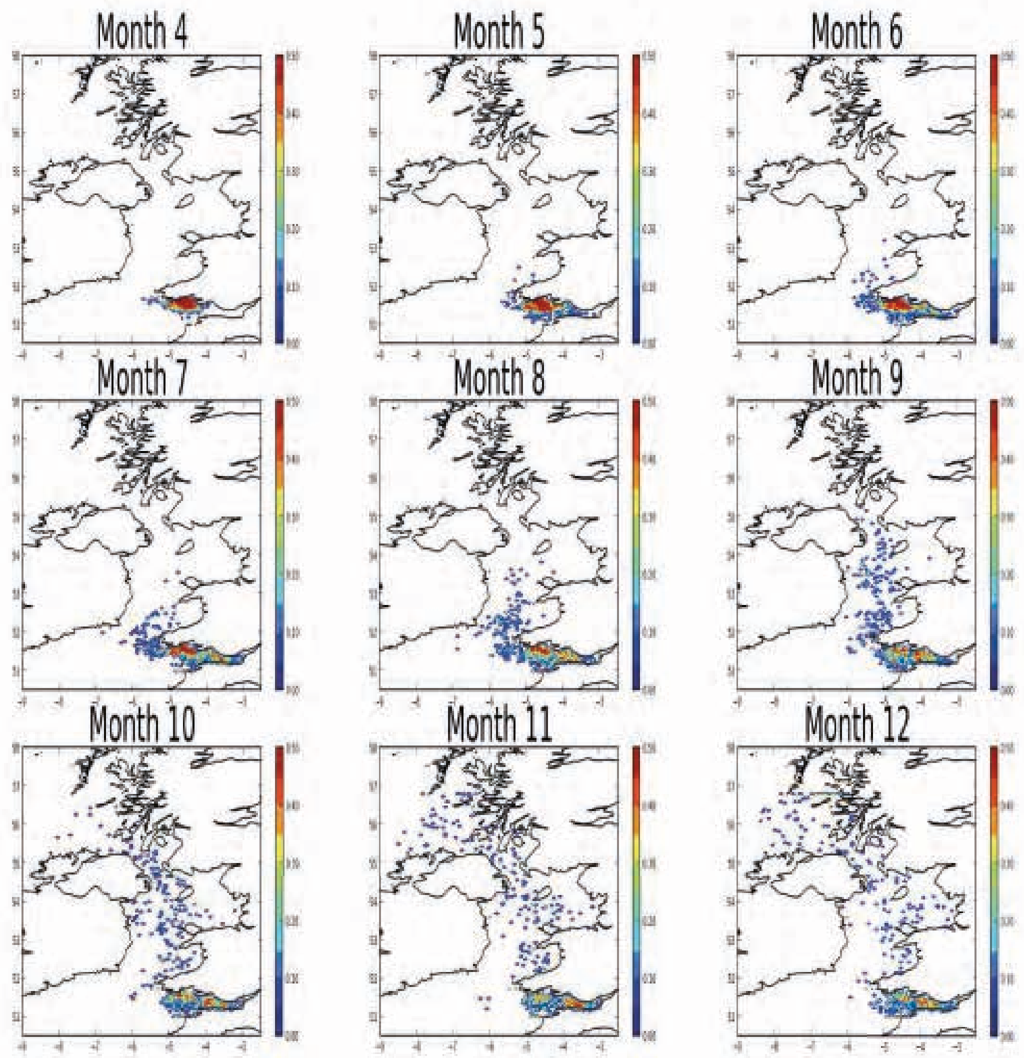


Figure 7.7.21 Simulated tracks of 672 sea trout smolts emigrating from the River Tywi, Wales at hourly intervals from 00:00 on 1st April 2011 until 23:00 on 28th April. Panels show estimated positions at the end of each month from April to December 2011.

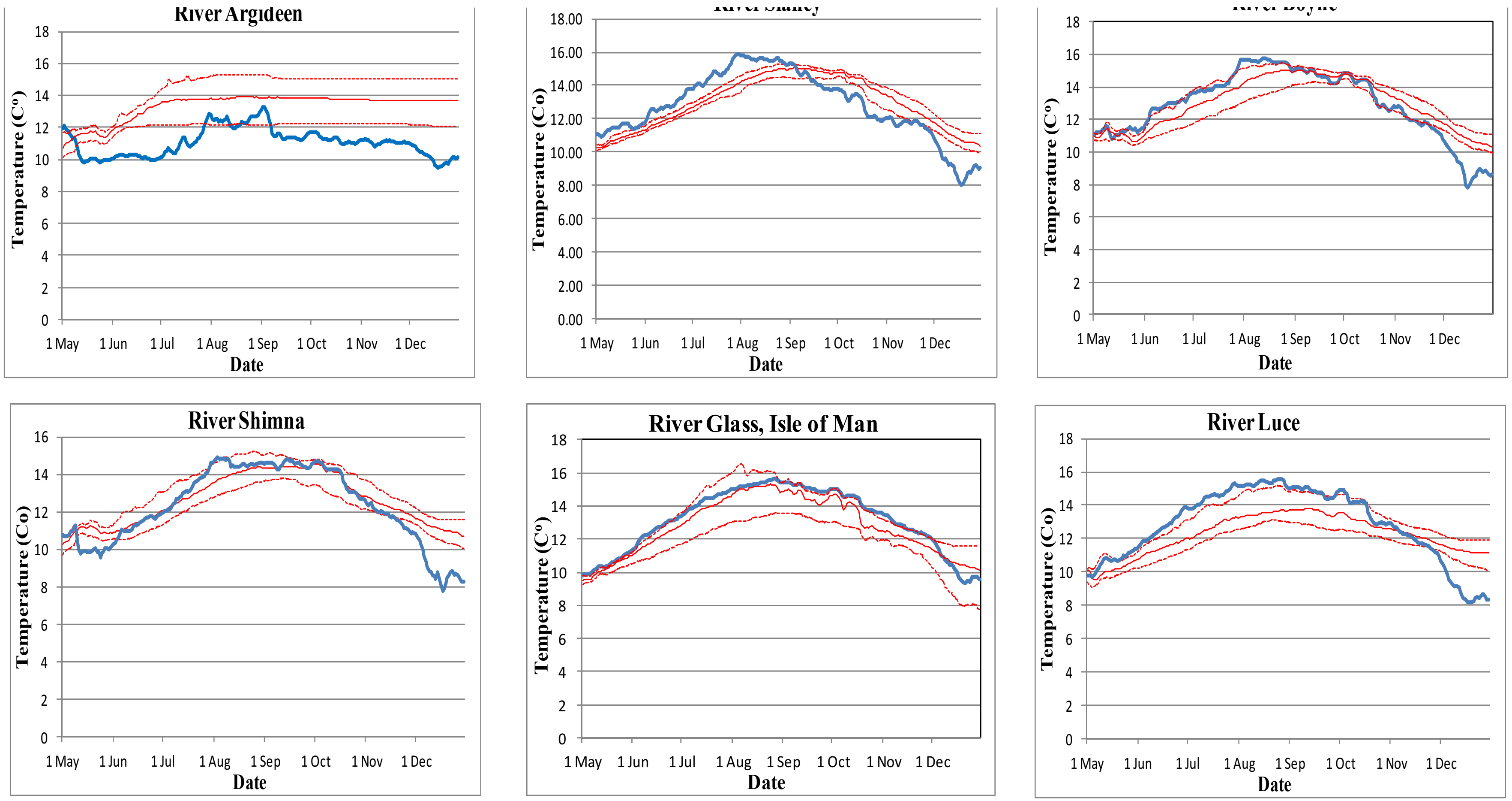


Figure 7.7.22 Temperature at a fixed location 10 km off the mouth of the rivers Argideen, Slaney, Boyne, Shimna, Glass and Luce (solid blue lines) and median temperature (solid red line) with 25th and 75th percentiles (red dotted lines) of the mean daily temperatures experienced by all simulated post-smolts leaving the same rivers from May 1st to December 31st.

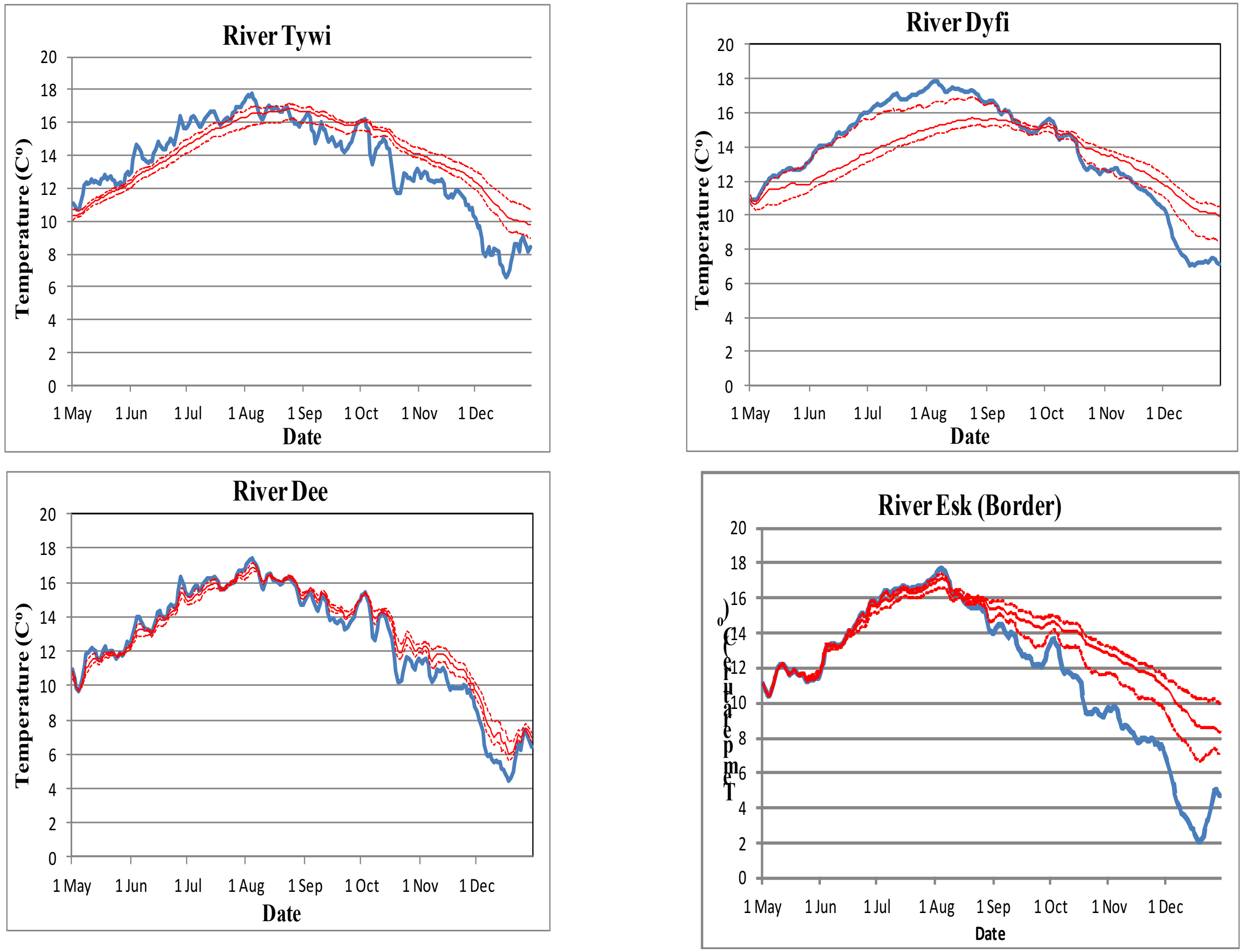
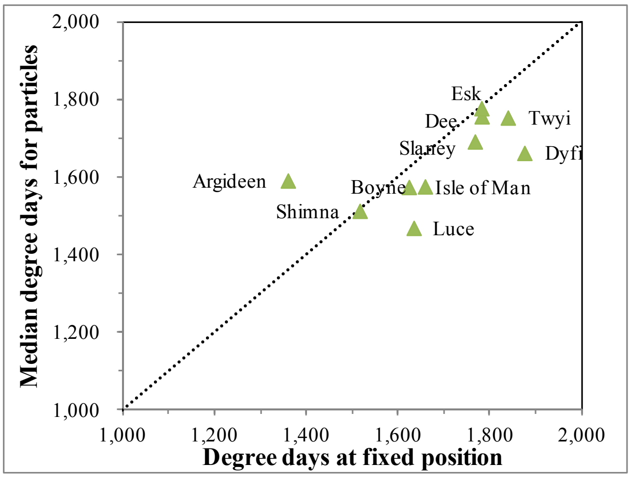


Figure 7.7.22 (continued) Temperature at a fixed location 10 km off the mouth of the rivers Esk, Dee, Dyfi and Tywi (solid blue lines) and median temperature (solid red line) with 25th and 75th percentiles (red dotted lines) of the mean daily temperatures experienced by all simulated post-smolts leaving the same rivers from May 1st to December 31st.

Table 7.7.6 Total degree days between May 1st and (a) August 31st and (b) December 31st at fixed locations 10 km off the mouth of 10 rivers around the Irish and Celtic Sea and median degree days experienced by simulated fish emigrating from those rivers.

			May 1st to August 31st				May 1st to December 31st			
			Fixed	Particle tracks			Fixed	Particle tracks		
River	Lat	Long		25%ile	50%ile	75%ile		25%ile	50%ile	75%ile
Argideen	51° 38' 42"	08° 45' 48"W	1,359	1,453	1,591	1,702	2,695	2,927	3,256	3,522
Slaney	52° 21' 37"	06° 32' 44"W	1,767	1,647	1,692	1,726	3,132	3,060	3,161	3,245
Boyne	53° 43' 52"	06° 15' 38"W	1,658	1,475	1,576	1,654	3,154	2,991	3,162	3,294
Shimna	54° 12' 37"	05° 53' 26"W	1,516	1,434	1,513	1,607	2,997	2,908	3,072	3,236
Glass (I.of Ma	54° 13' 48"	04° 34' 12"W	1,623	1,438	1,574	1,658	3,212	2,827	3,111	3,278
Luce	54° 51' 50"	04° 48' 39"W	1,634	1,396	1,469	1,594	3,130	2,823	2,984	3,209
Esk (Border)	54° 58' 07"	03° 02' 00"W	1,781	1,745	1,778	1,796	2,886	3,108	3,288	3,384
Dee	53° 16' 38"	03° 10' 09"W	1,782	1,734	1,757	1,775	3,098	3,120	3,179	3,240
Dyfi	52° 32' 40"	04° 00' 20"W	1,875	1,597	1,662	1,826	3,367	3,117	3,274	3,487
Tywi	51° 46' 15"	04° 22' 27"W	1,839	1,699	1,753	1,787	3,326	3,319	3,432	3,522

(a)



(b)

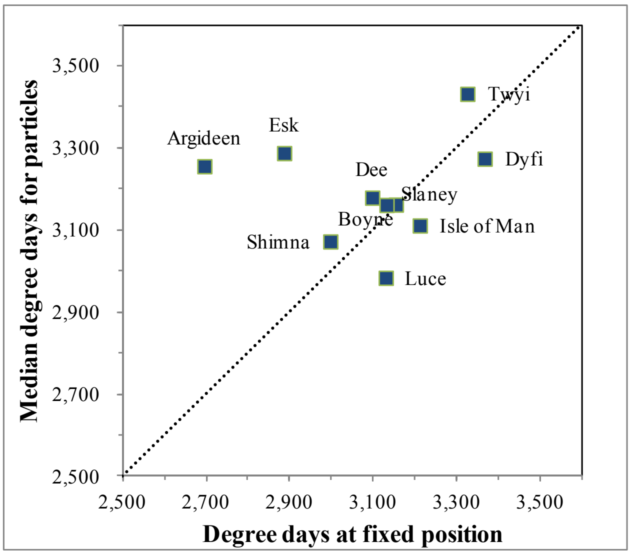
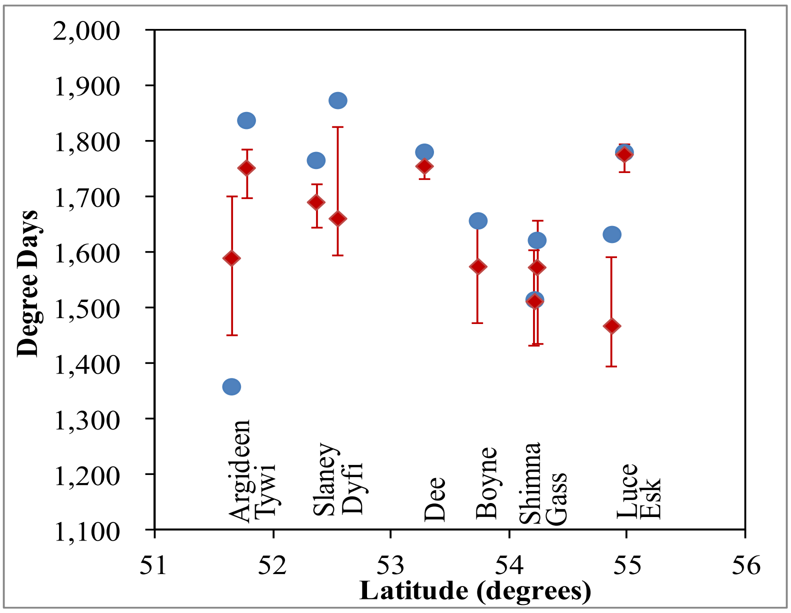


Figure 7.7.23 Total degree days between May 1st and (a) August 31st and (b) December 31st at fixed locations 10 km off the mouth of 10 rivers around the Irish and Celtic Sea and median of temperatures experienced by simulated particles leaving those rivers (see text).

a.



b.

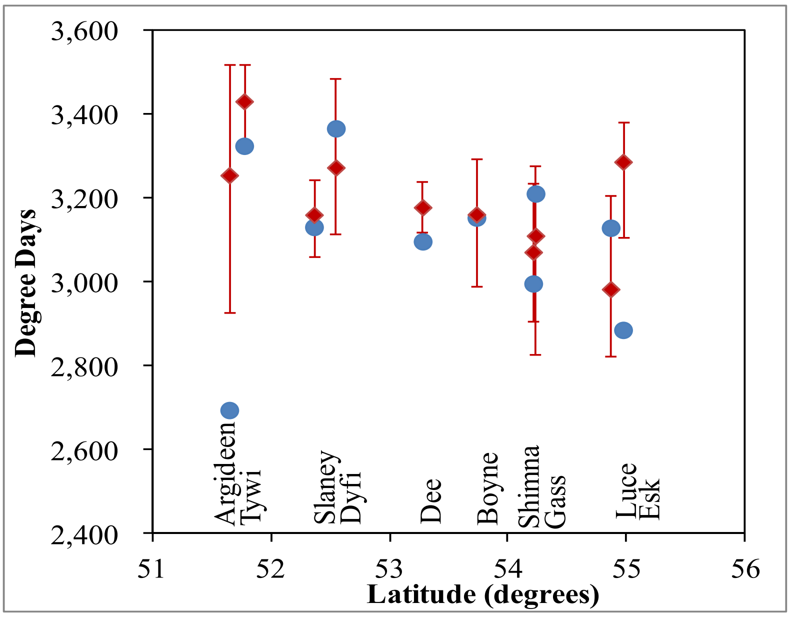


Figure 7.7.24 Total degree days between May 1st and (a) August 31st and (b) December 31st at fixed locations 10 km off the mouth of 10 rivers around the Irish and Celtic Sea (blue circles) and median of temperatures experienced by simulated particles leaving those rivers (red diamonds) (bars show 25th and 75th percentiles) plotted against latitude of river.

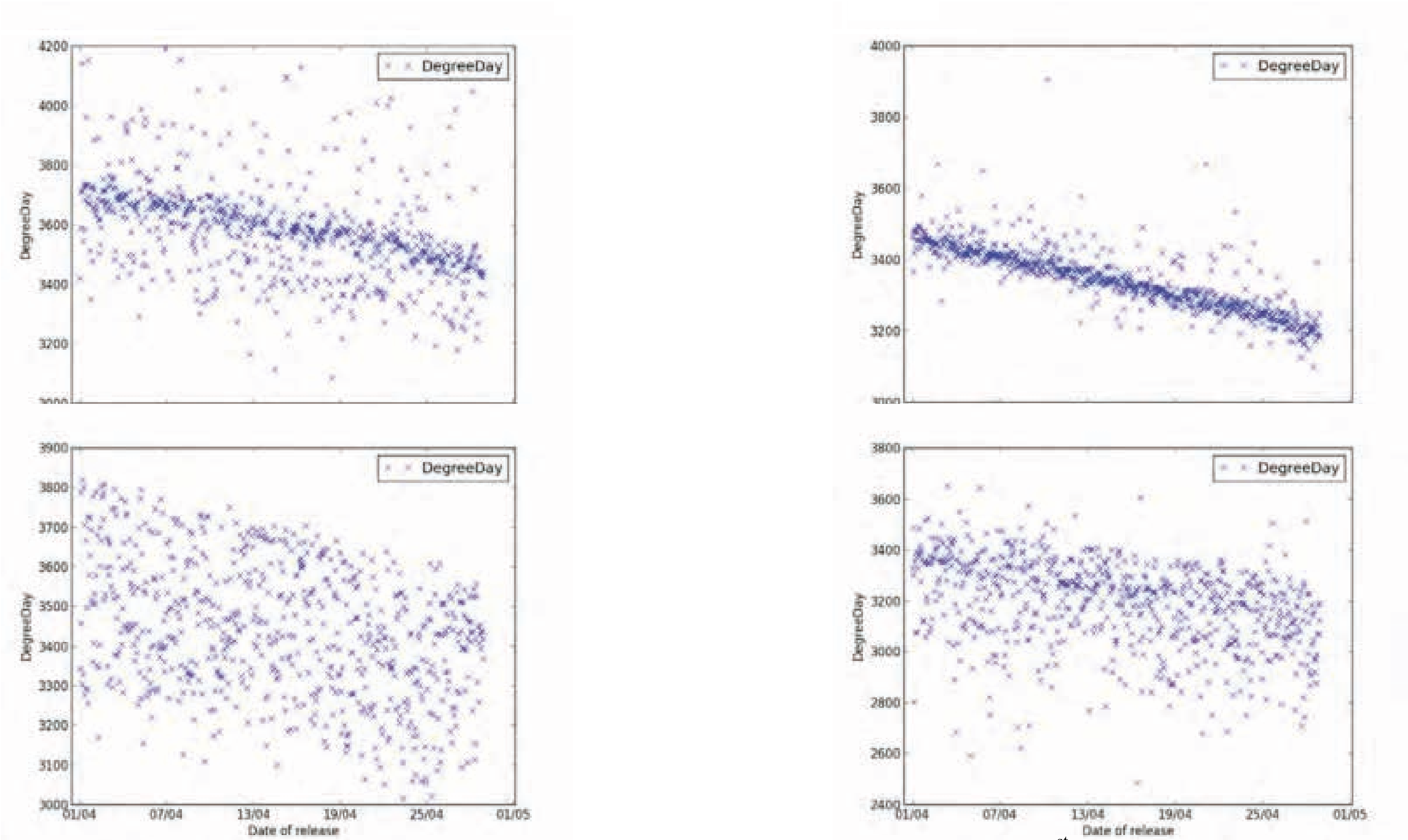


Figure 7.7.25 Degree days experienced by each simulated fish from its release date until December 31st plotter against the release date for the River Tywi (top left panel), River Dyfi (top right panel), River Dee (bottom left panel) and (d) River Gass (bottom right panel).

7.7.3 Discussion

Relatively few studies have been undertaken on the migratory behaviour of sea trout once they have emigrated as smolts. Berg and Berg (1986) reported on the recaptures of sea trout smolts tagged in the Vardnes river in northern Norway. Of the 2122 recaptures in the sea, 52.8% were reported within 3 km of the river mouth, compared to only 0.7% more than 80 km away. Similar observations have been reported from more recent telemetry studies. Thorstad *et al*. (2007) tagged and released 34 sea trout smolts with acoustic tags in a Norwegian fjord system between May and early June. Eight fish were detected at a receiver located 9.5 km from the release location and three 37 km from the release point; no fish were detected at 65 km. Finstad *et al*. (2005) similarly followed the movements of 15 wild sea trout post-smolts tagged with acoustic tags in a Norwegian fjord. Only four post-smolts were recorded more than 9 km from the release site, taking an average of 438 h to cover the distance. No sea trout were recorded as far as 77 km from the release site (still within the fjord) during the course of the study (May to September).

Similar studies have been conducted in Scotland. Johnstone et al. (1995) used active tracking to monitor the movements of 12 sea trout post-smolts in Loch Ewe in north-west Scotland. Three fish returned quickly to fresh water, while the other nine were tracked for periods ranging from 1 to 68 h. These fish mainly remained in the inshore littoral zone, with some extensive and directed movements; the maximum distance that a fish moved from the release point was 1.5 km. In a similar study, Middlemas et al. (2009) used logging acoustic receivers to track the movements of sea trout post-smolts in Loch Torridon, focussing on two connected sea loch basins within the wider Loch Torridon area, Upper Loch Torridon and Loch Shieldaig. Out of a total of 48 fish tagged, five left the study area to move further out to sea and two re-entered fresh water. In general, the post-smolts dispersed slowly into the marine environment in the weeks following emigration from fresh water, with only 36% of fish detected >6 km from their release site.

All the above studies were conducted in relatively protected lochs or fjords, where fish may not be subject to strong currents along the coast, and some only covered a short period after smolt emigration. In contrast, studies of sea trout smolts leaving the rivers in north east England using both conventional tags (Potter, 1990) and acoustic tags (Barry Bendall, pers.comm.) show that the fish migrate rapidly to the south, covering a distance of over 300 km to the East Anglian coast in about 6-8 weeks and continuing on to the Belgium and Dutch coast. However, very few of these fish return to spawn as whitling. Long distance migrations have also been reported for hatchery-reared sea trout released into nine Swedish rivers in the Baltic between 1998 and 2007 (Degerman et al., 2012). While the majority of the recaptures (61.4%) were still caught within 50 km of their river of origin, 14.2% were caught >150 km from the river of release, 2.2% >500 km away, and 0.2% >1000 km away.

These studies indicate that sea trout can adopt quite variable migratory behaviours in the sea, probably reflecting the different topography of the estuary and coastline around their rivers of origin, as well as the prevailing currents. Such variability was also seen in the particle tracking results, with simulated fish from the Rivers Esk, Dee and Tywi dispersing much more slowly than those from rivers like the Dyfi and Glass, and the distribution of simulated fish from the Rivers Argideen and Slaney being clearly separated by the current patterns in the Irish and Celtic Seas.

The simulated distributions of sea age 0/0+ fish appear broadly consistent with the information obtained from the genetic assignments of the fish sampled at sea for the first few month after they emigrate as smolts. This suggests that they adopt a behaviour which tends to keep them in coastal waters close to their river of origin. The depth related behaviour used in the particle tracking simulations was a simple mechanism for achieving this effect, but it is quite possible that the fish use alternative behaviours to achieve the same end. More detailed tracking studies of sea trout in coastal waters will be required to determine the precise behaviours used by the fish.

It was not possible to compare the particle tracking results with the genetic assignment results statistically. Not only were the samples of sea age 0/0+ fish very small, but the sampling varied markedly between regions. In order to maximise catches, the surveys were undertaken using a range of different fishing methods with different selective properties, and the timing and extent of sampling varied greatly between areas. Furthermore, the probability of fish from a particular region being caught in any sample will have depended, in part, on the relative size of the stocks in that region. For example, the sea trout stocks on the Isle of Man are relatively small and so the probability of catching any in the sampling programme may have been small. As a result, the fact that very few were identified by the genetic assignments does not necessarily mean that they were not present in the survey areas. However, little information is available on the total sea trout stocks in the regions around the Irish and Celtic Sea, and only very approximate estimates could be obtained from catch data

A further uncertainty arises from the probable misassignment of some of the samples in the genetic analysis. This is to be expected because of the assignments are based on the likelihood of a genotype occurring in the baseline sample from a particular river/region. There may also be a bias in the misassignments due to the relative heterogeneity in the baseline samples from different regions. The genetic assignments are discussed in more detail in Chapter 4.

Few data are available on morality rates for sea trout post-smolts during the first few months are sea, and so natural mortality has not been incorporated in the particle tracking model. The effect of mortality will be to reduce the numbers of simulated tracks in the later months shown in Figure 7.7.12 to Figure 7.7.21, but unless mortality rates vary significantly between areas, it will not affect the simulated distribution of fish after a particular time period. Similarly, investigations of the degree-days experienced by the fish are based on survivors at the end of any time period and will not be affected by including mortality.

It has also not been possible to include the return migration of fish to their river of origin in the simulations because very little information is available on this phase of the life-cycle. It is likely that the return migration is more directed and rapid than the outward migration, and the fish may feed less at this time. If this is the case then this phase may have relatively little effect on the growth potential of the fish over the total period in the sea. However, it is possible that maturation begins some months before the fish return to freshwater and affects their behaviour over a longer period. Clearly, the fish that are on their return migration will affect the distribution of fish in the sea by increasing the numbers estimated to be closer to their river of origin. While it would be possible to use the hydrodynamic and particle tracking models to simulate and test more complex migratory scenarios, in the absence of more detailed data against which to validate the results, these would be speculative.

The results indicate that there is potential for fish from a large number of different river stocks to be caught in any fisheries operating in coastal waters in most areas of the the Irish and Celtic Seas. While there are few such mixed stock sea trout fisheries now operating in coastal waters, where they occur they can clearly make the sustainable management of individual stocks more difficult. There is also potential for estuary fisheries to exploit mixed stocks if sea trout regularly venture into foreign estuaries during the marine phase of their life-cycle. There is therefore a need to conduct further genetic studies of sea trout caught in legal estuary fisheries to determine the extent of stock mixing.

The temperatures experienced by post-smolts appear to be strongly influenced by the nature of the estuary from which they emigrate and its latitude. Where the fish are retained for longer in a large estuary, they may experience higher temperatures (e.g. River Esk), whereas on the more exposed coastline in the south of Ireland, fish may experience lower temperatures than in the more protected waters at similar latitudes in Wales. While the simulated fish have been kept at a constant depth of 2m, post-smolts are known to make some large vertical movements, albeit only for a small proportion of the time (Middlemas et al., 2009; Sturlaugsson and Johannsson, 1998). Such movements may result in them experiencing different temperatures, depending upon whether or not there is a thermocline (Figure 7.7.5).

The genetic assignments suggest that sea age 1/1+ sea trout are more widely dispersed from their rivers of origin than sea age 0/0+ fish and there is extensive overlap in the distributions of fish from different regions. This should result in their being less difference in the temperatures experienced by therefore tend to result in the temperatures experienced by the populations as a whole .

7.8 Feeding Ecology and Marine Biotopes

7.8.1 Introduction

The benefits of feeding in the sea, with its provision of a wide variety of large, lipid and protein rich prey species appears to be a major driver behind anadromy in salmonids. This introduces sea trout to a range of completely different ecosystems and physical habitats to those experienced in freshwater. The ecology of feeding and the types of prey species are therefore important features to describe and understand. The term biotope means an area of uniform environmental conditions providing a living place for a specific assemblage of plants and animals. It is almost synonymous with habitat, but because biotope is more associated with communities and habitat is more with the single species, the term biotope is used here. Sea trout go to sea to feed and grow and to survive. Therefore the distribution of biotopes that might influence migration routes, support prey species, predators and offer environmental conditions suitable for growth is also expected to be important in determining the distribution of stocks and variety of sea trout life histories.

The feeding ecology of sea trout at sea has been studied in a number of investigations primarily around Ireland, Norway, and Scotland (Pemberton, 1976; Fahy, 1985a & d; Lyse *et al.*, 1998; Knutsen *et al.*, 2001; Rikardsen *et al.*, 2006) but has received comparatively little attention around the British Isles (Pemberton, 1976; Fahy, 1985c; Potter, 1985). Trout are known to be opportunistic feeders in both freshwater and marine environments (Elliott, 1997; Klemetsen *et al.*, 2003; Rikardsen and Amundsen, 2005). Pemberton (1976) analysed the stomach contents of 1,277 stomachs of sea trout caught in five sea lochs in Scotland; clupeids, sand eels, amphipods and diptera were the most frequently occurring food types. Fahy (1985c) investigated gut contents from 125 sea trout off the east coast of Ireland; the most common prey types were sand eel, *Eunereis longissima* (a polychaete worm) and sprat. Knutsen *et al.* (2001) showed that Diptera, amphipods and Clupeidae were the most frequently consumed prey items in areas of the Norwegian coast. Rikardsen *et al.* (2006) showed seasonal variation in percentages of prey items. Fish species (herring, sand eel, capelin) comprised the majority of the stomach contents during the warmer summer months and crustaceans comprised the majority during other times of the year. The purpose of this study was to describe the marine feeding ecology of sea trout in the Irish Sea (Figure 7.8.1).

7.8.2 Methods

Sea trout were obtained from strategic scientific sampling efforts, donations by commercial fishermen and anglers fishing under personal licence (see Chapter 3) within designated marine zones (Figure 7.8.1). The methods of catching sea trout at sea during this study ranged between areas with some methods being traditional to an area or specially adapted scientific procedures for local conditions (Table 7.8.1) (see Sampling Chapter 3 for details).

The main sampling period was between 2010 and 2012 with some samples from earlier years incorporated into the study having been obtained from seizures by the regulating agencies of illegally caught sea trout, bycatch from other studies or various spurious sources (Figure 7.8.1). Exact catch locations were recorded and converted to digital latitude and longitude (WGS1984).

The fish were dispatched by a method appropriate to catch type; all scientifically caught samples were dispatched in accordance with regulatory guidelines. Each fish was placed in a labeled individual plastic bag and frozen whole where possible, or the head and contents of the body cavity were retained by the sampler on behalf of the project. The fork length L_F to the nearest mm and weight (W) to the nearest g, were recorded for freshly caught sea trout where possible, and for all sea trout when thawed (if possible). A correction factor was ascertained for all fish from sea trout where a fresh and thawed length and weight were recorded ($L_F = 1.0157\ L_T + 4.8084$ and $W_F = 1.0235W_T + 10.925$). Where only thawed lengths and weights of sea trout exist, these were corrected using the equations above. During laboratory processing the sex of each sea trout was recorded.

Stomach content from a rod caught sea trout taken in Wales

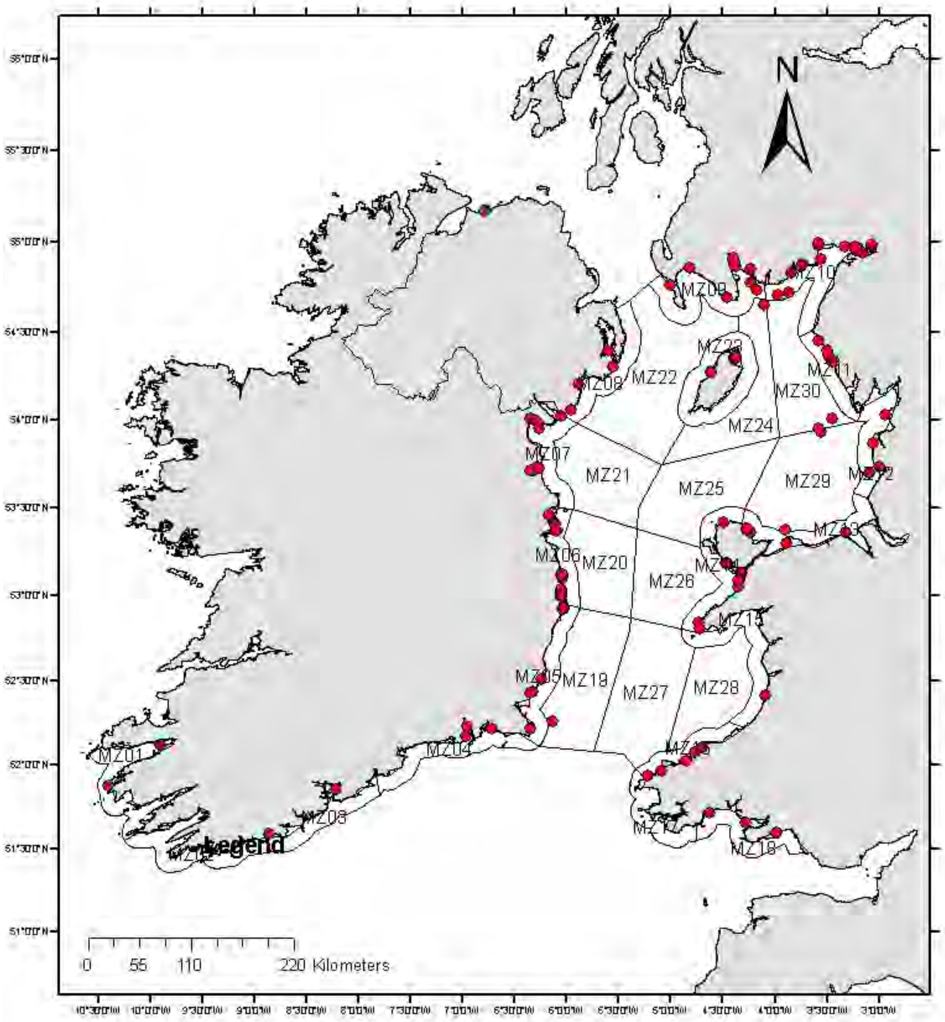


Figure 7.8.1 The position of the Celtic Sea Trout Project Marine Zones (labeled) and positions of sea trout samples obtained for the study (red dots). ©GADM

Stomachs were removed as part of the sampling procedure on thawed sea trout. Stomachs were cut from the body between the oesophagus and the pyloric sphincter. Any prey items in the buccal cavity (protruding out from the stomach into the mouth) were collected, retained and counted as part of the stomach contents. Total stomach weight including contents was recorded to 0.01g. Prey items were identified to species level where possible, and numbers of each recorded. The weights of each prey type were recorded to 0.01g. The frequency of occurrence and relative abundance of different prey types were calculated for the whole survey area (Amundsen *et al.*, 1996). The percentage occurrence (%*F*) and the percentage abundance (%*A*) of prey type (*i*) is described by the following equations:

$$\%F = (N_i/N) \times 100$$
$$\%A_i = (\Sigma S_i/\Sigma S_t) \times 100$$

where N_i is the number of sea trout with prey *i* in their stomachs, *N* is the total number of sea trout with stomach contents, S_i is the stomach content (by weight in g) composed by prey *i*, and S_t is the total stomach content in the entire sample. Individual sea trout stomach fullness was defined as the ratio between the weight of the whole stomach (including contents in g) and the measured or estimated individual sea trout weight (Goñi et. al., 2011).

Table 7.8.1 Number and percentage of stomach samples by different sampling methods

Catch Method	Total Stomachs	%	Marine Zone
Draft Net	388	39.2	MZ04, MZ05, MZ06, MZ07, MZ08
Gill Net	207	20.9	MZ05, MZ06, MZ09, MZ10, MZ11, MZ12, MZ13, MZ14, MZ15, MZ16, MZ18, MZ23
Fish Kill	123	12.4	MZ12, MZ14, MZ16, MZ23
Stake Net	99	10.0	MZ09, MZ10
Trawl Net	71	7.2	MZ05, MZ07, MZ13, MZ29, MZ30
Haaf Net	32	3.2	MZ10
Seine Net	18	1.8	MZ13, MZ14
Drift Net	14	1.4	MZ01, MZ07, MZ10, MZ11
Coastal Net	3	0.3	MZ09, MZ10
Angling (spinning)	27	2.7	MZ13
Angling (bait)	3	0.3	MZ03, MZ13
Unknown	6	0.6	MZ9, MZ15, MZ18
Total	991		

Prey type was examined according to MZ, catch method, sex of fish, size category of fish, season, month and year of catch. Exploratory and statistical analyses were undertaken in Microsoft Excel and Minitab® v.16. Information relating to marine substrate type and depth profiles for the Irish Sea was acquired under licence from www.edina.ac.uk. Collected data was mapped in ArcGIS v 9.3.

7.8.3 Results

A total of 991 stomachs were collected from sea trout caught in the Irish Sea between 2007 and 2012. The mean fork length (L_F) of these sea trout was 385mm (range 128 to 760mm). The mean weight was 845g (range 29g to 6,070g). Of the 991 sea trout 722 (72.9%) were female, 247 (24.9%) were male and 21 (2.2%) were either undetermined sex or not examined. The stomachs of 543 sea trout (54.8%) contained a total of 2,383 prey items, giving a mean of 4.4 items per feeding fish (2.4 when all fish with empty stomachs were included). The majority (84%) of stomachs available for analysis were from sea trout caught between March and August (Figure 7.8.2), which coincides with the commercial fishing season for sea trout in the UK and the more conducive weather conditions for undertaking scientific sampling.

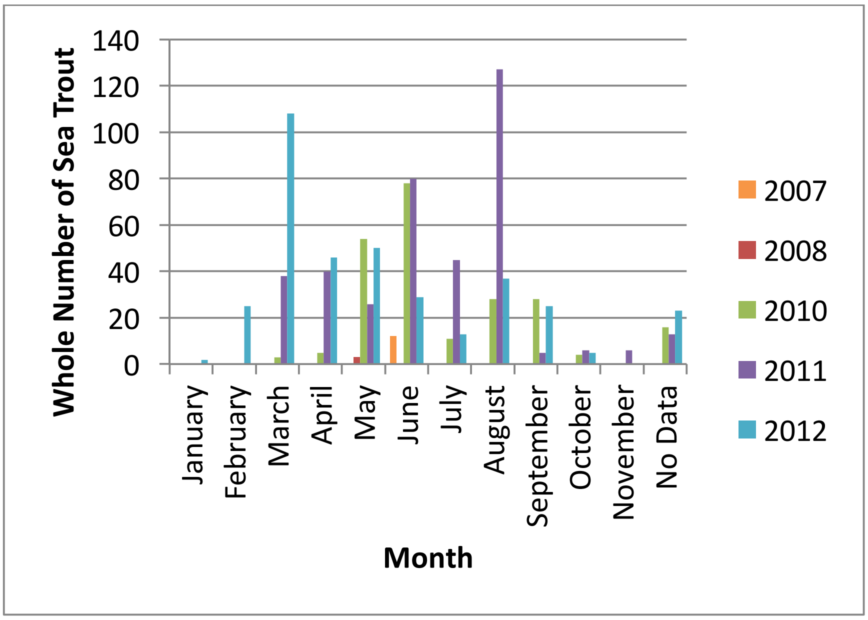


Figure 7.8.2 Numbers of sea trout caught (commercial nets, seizures from illegal fishing or scientific sampling) during the CSTP by month and year.

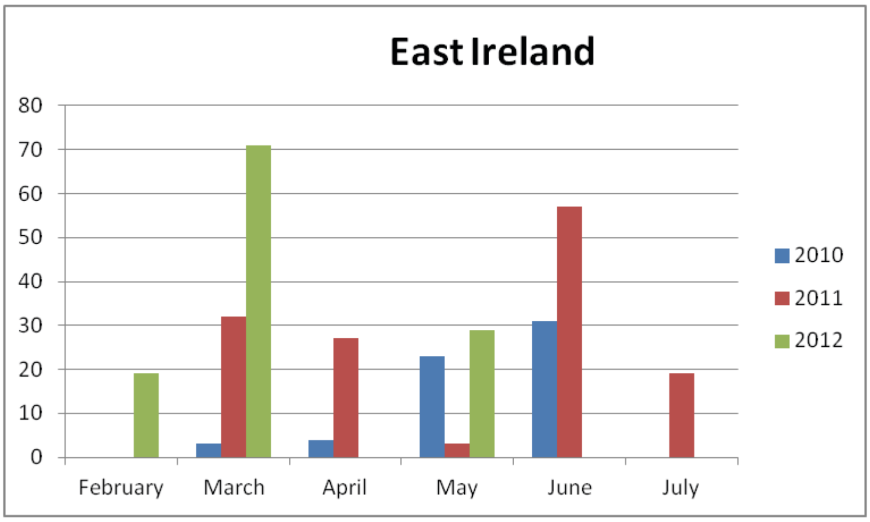


Figure 7.8.3 Monthly distribution of sea trout stomach samples collected along the east of Ireland between 2010 and 2012.

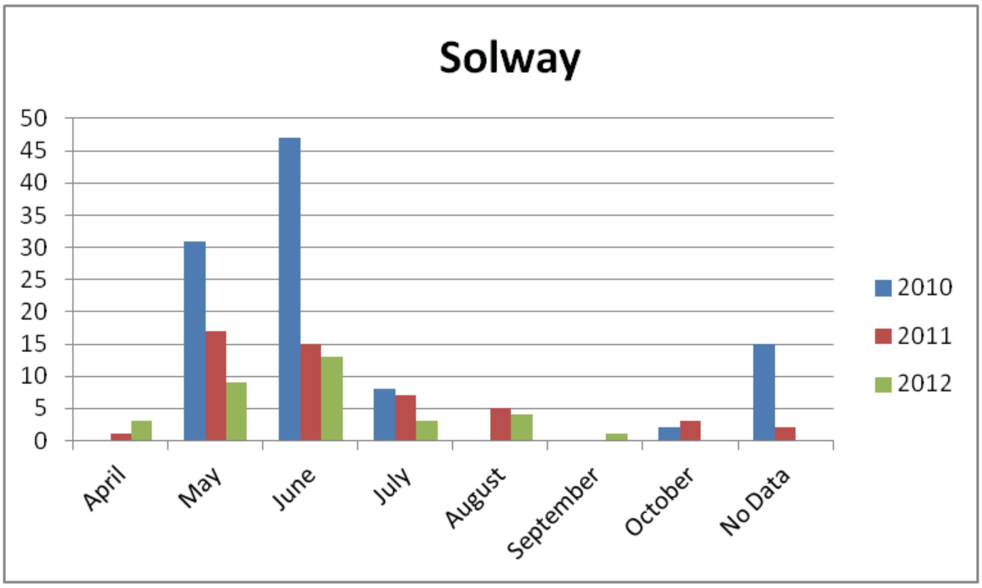


Figure 7.8.4 Monthly distribution of sea trout stomach samples collected along the Solway coast between 2010 and 2012.

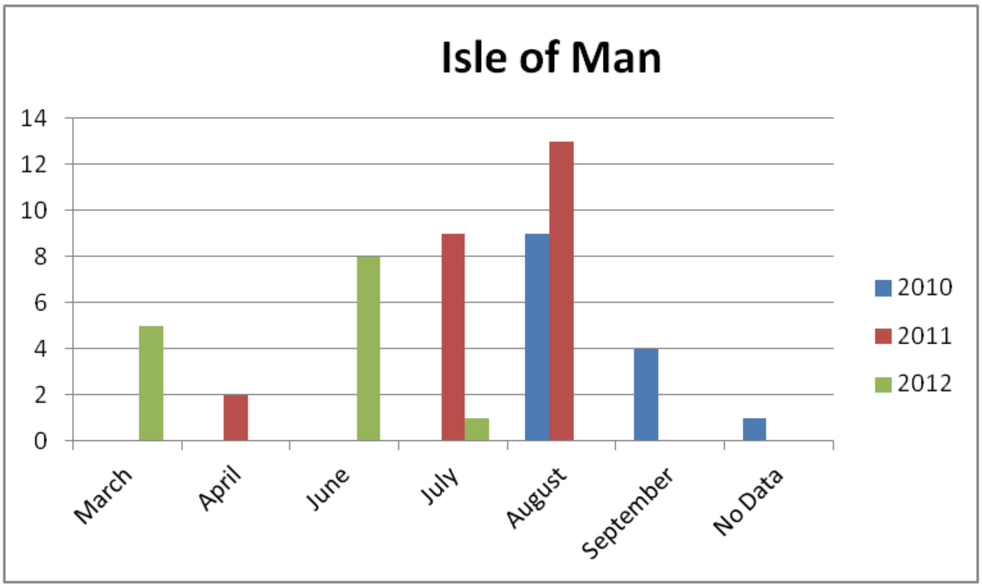


Figure 7.8.5 Monthly distribution of sea trout stomach samples collected around the Isle of Man between 2010 and 2012.

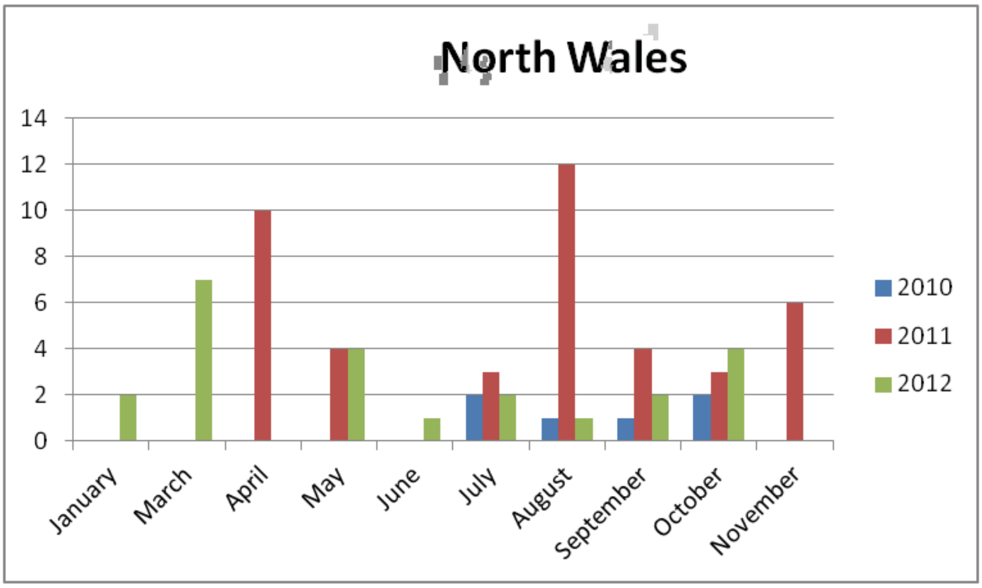


Figure 7.8.6 Monthly distribution of sea trout stomach samples collected around the coast of north Wales between 2010 and 2012.

The most seasonally uniform samples were obtained in the east of Ireland, Solway, north Wales and around the Isle of Man. Sampling in the east of Ireland from August onwards was hampered by local conditions which caused choking of the net with seaweed (Figure 7.8.3). Similar catch profiles were observed in the Solway, where most fish were caught the early part (May and June) of the commercial sea trout fishing season (Figure 7.8.4). Samples from the Isle of Man were obtained across similar time scales as those caught in the Solway with the majority of samples being caught in the summer months during periods of good weather (Figure 7.8.5). Samples collected in north Wales ranged over all months of the year with the exception of December, when no suitable sampling conditions prevailed (Figure 7.8.6).

Fish formed the major (96%) component of diet, dominated by two species, sand eel and sprat. Sand eel was the most prevalent with percentage occurrence (%*F*) and percentage abundance (%*A*) of 56% and 63%, respectively (Table 7.51), followed by sprat (28% and 18% respectively). Herring had the third highest percentage abundance of 8.2%. Of the other taxa, amphipods were most prevalent with percentage occurrence of 4.8% (Table 7.8.2).

Table 7.8.2 Percentage abundance (%A_i) and percentage occurrence (%F_i) of prey types in all sea trout caught in the Irish Sea.

Prey Item	%A_i	%Fi
Sand eel	62.560	55.617
Sprat	17.773	27.993
Herring	8.239	1.657
Sea Scorpion	0.055	0.368
Mackerel	0.961	0.184
Clupeid	0.150	0.368
Benthic Fish	0.055	0.184
Other Fish	6.241	21.547
Crabs	0.019	0.368
Prawn/Shrimp	0.161	0.552
Amphipods	0.149	4.788
Polychaetes	0.063	0.368
Other invertebrates	0.181	4.420
Mush	3.394	8.840
Total	100	

There were no observable differences in diet between the sexes (Figure 7.8.7).

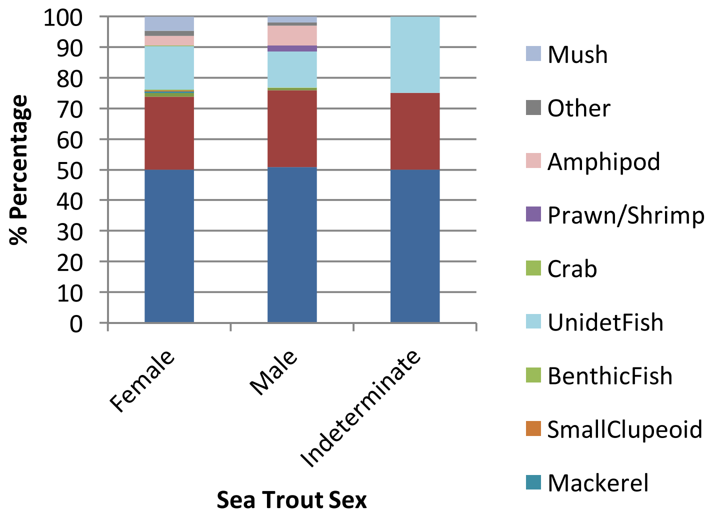


Figure 7.8.7 Percentage occurrence of prey items in sea trout stomachs based on fish sex

The cumulative percentages of prey weight were categorised by sea trout length. Smaller sea trout (<200mm) were heavy predators of small crustacean amphipods (Figure 7.8.7). Between 200 and 600mm, the main prey items were sand eel and sprat. Fish larger than 600mm tended to consuming larger prey items such as whole herrings or mackerel, or other larger benthic fish (Figure 7.8.8); but there were exceptions and one small sea trout (approx. 18cm) was observed to have an entire sprat (approx. 6cm) in its stomach. Photographs were taken for many of the stomach contents and are available for future prey size estimation.

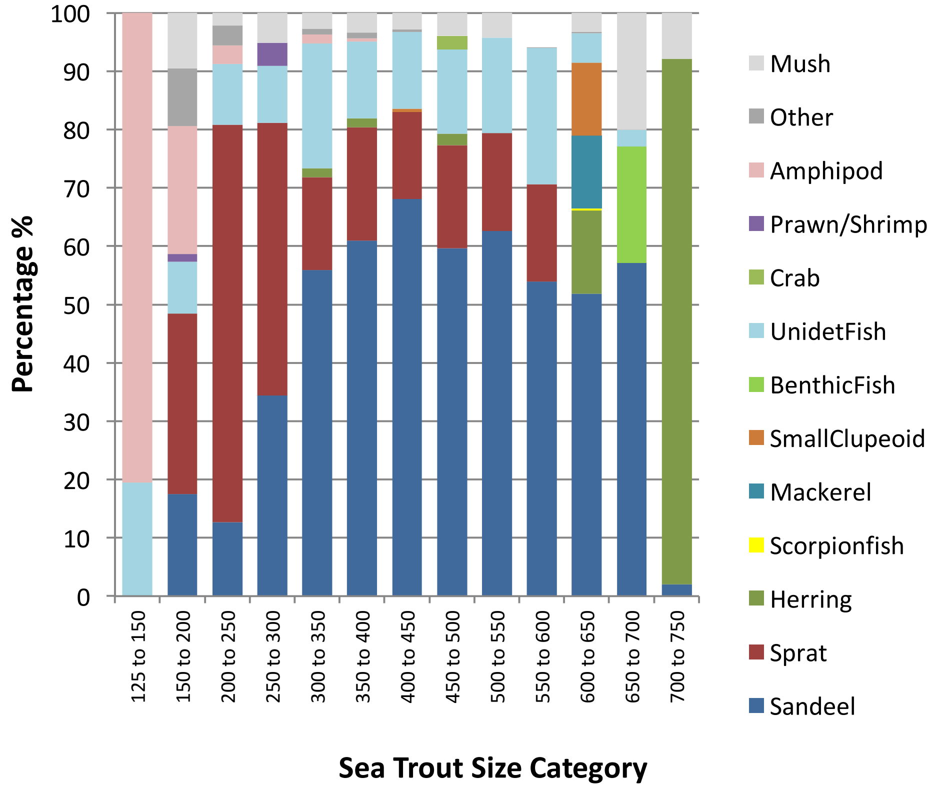


Figure 7.8.8 Cumulative percentages of weight of prey items by sea trout size category (fork length, L_F in 50mm increments).

Sandeels in sea trout stomach

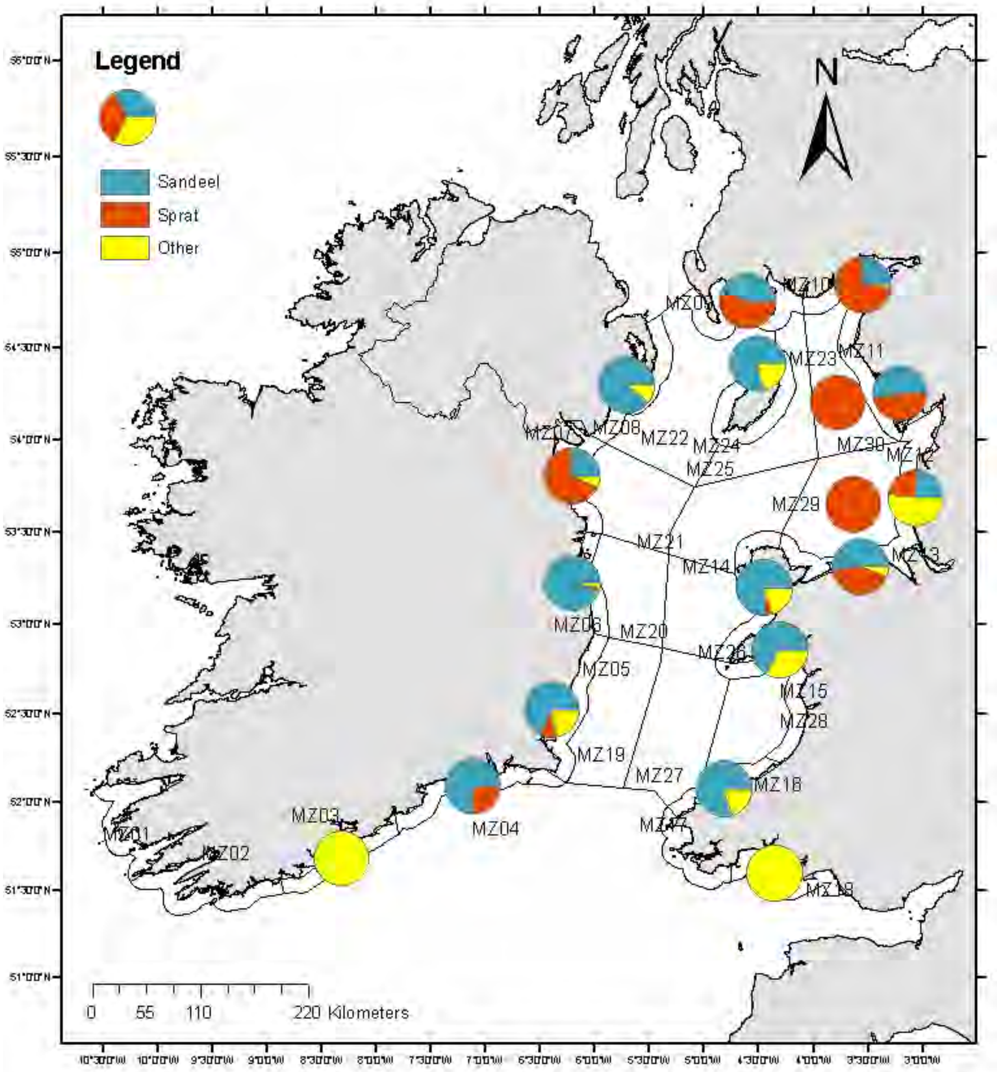


Figure 7.8.9 Proportion of prey items (sand eel, sprat and other) for each Marine Zone. Note that this is for all data combined (NB any size or season interactions here?) ©GADM

Proportion of sand eel, sprat and "other" prey in the diet were mapped for each marine zone (Figure 7.8.9), indicating geographical distributions. Although sand eel had the highest percentage occurrence and abundance by number (Table 7.8.2), sea trout diet in several areas had higher proportions of sprat (Figure 7.8.9). Habitat types typically preferred by sand eel (Wright et al., 2000) of marine sediments and bathymetry have been mapped for the Irish Sea (Figure 7.8.10). It is evident that the areas such as Dundalk Bay in MZ07, the outer Solway area (MZ09), and areas along the east coast of England (MZ11, MZ12, MZ29 and MZ30) did not contain significant areas of suitable habitat for sand eel (Figure 7.8.10, Figure 7.8.11). In MZ10 there was a large area of sand eel suitable habitat, however approximately 75% of the proportion of prey in this area was also sprat (Figure 7.8.9).

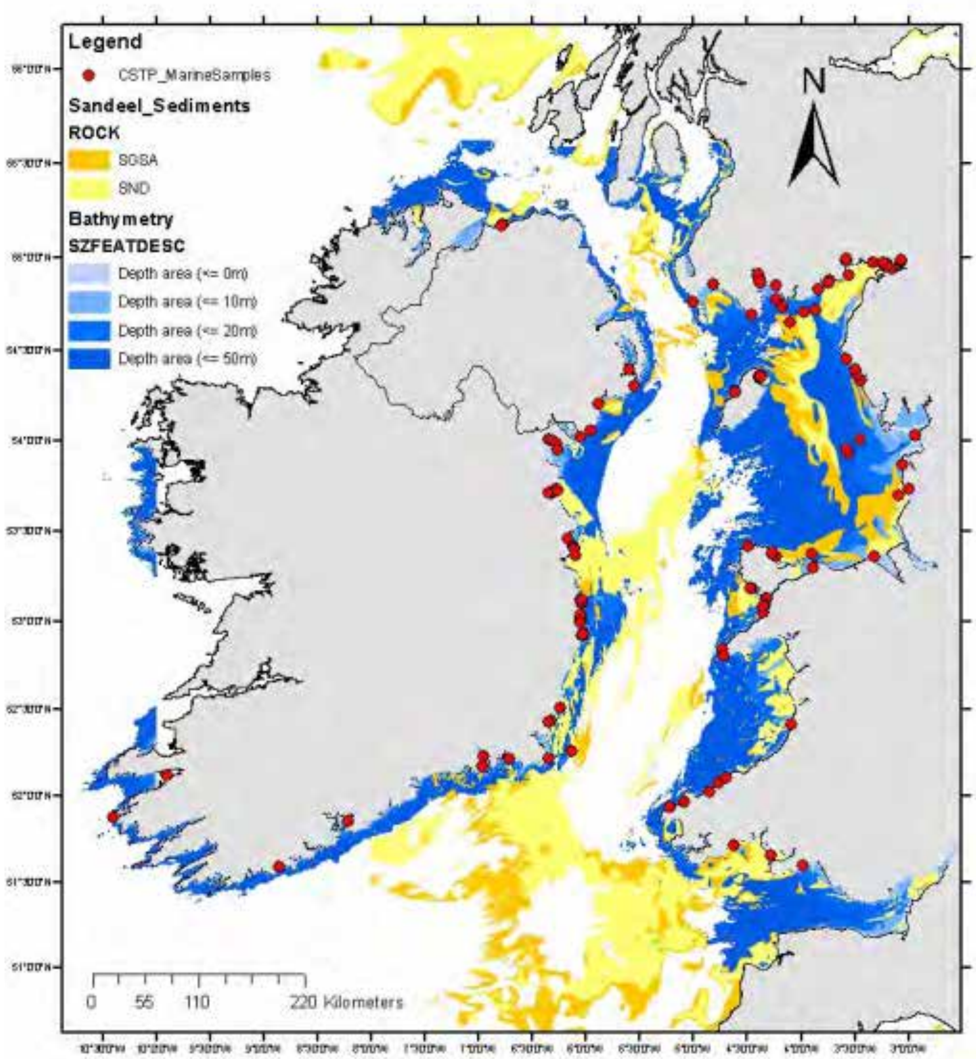


Figure 7.8.10 Sand eel preferred habitat types (marine sediments and bathymetry) within the Irish Sea. ©GADM ©British Geological Society © www.edina.ac.uk.

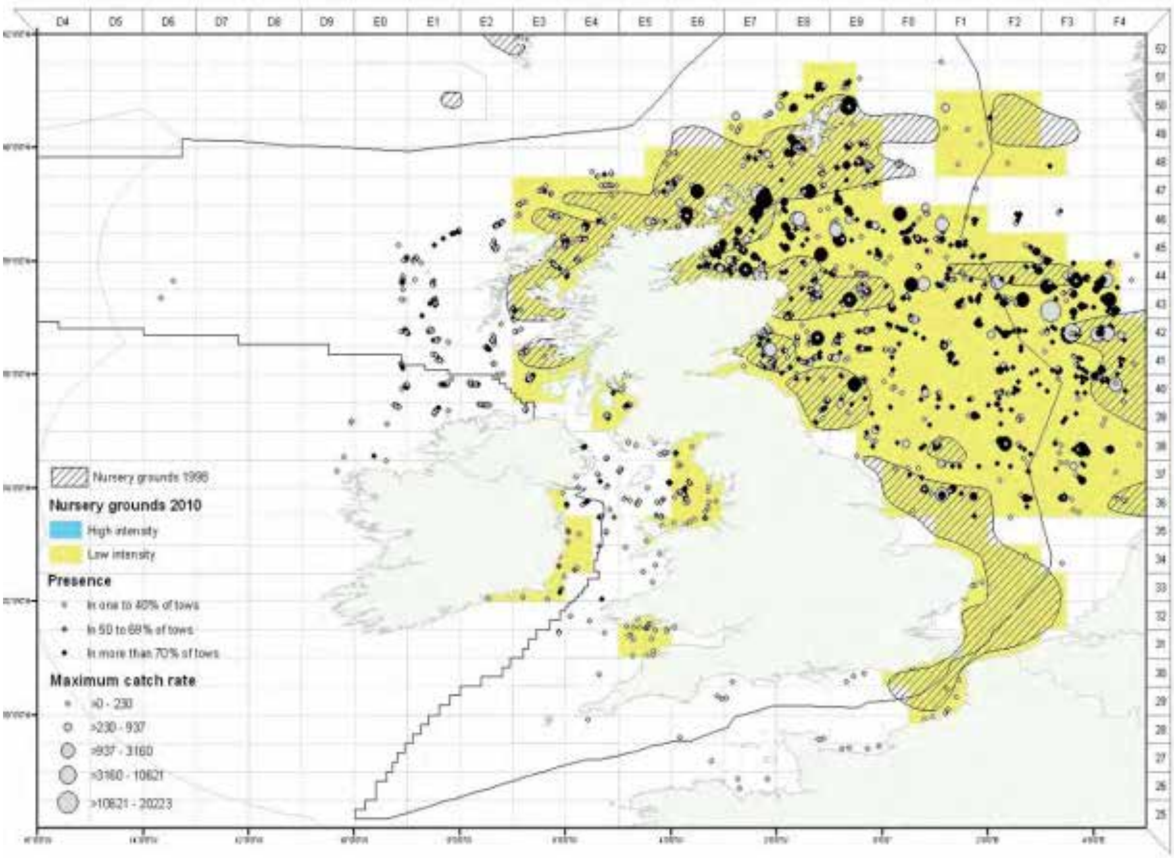


Figure 7.8.11 Sand eel nursery grounds around the British Isles (from Ellis, 2012).

7.8.4 Sea trout prey species ecology and marine biotopes

The Irish Sea marine habitat is highly structured, with contrasting coastal geography, marine seascapes and hydrology. The eastern sea board is more featured, with more and larger embayments and estuaries (=greater freshwater inputs), more extensive shallow waters (Figure 7.8.10 and Figure 7.8.12), weaker circulation patterns and higher residence times (Kennington *et al*., 2002; Kennington and Rowlands, 2006).

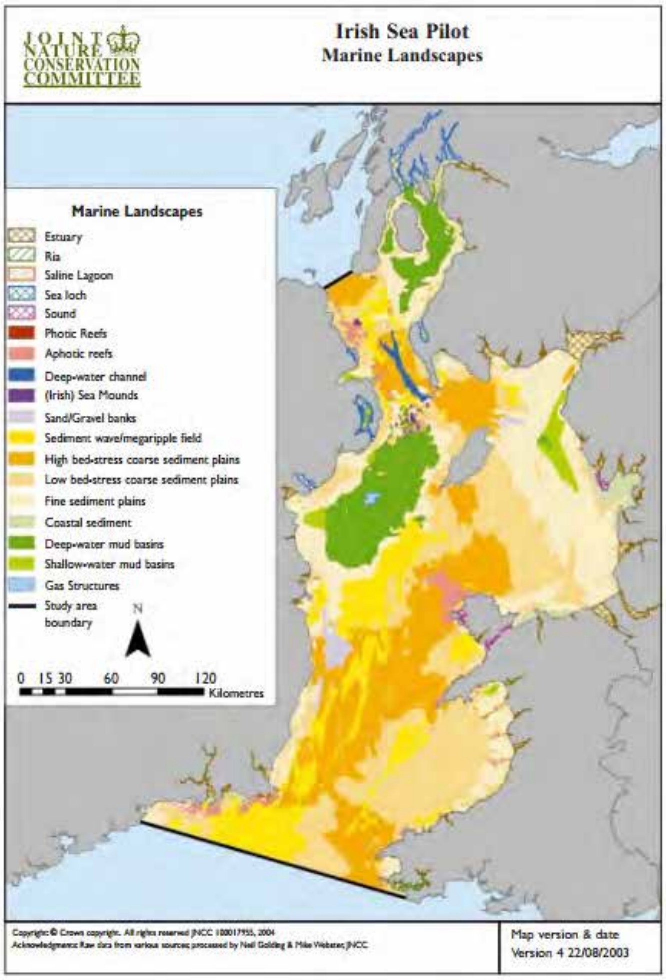


Figure 7.8.12 Some key features of Irish sea geophysical and hydrographic features assembled to describe marine landscape (from Irish Sea Pilot, *Vincent et al*., 2004).

Temperatures have been shown above to be higher and more seasonally variable in the east coast shallow water areas. Marine dissolved available inorganic nitrogen and phosphorous (DAIN and DAIP respectively) are much higher on the eastern side of the Irish Sea (Kennington *et al*., 2002), due to its lower volume and to major inputs from the Solway Firth, Mersey and Dee and various point sources. In contrast, the west side has lower freshwater DAIN and DAIP inputs into deeper water with lower residence time due to the residual current patterns. The elevated nutrient concentrations in the eastern Irish Sea are believed to account for the high spring phytoplankton production there (Kennington *et al*., 1999; Kennington and Rowlands, 2006; Gowen and Stewart, 2005). However, the relationships between primary production and secondary production (herbivorous and carnivorous zooplankton), other planktonic forms and higher trophic levels are complex and not a simple reflection of the distribution of primary production. The regional distribution of plankton and adjacent lower trophic levels are influenced by seasonal patterns of penetration of Atlantic waters and by local hydrography; for example an anticlockwise summer time gyre that forms in stratified deep water west of the Isle of Man and is thought to be responsible for accumulation of some copepod species (Kennington and Rowlands, 2006). Thus a direct connection between sea trout principal prey and lower trophic levels is not immediately evident. Virtually nothing is known about the coupling of trophic linkages in the sea trout marine food web. Therefore, if food is ever a limiting factor for the growth and survival of post-smolts, then much more work is needed to demonstrate that and to understand any mechanisms. Nevertheless, descriptions of the basic distribution patterns of sea trout prey species are a first step in that understanding.

The biotope features outlined above are relevant to sea trout behaviour and ecology. Sea trout have been observed to largely remain in the top few metres of the water column, with occasional excursions into deeper waters, thought to be for direction-finding purposes (Rikardsen *et al*. 2007). This observation combined with the observed dominance of sand eel and sprat in the diet for most marine zones supports the contention from gut contents that sea trout are chiefly pelagic feeders, though the CSTP results provide evidence of some bottom feeding, with crab, prawn/shrimp and benthic fish recorded in stomach samples. The proportion of sand eel to sprat recorded in stomach samples varied, with fish caught in MZ7 and in the NE Irish Sea (Liverpool Bay to the Solway Firth) having more sprat than sand eels in their diets, whereas sprat forms a relatively minor part of the diet elsewhere. Both species have a wide distribution in the Irish Sea. Sprats are found throughout the Irish Sea (FAO 2015); their spawning grounds are also found throughout the Irish Sea with the exception of the Bristol Channel and Cardigan Bay (Coull *et al*. 1998). Sand eel eggs are demersal making identification of spawning grounds from plankton surveys impractical, however Ellis *et al*. (2012), using larval and juvenile distributions, identified much of the northern and eastern Irish Sea as a sand eel spawning area as well as much of the East coast of Ireland, the western Bristol Channel and the NE Irish Sea as low intensity nursery grounds for this species.

Whilst these distributions may offer a speculative explanation for the dominance of sand eels in the diet of fish captured on the Welsh coast, they do not by themselves explain the dominance of sand eel in sea trout diets on the Irish coast, the dominance of sprat in the NE Irish Sea or the absence of both species in the southern-most samples taken on both coasts of the study area and it is therefore worth exploring the distribution of adult prey species in more detail through examination of their preferred habitats.

Adult *Ammodytes marinus* have a preference for sand and gravelly sand, low in silt, for their burrows. This equates roughly to two biotopes on the BGS classification; SND (Sand) and SGSA (SGSA) (Figure 7.8.10). They have a preferred depth range of up to 70m (Wright *et al*., 2000), though juvenile sand eels of other species are regularly caught up to depths of 270m (see *Table 2* in Ellis *et al*., 2012). Whilst all sea trout samples were captured in areas with depths of less than 50m, it remains possible to attempt to correlate gut content with the distribution of preferred biotopes of *A. marinus* further; Van der Kooij *et al*., (2008) confirmed that the distribution of the nocturnal burrow habitat provides a good proxy for daytime distribution in the water column, with sand eels on the Dogger Bank moving a short distance from their burrows on shallower sandbanks to deeper water to feed. Thus it would appear reasonable to assume that sand eels will be uncommon beyond the SND and SGSA biotopes, however this does not infer universal presence within these biotopes as the SND biotope includes fine sand, which sand eels are reported to find less favourable for burrows.

The greater proportion of sprat in the gut of sea trout captured in MZ7 correlates with an absence of suitable sand eel habitat in most of that zone, and a similar lack of suitable sand eel habitat is observed on the south west coast of Scotland (MZ 09 and west MZ10), NW England (MZ11 and 12) and the offshore samples in MZ 29 and MZ30. However the inner Solway Firth (east MZ10) has large areas of SND and SGSA biotopes and stomach samples taken here were dominated by sprat. Cutts and Hemmingway (1996) mapped a complex sediment profile for the Solway Firth and this included sediments suitable for sand eels.

When investigating the dominance of sprat in the diet of sea trout in the Solway Firth there are a number of possibilities that could be explored. Van der Kooij et al. (2008) found that a number of environmental variables influenced sand eel density, including salinity, bottom temperature, and difference between bottom and surface temperatures, (with covariance between some variables observed), in this study data could not be obtained for all of these variables to allow a similar assessment to be made. Burkart et al. (1995) proved that distributions of copepod nauplii in the Irish Sea are quantitatively associated with hydrographic variability during the spring resulting in different hydrographic areas supporting different assemblages, providing distinct food environments for predators such as fish larvae. However, diets for sand eel and sprat larve have been reported as similar. It may also be that the higher sprat content in sea tout diets in this area are related to relative abundance of the two species and that some kind of prey selection theory should be used to model this, with patchiness of prey distribution having an influence, however, we do not have sufficient data to pursue this further.

7.8.5 Discussion and Conclusions

Sea feeding, with its particular diet and notional advantages for growth and fertility (Jonsson and Jonsson, 2006), appears to be the single biggest benefit at stake against the major risks incurred by anadromy in trout (dispersal is the other major benefit). Availability and capture of suitable prey are essential for life at sea; therefore it is important to describe the marine diet of sea trout and to understand how this links with marine ecosystems and trout marine ecology.

Sea trout are opportunistic feeders, with varied diets reported in different studies (Fahy, 1985; Lyse *et al.*, 1998, Knutsen *et al.*, 2001). From these studies it was anticipated that the diet of sea trout in the Irish Sea would comprise mainly sand eel, sprat and polychaete worms. This study confirmed the importance of the pelagic fish and the importance of amphipods and benthic invertebrates in the diet of small sea trout, although polychates were at low abundance. Sea trout diet varied with size as reported for a Norwegian study (Knutsen *et al*., 2001). Selection of prey is dependent on predator size; features such as mouth gape are a limiting factor in the selection of prey (Wankowski, 1979), which is why, apart from some specialist feeders, prey size tends to increase with increased size of the predator. Smaller sea trout were observed to predate on a variety of small prey items such as small crustaceans, small polychaete worms and small fish (Figure 7.8.8). As the sea trout grow larger in size the food preference moves onto fish such as sand eel and sprat, and lastly larger prey items such as whole mackerel or herrings were found in stomachs of sea trout greater than 600mm (Figure 7.8.8). The selection of larger prey items as the sea trout grows is more cost–effective as less relative energy is required to hunt compared to hunting large numbers of small prey items. Hislop *et al.* (1991) showed that sprat have a higher calorific value per mean length of fish compared to sand eel; but such variation is inconsequential in relation to the variability prey abundance which will be a far more important influence foraging selection and efficiency in an opportunistic feeder like sea trout. Overall, sand eel were the most prevalent food of sea trout in the Irish Sea (Table 7.8.2), possibly reflecting their abundance relative to sprat, although good data on relative abundance are lacking However, it was noted that there was a geographic separation of prey consumption (Figure 7.8.9) from north to south. Sea trout in Dundalk Bay in Ireland, around North West England and the Solway coast of Scotland were observed to have ingested proportionally higher quantities of sprat compared to other areas, where sand eel were consumed in greater numbers. This separation of prey preference was very loosely associated with known sand eel habitat types (Figure 7.8.10). However observed sand eel distribution was not obviously correlated with presence in sea trout diet at least with available low resolution survey data (Figure 7.8.11, Figure 7.8.12). The occurrence of sprat in the diet did appear to be more closely with observed sprat distribution (Figure 7.8.13), reaffirming the opportunistic feeding of sea trout.

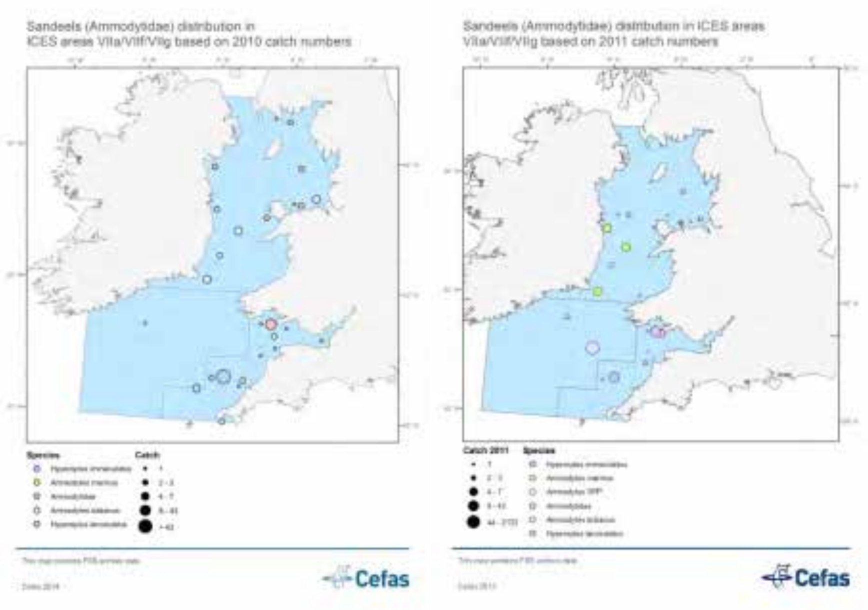


Figure 7.8.13 Distribution of sand eel in the Irish Sea in 2010 and 2011. Data from Cefas.

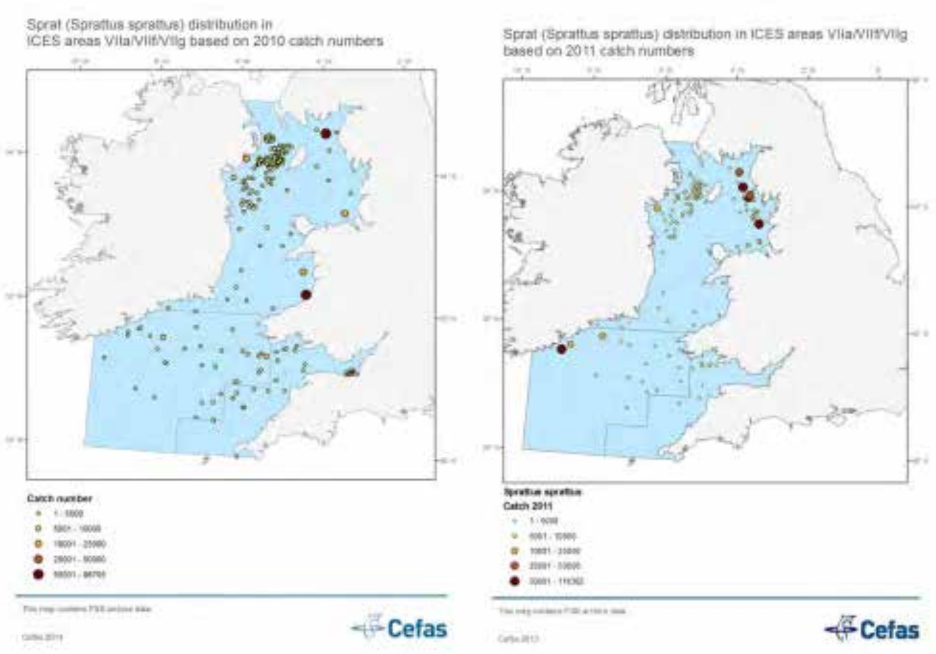


Figure 7.8.14 Distribution of sprat in the Irish Sea in 2010 and 2011. Data from Cefas.

It is possible that seasonal variation of prey abundance affected diet. For example, around north Wales, although sand eel comprised the majority of the sea trout diet, some sprat were found in sea trout stomachs during the winter months, when anecdotal evidence suggest that it becomes abundant in coastal waters.

The Irish Sea ecosystem has attracted less attention that areas such as the North Sea, and there has been less collation and integration of data that do exist (ICES, 2008). The data on distribution of key prey species in the Irish Sea is sparse, incomplete and certainly not up to the task of making robust spatial or temporal comparisons on availability to predators. These keystone species (sand eel and sprat in particular) are an important part of the marine trophic web upon which sea trout, many fully marine fish and birds depend and should be a focus for monitoring. During this study new information was gathered on sea trout marine diet, specifically in relation to the geographic distribution of preferred prey in sea trout diet that partly coincided with prey habitat types. Better (more systematic, stratified and more spatially extensive) data on prey availability, marine habitats and the extent of coupling in sea trout food webs would greatly improve understanding of sea trout marine ecology and their response to wider ecosystem changes.

7.9 Infestation parameters of the Caligid copedod sea lice, *Lepeophtheirus salmonis* and *Caligus elongates*, on sea trout (*Salmo trutta L.*) around the Irish Sea.

7.9.1 Introduction

Wild Atlantic salmon and sea trout are parasitised by two species of caligid copepod sea lice, *Lepeophtheirus salmonis* and *Caligus elongates* in the marine environment. Generally, levels of lice infestation on salmonids are low and few adverse effects on the host have been reported (Finstad *et al*. 2011). With the advent of marine salmon farming since the 1980's, there have been reports of sea lice epizootics on salmonids in aquaculture areas in Norway, Scotland and Ireland (Heuch *et al.* 2005, Revie *et al.* 2009). Several studies have assessed sea lice levels on sea trout close to and distant from marine aquaculture facilities in an attempt to determine the impact of increased lice production from aquaculture on wild sea trout. (Gargan *et al*. 2003, Middlemas *et al*. 2013). Thorstad et al. 2015 comments that ideally, in order to evaluate whether or not salmon lice levels have become elevated in wild populations, and their possible association with salmon farming, baseline information on lice levels and their year-round population dynamics would be required for time periods preceding the development of fish farming, or from areas lacking fish farming. A number of previous studies document historical salmon lice levels on sea trout prior to salmon farming (Boxshall 1974), or provide data for areas lacking fish farming (Tingley et al. 1997, Schram et al. 1998, Heuch et al. 2002, Rikardsen 2004, Urquhart et al. 2010). However, few large scale studies are available on the levels of sea lice infestation of sea trout in areas distant from aquaculture or prior to the development of marine salmon farming to establish natural baseline lice levels on sea trout so that the effect of potential increases in lice from aquaculture can be evaluated.

The Celtic Sea Trout Project (CSTP) was an INTERREG IVA Ireland Wales EU funded collaborative project examining the status, distribution, genetics and ecology of sea trout around the Irish Sea. The project was undertaken over the 2009 - 2012 period, intended to improve the management and long term sustainability of sea trout in the Irish Sea by providing information and management advice. Sea trout were sampled at sea over a wide geographic range around the Irish Sea from southern Scotland, along the English and Welsh coast, along the coast of Ireland and Northern Ireland and around the Isle of Mann. This sampling programme provided an opportunity to assess the levels of sea lice on sea trout spatially and temporally over a wide geographic area. There were no marine salmon farms in the area covered by the Celtic Sea Trout Project and therefore the sampling programme allowed establishment of sea lice infestation parameters on sea trout at natural background levels in a large scale study.

7.9.2 Materials and Methods

7.9.2.1 Fish Capture Method

Sea trout were obtained by either directed scientific surveys (85.5%) from commercial fisheries (12%) or by angling (2%). Scientific sampling methods included draft, seine and gill netting. The majority (49%) of fish sampled during scientific surveys were captured by draft nets or seine nets. Draft and seine nets were set from a boat and fished in the traditional manner from the shore with the net being closed off and hauled on shore. A variation of this technique involved a boat crew and a shore crew drawing the net through the water (with the incoming tide) along the shore for 500-800m before closing off and hauling the net ashore.

Gill nets comprised various types including a standard CSTP multi-panelled gill net or gill nets designed for local habitat or conditions (i.e. locally modified). The standard CSTP gill net comprised six panels of stretched monofilament mesh, 51, 76, 89, 102, 127, & 140 mm with a net depth of 2.5m. Where CSTP gill nets were deployed they were set perpendicular to the shore for one tidal cycle and lifted at low tide. Gillnets set along the Welsh coast were inspected every hour and fish captured were removed. Modified gill nets were also deployed at some locations along the east coast of Ireland and the south cost of Wales. These functioned as drift nets which moved through the water column with the incoming tide. Any fish captured were removed immediately. The majority of fish were gilled around the head and operculum and were removed by cutting the single mesh and pulling the fish through the mesh was avoided. Any sea trout captured were individually bagged and frozen as soon as possible following capture (within 6 hours). A sample of sea trout was obtained by offshore marine trawling. Sea trout were generally alive and when the contents of the cod end were emptied into a large container on deck, fish were immediately killed and placed in individual plastic bags.

7.9.3 Results

7.9.3.1 The Sea Trout Population

In total, 850 sea trout were available for analysis over the 2010-2012 period, 682 fish captured at sea, 71 fish captured by trawling and 97 fish captured in estuaries. The number of sea trout available by capture method, mean length and range are shown, Table 7.9.1. The majority (95%) of sea trout captured over the three year period were captured during the March to September period (Table 7.9.2).

Table 7.9.1 Number of sea trout by capture method

Capture Method	N	Length		
		Mean (mm)	N*	Range (mm)
Angling	19	276	16	234-329
Draft	416	402	408	166-719
Gill Net/Meshed	217	433	212	196-760
Trap Net	120	418	120	256-620
Trawl	71	237	71	150-397
Unknown	7	473	7	416-583
TOTAL	850		834	

* measured fish

Table 7.9.2 Number of sea trout by captured month

Month	N	Length		
		Mean (mm)	N*	Range (mm)
January	2	326.0	2	317-335
February	19	440.5	17	351-670
March	132	394.0	125	205-615
April	49	376.2	48	166-599
May	93	410.3	93	199-760
June	181	413.8	181	224-713
July	83	380.3	80	222-720
August	185	356.8	185	150-706
September	58	448.7	56	270-660
October	16	421.3	15	234-544
November	6	387.2	6	256-719
TOTAL	824	362.9	808	

* measured fish

7.9.3.2 Annual Sealice Parameters

The prevalence, abundance, intensity and proportion of chalimus life stages of both *L.salmonis* and *C.elongatus* over the three year study period are presented**,** Table 7.9.3. Prevalence of *L.salmonis* remained constant over the three years while prevalence of *C. elongatus* was lower in comparison and peaked in 2011. Mean abundance of *L. salmonis* ranged from 3.6 – 3.8 and mean abundance of *C. elongatus* ranging from 0.6 – 4.3. Maximum lice levels of 53 and 65 were recorded for *L.salmonis* and *C.elongatus* respectively over the study period. A low proportion of *L.salmonis* chalimus lice stage (range 1.1% – 4%) was recorded annually while chalimus life stage of *C.elongatus* exhibited a broader annual range (1.9% – 50.8%). There was no significant variation in *L.salmonis* abundance between years (2010-12) (ANCOVA, F3, 770=0.54, P=0.58) and also no significant variation in *C. elongatus* abundance between years (2010-12) (ANCOVA, $F_{2,\ 770}$=1.88, P=0.15).

Table 7.9.3 Abundance & Intensity of Sea Lice In Combined Marine Zones For Each Year

			Lepeoptheirus salmonis			
Year	**N**	**Prev. %**	**Abundance Mean**	**Abundance S.D**	**Intensity range**	**Prop. chal. (%)**
2010	217	69	3.7	4.6	1 - 31	1.5
2011	373	63	3.6	5.1	1 - 33	1.1
2012	260	63	3.8	6.5	1 - 53	4
All	850	65	3.7	5.4		

			Caligus elongatus			
Year	**N**	**Prev. %**	**Abundance Mean**	**Abundance S.D**	**Intensity range**	**Prop. chal. (%)**
2010	217	29	1.2	4.4	1 - 53	1.9
2011	373	40	4.3	9.4	1 - 65	50.8
2012	260	20	0.6	2.6	1 - 35	2.5
All	850	31	2.4	7		

7.9.3.3 Fish Capture Method

The prevalence, abundance, intensity range and proportion of chalimus life stages of *L.salmonis* and *C.elongatus* by capture method are presented, Table 7.9.4. Prevalence of *L.salmonis* ranged from 42.3 (trawling) to 78.9 (angling) and mean abundance ranged 2.9 (gill net) – 8.9 (angling). The prevalence of *C. elongatus* species ranged from 25.8% (trap net) to 73.7% (angling). Angling also had the highest mean abundance *C.elongatus* level (18.1) while draft net recoded lowest *C.elongatus* mean abundance (0.8). The proportion of *L.salmonis* recorded as chalimus stage was low over all capture methods (range 0% - 6.5%). The proportion of *C.elongatus* recorded as chalimus was also low with the exception of offshore marine trawl captured fish where the percentage chalimus life stage was 92.6%. The majority (90%) of these fish were captured in marine zone 29 & 30.

Sampling catch method was significantly related to *L. salmonis* abundance (ANCOVA, $F_{4,770}$=10.99, P<<0.001). Lowest mean abundance was observed among fish caught with gillnets (2.9, N=208), followed by 3.7 (Draft nets, N=406), 3.8 (Trawl, N=71) and 5.4 (Trap nets, N=105). Most *L. salmonis* was observed on angled fish (9.2), but only 16 fish were caught using this method. These mostly represented Welch trout caught in August.

Sampling catch method was significantly related to *C. elongatus* abundance (ANVOVA, $F_{4,795}$=7.71, P<<0.001), with fish caught with trawl or angling harbouring significantly higher *C. elongatus* abundance than fish caught with other methods. Lowest mean abundance was observed among fish caught with draft nets (0.8; N=416), followed by gillnets (1.1, N=213) and trap nets (1.9; N=120). Most *C. elongatus* was observed on seatrout caught by trawl (12.2; N=71) and on the few angled fish examined (18.1; N=16). The latter mostly represented Welch trout caught in August.

Table 7.9.4 Abundance & Intensity of Sea Lice by Capture Method

	Lepeoptheirus salmonis					
Capture Method	**N**	**Prev. %**	**Abundance Mean**	**Abundance S.D**	**Intensity range**	**Prop. chal. (%)**
Angling	19	78.9	8.9	6.51	1 - 22	6.5
Draft	416	69.0	3.6	4.67	1 - 33	2.4
Gill Net/Meshed	217	61.8	2.9	4	1 - 22	1.1
Trap Net	120	68.3	5.0	7.91	1 - 53	2.2
Trawl Net	71	42.3	3.8	7.00	1 - 27	0.0
All	843	65.0	3.7	5.46		

	Caligus elongatus					
Capture Method	**N**	**Prev. %**	**Abundance Mean**	**Abundance S.D**	**Intensity range**	**Prop. chal. (%)**
Angling	19	73.7	18.1	16.45	1 - 53	2.6
Draft	416	27.2	0.8	1.93	1 - 12	0.0
Gill Net/Meshed	217	26.3	1.1	3	1 - 21	1.7
Trap Net	120	25.8	1.9	7.49	1 - 65	2.2
Trawl Net	71	69.0	12.2	14.01	1 - 65	92.6
All	843	31.3	2.4	7.03		

7.9.3.4 Aquatic Biome

Sea lice data is presented on sea trout captured in estuaries, at sea (coastal marine) or by offshore marine trawling, Table 7.9.5. Prevalence of *L.salmonis* was lowest for offshore marine trawl (42%) caught fish and highest for coastal marine (68%) caught fish. Mean abundance was similar for the three areas, overall mean (3.7) and lowest in estuaries (2.9). Highest intensity (n=53) of *L.salmonis* was recorded on a coastal marine caught sea trout. The proportion of *L.salmonis* recorded as chalimus was highest for estuary caught sea trout and no chalimus life stages were recorded on offshore marine trawl captured fish. Trout caught in brackish water had significantly less *L. salmonis* (mean abundance 2.9) than those caught in full seawater (3.8) (ANCOVA, $F_{1,770}$=6.3, P<0.02).

Prevalence of *C. elongatus* ranged from, 8% in estuaries, 31% in the coastal marine and 69% in offshore marine (trawling), table 5. The highest mean abundance was from samples captured by trawling in the offshore marine (12.2). Maximum number of *C. elongatus* (65) were recorded from sea trout in the coastal marine and offshore marine sample. *C.elongatus* chalimus stages were absent from estuarine samples, very low in coastal marine caught samples (1.6%) and predominated in fish captured by trawling in the offshore marine (92.6%). Trout caught in brackish water had significantly less *C. elongatus* (mean abundance 0.24, N=97) than those caught in full seawater (2.7, N=749) (ANCOVA, $F_{1,795}$=35.6, P<0.001).

Table 7.9.5 Abundance & Intensity of Sea Lice by Aquatic Biome

			Lepeoptheirus salmonis			
Aquatic Biome	**N**	**Prev. %**	**Abundance Mean**	**Abundance S.D**	**Intensity range**	**Prop. chal. (%)**
Estuary	97	55.7	2.90	4.47	1 - 31	7.8
Marine	682	68.2	3.80	5.38	1 - 53	1.7
Offshore Marine (Trawl)	71	42.3	3.80	7.00	1 - 27	0.0
All	850	64.6	3.70	5.44		

	Lepeoptheirus salmonis		***Caligus elongatus***			
Aquatic Biome	**N**	**Prev. %**	**Abundance Mean**	**Abundance S.D**	**Intensity range**	**Prop. chal. (%)**
Estuary	97	8.2	0.24	0.95	1 - 6	0
Marine	682	30.5	1.66	5.45	1 - 65	1.6
Offshore Marine (Trawl)	71	69.0	12.15	14.01	1 - 65	92.6
All	850	31.2	2.38	7.00		

7.9.4 Discussion

Sea trout are naturally parasitized by both species of caligid copepod, *Lepeophtheirus salmonis* and *Caligus elongates* in the marine environment. Natural background sealice levels generally show a relatively high prevalence, but low intensity of sea lice, (Boxshall 1974, Tingley *et al.* 1997, Schram *et al*. 1998, Heuch et al. 2002, Rikardsen, 2004). Farmed salmon also act as hosts for sea lice and therefore open net pen farms can increase the production of infective larvae in coastal areas, Finstad *et al.* (2011). Thorstad *et al.* (2015) undertook a review of sealice levels in areas prior to salmon farming and data for areas lacking salmon farming. They report that the "natural background" intensity of salmon lice on sea trout may be as low as 0-3 lice per fish, with a prevalence of 0-20% during late winter and spring (Schram *et al.* 1998, Heuch *et al.* 2002, Rikardsen, 2004). Available data indicate intensities increasing to a peak of up to 4-8 lice per fish and higher prevalences in the late summer and autumn (Tingley *et al.* 1997, Schram *et al*. 1998, Rikardsen 2004, Urquhart *et al*. 2010). In a study of sea trout captured in the sea off East Anglia in an area free of salmon aquaculture, Tingley *et al*. (1997) recorded a low mean abundances of *L.salmonis* (4.4 – 4.6) and *C.elongatus* (1.5 – 1.7). An overall *L.salmonis* mean abundance of 3.7 reported here is within the range of mean abundance from other studies in areas without salmon farming (Boxshall, 1974, Tingley *et al*. 1997, Mo & Heuch 1998, Schram *et al*. 1998, Bjorn *et al*. 2001, Heuch *et al*. 2002, Bjorn & Finstad 2002, Rikardsen (2004), Urquhart *et al*. 2008, Serra Llinares *et al*. 2014) and likely represents natural background levels.

In a previous study of sea lice levels on sea trout around the Irish coast, Gargan *et al*. (2003) recorded a mean intensity of 2.4 *L.salmonis* on sea trout >30km distant from marine salmon farms. The great majority of these samples were from rivers on the east and south east coast of Ireland, corresponding to Marine zones 1 – 6 in the present study. While Gargan *et al*. (2003) sampled sea trout entering inner estuaries and river mouths, the low *L.salmonis* infestation recorded is consistent with the findings of the present study. Thorstad *et al*. (2015) found that salmon lice levels reported for sea trout in farm intensive areas are generally higher than in areas without fish farming and studies in farming areas show that chalimus dominate in spring and early summer. Results from the present study, undertaken over a wide geographic area around the Irish Sea in a salmon aquaculture free environment, concur with the natural background levels of sealice previously reported in other similar studies. The relative stability in prevelance and mean intensity of both lice species observed are most likely reflective of the nature of sea lice infestations in sea trout populations throughout the areas studied.

7.10 Climate Change

The Irish Sea is warming. Temperature records from the Isle of Man have shown that sea surface temperature (SST) has warmed by 0.7^{o}C since 2004 (Kennington and Rowlands, 2006). The rate of change is not uniform and the analysis of SST at various sites around the Irish Sea for the period 1960 to 2005 showed that the rate of increase was 0.29^{o}C per decade (see Section 7.4.4.1). SST correlates with air temperature, for which the record is much longer and more comprehensive (Orr *et al*., 2014). For example the CET (Central England Temperature) air temperature records correlated closely with the monthly SST data (Figure 7.10.1) reported in Section 7.4.3.1. Orr *et al*. (2014) reported that between 1990 and 2006 CET increased at 0.3^{o}C per decade, close to the SST increase reported here.

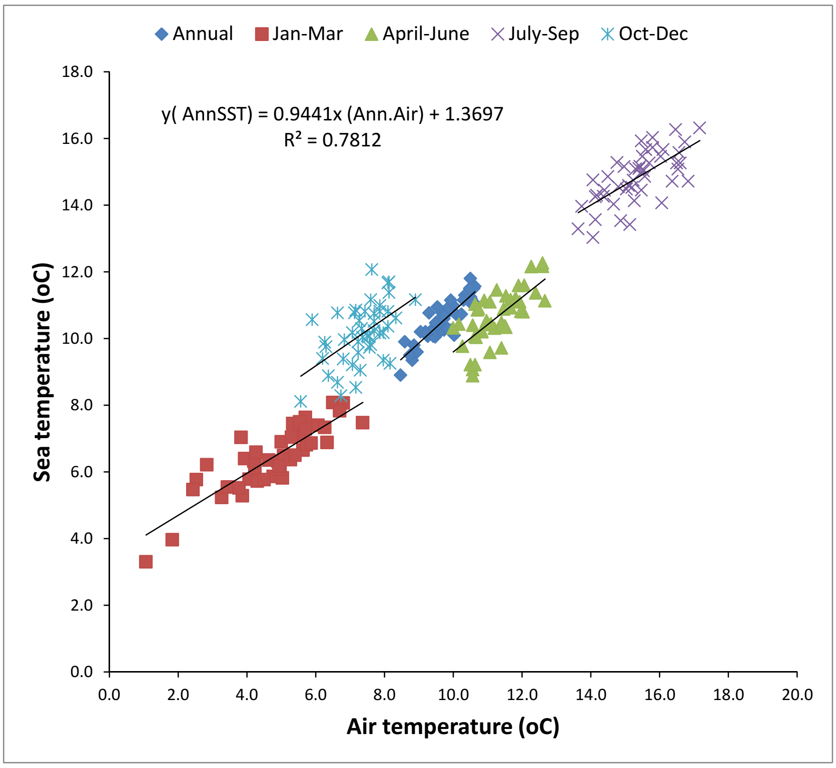


Figure 7.10.1 Relationships between monthly mean SST in the Irish Sea (average of measurements at Moelfre, Heysham and Port Erin) and CET air temperature for the period 1960 to 2004. (SST data from Joyce 2004).

SST is just one example of many effects of climate change, but these have not been well-studied in the Irish Sea. Plankton communities have altered over the last 30 years with likely impact on the marine trophic webs, nutrient (N and P) inputs have altered, in part from atmospheric sources and in part from increasing discharge from rivers due to higher winter precipitation (Kennington and Rowlands, 2006). Some marine fish species have also shown distributional change as their thermal habitat has extended northwards, such as bass (*Dicentrachus labrax*) (Pawson *et al*., 2007). Sea trout spend critical early years in freshwater where a similar set of changes exert different pressures on the biological, ecological and evolutionary processes also influencing their life histories. The impacts of climate change have been extensively reviewed (Webb and Walsh, 2004; Graham and Garrod, 2009) including specific changes on sea trout and Atlantic salmon (Davidson and Cove 2006b; Jonsson and Jonsson, 2009).

The drivers behind climate change are complex and the effects are mediated through the complex and still poorly understood biosphere such that establishing cause and effect is difficult (Hughes and Turrell, 2003). The North Atlantic Oscillation Index (NOAI) is a measure of the atmospheric pressure difference between Iceland and the Azores and is regarded as a major driver of hydrographic conditions and other climate-related factors in the North East Atlantic regions (Dickson and Turrell, 2000). Its relationship with changes in anadromous salmonid populations has been reported for the marine environment (Friedland 1998, Friedland *et al*., 2000; Boylan and Adams, 2006) and in freshwater (Elliott, 2000, Clews *et al*., 2010).

A preliminary examination was made of the relationships between some long-term sea trout variables and climate measures (Figure 7.10.2). The most reliable sea trout stock metrics available for extended periods were thought to be the Welsh total rod catch (1975 to 2012) and the proportion of sea trout <0.8kg in the 5 Welsh rivers (Teifi, Dyfi, Clwyd, Dee) selected for analysis in section 7.4.4.5 (1977 to 2007).

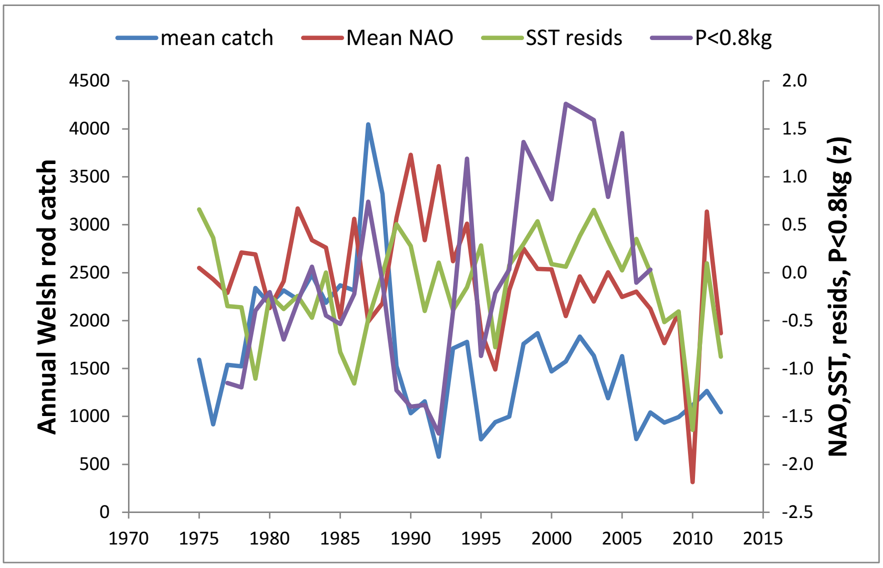


Figure 7.10.2 Long-term changes in two sea trout stock metrics (total Welsh rod catch and proportion of fish <0.8kg in rod catch of five rivers and two climate indices: the NAOI and the Irish Sea SST residuals.

SST was expressed as residual of the observed annual mean SST from the predicted trends shown in Figure 7.10.1, up to 2004 when those records ceased. For the period 2005 to 2012, the observed temperature was predicted from the relationship between observed SST and CET shown in Figure 7.10.1.

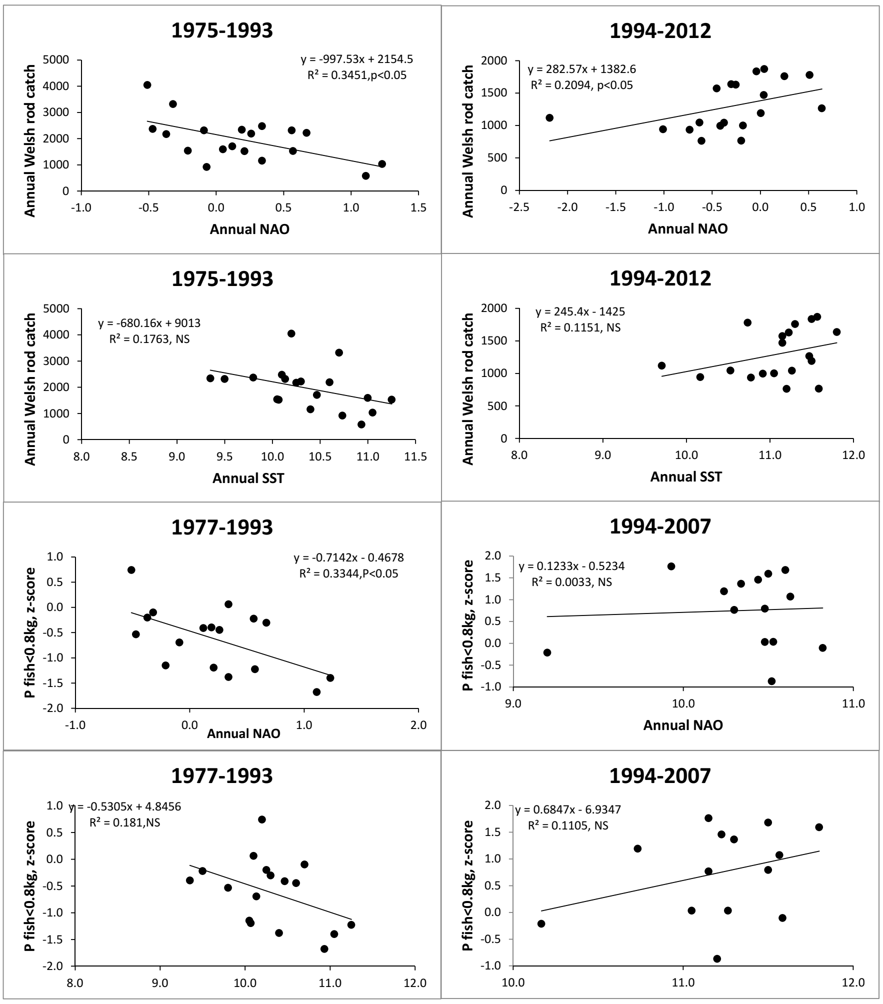


Figure 7.10.3 Relationships between two stock metrics, Welsh sea trout rod catch, proportion of small fish (<0.8kg), and two climate indices, annual NAO and mean SST residuals (see text) for contrasting early and late periods, showing a reversal of the correlations in 1993/94.

Inspection of Figure 7.10.2 using correlation analysis indicated that the associations between the fish stock and climate indices trends reversed over time. Up to 1993 there was a significant negative relationship between catch and NAO, and with SST it was negative but not significant at the p=0.05 level. After that 1993 the relationship with NAO became significantly positive and for SST was positive but not significant at p=0.05. Data for the proportion of small fish were fewer; but like total catch, it was significantly negatively associated with NAO and the relationship with SST was also negative in the early period (Figure 7.10.3). After 1993 the associations with both climate variables became positive, although the relationships were weak and not significant (Figure 7.10.3).

Empirical relationships of the stock metrics with the NAO were inconsistent over time and do not offer evidence of a climate-related mechanism, although some significant relationships were evident for periods of up to 19 years. Preliminary exploration of relationships in this way is very basic and takes no account of the ways in which development and survival at different life history stages might influence each other, nor of the anticipated complex interactions between genotype and environment.

Numerous effects of climate change on fish can be proposed on first principles. For example, growth in poikilotherms such as fish will inevitably be affected by temperature change in freshwater and at sea; although the relative effects will vary according to the starting ambient conditions. Temperature increase can increase or decrease growth and other developmental rates depending where the thermal optima lie. In freshwater climate might operate through temperature, food availability, flow regimes (e.g. extremes, seasonality, rates of change), new pathogens, non-native competitors or changing land use. The final population outcomes in terms of numbers, size and age distribution of smolts in different rivers are not possible to predict with current understanding. But it seems likely that in sea trout, as thought to occur in Atlantic salmon, environmental change in freshwater may have implications for later life history traits in the sea (Russell *et al*., 2012).

In the sea, the lower levels of marine trophic webs are already changing; but the impacts on keystone prey species such as sand eel and sprat are unknown because they are not monitored effectively to measure any change and the process understanding is not yet available. Sea trout growth rates have increased since the 1920s and faster growth in post-smolts is thought to lead to earlier maturity and time of return. This would lead to higher incidence of whitling, which has increased in Welsh rivers over the last forty years, with fluctuations. It points also to a stock response that might explain the reduction in proportion and absolute abundance of larger sea trout in some rivers; because earlier age of return would normally be associated with higher subsequent mortality. However, questions remain about the nature and extent of variation in climate-induced changes in smolt age and size, the effect of this on marine survival and maturation timing, on life time fitness and on stock resilience (Fleming *et al*., 2014). Such questions can only be answered with detailed long-term studies of the type on the river Dee. Unfortunately the river Dee programme is the only one of its kind in the Irish Sea.

7.11 Task Conclusions

1) Rod catches in rivers around the Irish Sea demonstrated synchronous variation. Although it was a small part (<35%) of the overall variation, it was unexpected given the questionable quality and provenance of the data; but points to some common factor/s affecting either stock, river entry or angling effectiveness. Further analyses on the factors contributing to synchrony are recommended (see Climate conclusions below).

2) The estimate of marine biomass in the Irish Sea placed sea trout low in the ranking of teleosts and showed them to be a small part of the marine ecosystem. However, in deriving this estimate the analysis demonstrated the abundance of small coastal streams (<10km^2 catchment area) which although having a small wetted area contribution and hence low numerical component of the whole stock, nevertheless offer a potentially significant contribution to overall biodiversity and, if individuals from such catchments have higher straying rates, to a potential portfolio effect (see below).

Stock Life History Characteristics

3) Stock descriptions through scale reading and analysis of biological features of fish sample in rivers demonstrated a wide variety of life histories and traits, characterised by smolt age, time of first return and multiple spawning, marine growth and annual post-smolt survival.

4) Scale reading was an important technique in this study, but the difficulties in ensuring common interpretation across multiple readers in different locations were significant. Moreover, collection of adequate unbiased samples through volunteers was also problematic. Protocols and some new terminology were introduced in the CSTP, but if this this potentially valuable technique is to be used routinely in assessment, it requires significant further development and validation. Given the importance attributed to life history variation (although this importance itself requires better characterisation), a more robust and long-term protocol for sea trout scale collection and analysis is needed to make the method suitable for scientific assessment. The CSTP collection and other historical

collections are invaluable resources and need careful curating to preserve and use for this purpose. Further work on these scale interpretation questions and on the use of combined microchemistry and scale reading is recommended.

5) Stocks in SE Ireland rivers tended to present simplified life history strategies and have characteristic life history traits. They were mostly dominated by finnock, had lower marine growth and lower annual survival (post sea age 1) than stocks from eastern seaboard rivers. . On the eastern seaboard (Wales to Galloway) statistically significant latitudinal variation was evident in marine growth rates, with lower values in more northerly rivers, a variation tentatively attributed to sea temperatures which decreased with increasing latitude. The latitude effect, although apparent amongst the western seaboard rivers, was less marked and not statistically significant.

6) Attempts to model growth in the sea using a conventional trout growth model were unsuccessful, as others have found. This might be due to the effects of a predominantly high protein and lipid fish diet, salinity or other confounding environmental and physiological factors, or be over-ridden by comparatively growth. The absence of a process-based growth model that adequately describes marine growth of trout remains a knowledge gap.

7) There was evidence of long-term changes in stock life history features. The average size of whitling in rivers of the eastern Irish Sea has increased significantly since the 1920s, but recent trends are unclear and there were no data for the rivers of the western sea board. No consistent temporal variation in annual survival could be detected between samples from the late 1990s and the present day. These long-term changes might be the consequences of climate change see below), but the proximate factors and mechanisms are unclear.

8) Rod catch size structure changes between 1976 and 2007 in some Welsh rivers showed different trends in different rivers, with some North Wales rivers (particularly the Afon Conwy) showing a large decline in abundance of large sea trout in contrast to increases in river of Cardigan Bay. This corresponded with an increase in the abundance (and proportion) of smaller fish (mainly whitling) and appears to indicate sub-regional scale influences on the time of first return and or survival (but see Task Conclusion 7).

9) Of the Irish rivers, the Currane consistently stood out compared with rivers draining to the Irish Sea, by having higher growth rates and annual post-smolt survival, more typical of South Wales.

Marine ecology and biotopes

10) Sea trout fed mainly on fish, principally sand eel and sprat and there was some evidence that a prevalence of sprat in the Northern Irish Sea was reflected in higher incident of sprat in the diet of sea trout. A constraint on evaluating marine biotopes was the limited routine stock assessment of these key prey species (for sea trout and many other marine fish and birds). Enhanced monitoring of sand eel and sprat is recommended.

11) The biotope description of the Irish Sea, based in previous literature, showed that it has highly structured seascape, offering contrasting habitats for sea trout. The eastern side, from Wales to Scotland, is characterised by a more featured coastline, shallower water, lower residence times and higher freshwater inputs leading to higher nutrient status and more variable temperature regimes. However although primary production is higher on the east coast, particularly in north of Liverpool Bay, there was no simple relationship with overall trophic dynamics and consequent potential effects on post smolt growth potential. Evidently, spatial patterns of various trophic levels are complex and influenced by hydrographical phenomena, such as the formation of seasonal fronts and stratification. The lack of

knowledge about coupling in sea trout food webs and the mechanisms governing them is a significant research need.

Climate Change Effects

12) Climate change impacts on sea trout at sea are possible through (a) direct effects of temperature change and (b) indirect effects through diet availability as influenced by oceanographic changes and factors such as plankton composition and consequent food web effects. The preliminary analysis here indicated that future temperature change will affect sea trout marine growth differently in the northern and southern parts of the Irish Sea and that they may be beneficial in the north and natural or slightly negative in the south. However the effects are expected to be small under likely climate change scenarios and translating these to life history and stock level changes is not possible at this stage.

13) In freshwater, other studies have shown that climate change has already influenced salmonid growth rates and consequent smolt size and age distributions. It was not possible to investigate such effects in the CSTP. However the existing data set coupled with further scale sample analysis would allow investigation of such effects and of the links between growth and subsequent life history variation.

14) Links with broad scale climate drivers (such as NAO) were equivocal suggesting reversals in their relationships with stock features over time and that such relationships require deeper more informed analyses.

15) Long term changes in growth and proportional abundance of small fish in some rivers (only Welsh rivers had data suitable for this analysis) were interpreted as a possible sea trout stock response to climate change, probably through sea surface temperature increase. However, climate influences acting through freshwater environmental change and subsequent smolt attributes might also be involved.

Management Implications

16) The demonstration of synchronous variation amongst widely dispersed sea trout stocks is evidence that they were responding to some common factors operating across the Irish Sea. However, the possibitility that environmental factors were influencing angling effectiveness throughout the rivers of the Irish Sea could not be completely ruled out. It was not possible to determine what these factors were or at what stage in the life cycle they operate. Arguments can be presented for impacts acting at sea, in freshwater (affecting smolt production) or both. Long-term changes in size at ages and size composition of catches suggest that marine stage influences acting through post-smolt growth are involved, but that does not rule out other factors.

17) The sea is not a black box into which sea trout disappear in their adult feeding phase. Mature. Marine habitats are highly variable and structured in the Irish Sea. They need to be better described, understood and managed as important determinants of sea trout stock well-being, in the same way as freshwater habitats are for juvenile production.

18) Hydrodynamic modelling showed that the simulated distributions of sea age 0/0+ fish appear broadly consistent with the information obtained from the genetic assignments and suggest that the fish adopt a behaviour which tends to keep them in coastal waters close to their river of origin. More detailed tracking studies of sea trout in coastal waters will be required to determine the precise behaviours used by the fish.

19) There is potential for fish from a large number of different river stocks to be caught in any fisheries operating in coastal waters in most areas of the the Irish and Celtic Seas. There is

therefore potential for both coastal and estuary fisheries to exploit mixed stocks of sea trout. There is therefore a need to conduct further genetic studies of sea trout caught in legal estuary fisheries to determine the extent of stock mixing. At present there are few marine fisheries for sea trout in the Irish Sea, but if they were to re-emerge then cross-border control is warranted.

20) Life history models that can simulate population responses to environmental pressures or changes in fishing regulations are at an early stage of development for sea trout due to the complexities of their life cycle. However, trials with innovative stage-based projection modelling set the foundation for further work and illustrated the potential for developing management advice. The prospects for integrating with environmental and genetic data using, for example, integrated, state-space projection models, were also shown. Parameterising the models using unbiased life history data remains a significant samplying related problem to solve.

21) The diversity of sea trout producing streams is high in the Irish Sea. However, most of these are small catchments that could not be covered in the CSTP surveys. Nevertheless they are discrete elements contributing to overall biodiversity. A knowledge gap area lies in how these might combine with the populations from larger watercourses to perform a wider portfolio function around the Irish Sea. The potential for interdependencies within putative meta-populations of sea trout was not testable with current information; but is important management information.

22) The increasingly intensive use of coastal waters of the Irish Sea for a wide range of activities such as shipping, aggregate extraction, renewable energy infrastructures also points to the needs for common approaches to sea trout assessment monitoring to contribute to consistent Strategic Environmental Assessment.

23) Sea trout are vulnerable to human activities in the sea, by virtue of their coastal occupancy and dependency of their life histories on marine ecosystem health. Marine spatial planning and the implementation of the EU Marine Strategy Framework Directive offer routes for integrated environmental protection that could benefit sea trout. However at present these policy processes do not appear to register the environmental dependencies of sea trout, which should therefore be promoted more explicitly.

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8 CSTP Synthesis

8.1 General

The CSTP was the first project in The British Isles to combine such a variety of disciplines in the study of sea trout and their fisheries on a large scale. The structure of the Irish Sea (a relatively enclosed water, approximately 400km by 150km) and the variety of rivers draining to it, ranging from the mountainous spate rivers of west Wales to the lowland productive rivers of eastern Ireland, offered a wide range of marine and freshwater environments within which life history variation could be expressed, yet a geographical scale at which the study of population exchange by genetics and microchemistry was feasible. The project was fortunate in being able to draw upon earlier studies that had provided some preliminary information on sea trout populations and allowed some comparisons over time.

The intentionally broad scale of the project (and its limited duration) meant that it was not possible to investigate the detail of some biological and ecological processes; but the alternative of detailed study at a few locations would not have revealed broad scale patterns in movements and life histories which are necessary to properly design more intensive targeted studies. It should be noted that recent years has seen a surge in valuable research worldwide into processes behind anadromy in salmonids including brown trout and the knowledge in this area is far greater than even ten years ago. Moreover, in seeking outputs that meet the diverse interests of the widely dispersed stakeholders in Ireland and Wales for Interreg purposes, and more widely in Scotland, NW England Isle of Man and Northern Ireland, it was imperative that a pan-Irish Sea perspective was maintained. The participating countries and regions have different ways of monitoring and managing their freshwater and marine fisheries, which significantly affected the way that parts of the CSTP dependent upon fisheries data could be delivered. Therefore a key aim was to describe this variation and to understand how sea trout populations around the area might interact during their sea phase and what that might mean for future fisheries, environmental management and for integrated marine spatial planning. Related to this was the intention that the CSTP be inclusive of stakeholders namely the fishers, the public, government, NGOs and third sector agencies that collectively influence and have an interest in the conservation and management of these aquatic resources.

An overarching theme explicit in the Interreg IVA programme aims was the potential impact of climate change. This is causing environmental change that could affect sea trout life histories in fresh and salt water through direct influences of temperature, changes in production, altered variability of regimes as well as indirect effects through trophic ecology, competitors and invasive biota. A further climate-related effect is the development of renewable energy supplies in offshore and coastal waters which in some cases might present changing hazards, or even opportunities, for sea trout.

8.2 New Information

Population Movements and Exchange

Sea trout movements and stock mixing were studied using a combination of genetic stock identification (GSI), microchemistry of otoliths and stable isotope work on a limited number of scales and the simulation of movements by particle tracking with a hydrodynamic model (HDM) of the Irish Sea. This was complemented by adult life history information which was taken to reflect the environments in which the fish lived.

It was known from previous low intensity tagging studies in Wales that some sea trout had been recorded on the Irish coast; therefore some exchange was expected. A parsimoniuos starting assumption is that sea trout simply have a marine feeding range extending evenly out from their natal river. This was the only assumption that could be made for the marine growth studies for example, which required some defined occupied location in order to derive water temperatures to relate to observed growth. However, movements from the natal estuary are most unlikely to be radially symmetrical. Energetic considerations mean that sea trout will probably seek out optimal food supplies, which are unevenly distributed in the sea, and residual tidal currents will inevitably lead to asymmetric geographical dispersal. The HDM simulation applied various simple behaviours to the "fish" particles and showed that there was considerable variation in potential movements depending on the location of the natal river. The pattern was of a general northward conveyor belt taking "fish" from SE Ireland towards the Northern and North eastern sectors of the Irish Sea. In addition, "fish" originating in major embayments and estuaries (e.g. Carmarthen Bay, Cardigan Bay and the Solway Firth) had tendencies to be retained by localised gyres, but even so a proportion strayed into the northward conveyor and may have eventually dispersed north out through the North Channel. It should not be concluded that there is therefore some major emigration of sea trout out of the North Channel. If there was such movement, to which most rivers in the Irish Sea would contribute, that would constitute a major fishery opportunity which has not been discovered, or reported! More importantly, it would be an evolutionary unsound tactic to develop migratory behaviours that caused a substantial part of the reproductive population to be lost each year and it can therefore be discounted.

The HDM study looked only at the outward movements of post-smolts and in the most of the southern rivers whitling (.0+) dominated the returning annual adult runs (particularly in many of the Irish rivers). Clearly, on the basis of observed age structures, large numbers of .0+ fish find their way back to their natal rivers in the first year. The HDM did not simulate the behaviour of >0+ maidens or multiple spawners, nor was it able to incorporate marine mortality; although these might be options for the future. Nevertheless, the potential for rapid widespread movement in the first few weeks of post-smolt life was clearly demonstrated and would lead to (a) (on the basis of the evolutionary fitness point above) the expression of migratory behaviours that return adults to their natal river and (b) the potential for exchange (gene flow) or dispersal between rivers and consequently present the intriguing possibility of asymmetrical recruitment effects where genuine reproductive straying occurs (*sensu* Quinn, 1993). Migratory traits and their spatial variation have been shown previously to influence the patterns of connectivity and genetic structure among populations such that anadromous individuals are more likely to contribute to gene flow than resident individuals (DeWoody & Avise, 2000). Dispersal refers here to any movement that has the potential to lead to gene flow (Ronce, 2007).

What did the other studies reveal about movements and exchange? The uneven sampling, for example very few fish from Welsh coastal waters and consequent biases, constrained some of the interpretation of the genetics and microchemistry results. However these techniques gave reasonably consistent results indicating that most sea trout remained in the vicinity of their natal rivers, but that some exchange took place. The extent of dispersal varied between the various sub-regions. For example, Manx fish tended to remain in Manx waters. The overall conclusion is of most sea trout marine movements in the Irish Sea being comparatively localised with respect to the natal river; but with a component of wider geographical dispersal existing in all populations. This component varies in extent and, while it cannot be specifically quantified with available information, it appears to be partly related to the particular combination of residual currents obtaining in different geographical locations resulting from the coastal profile. One can further speculate that oceanographic conditions, bathymetry, temperature regimes, salinity, trophic conditions and the need for winter shelter might also be factors influencing sea trout location, but there are no data on this at present.

This explanation for sea trout movement in the sea – that it simply reflects the need for sea trout to optimise feeding and survival in the prevailing marine landscape, which is a function of prevailing residual currents and coastal topography - reconciles the sometimes contrasting observations in the literature. Most studies report limited migratory distributions: some indicating very localised movements by which sea trout post-smolts are found in sea lochs and fjord systems (e.g. Pemberton, 1976). An intermediate stage is offered by the large embayments and estuaries of the eastern Irish Sea. Finally, long distance movements appear more prevalent in sea trout that emerge onto comparatively straight coastlines with directed residual currents. Examples being the eastern Irish coast, NE England and some sea trout in the northern Baltic (Degerman et al., 2014). The major difference in age structure (whitling dominated the SE Ireland *vs* the large 1+SW maidens in the North Sea) might reflect the better feeding and growth opportunities of the North Sea (Solomon, 1994) compared with the less productive and cooler waters of the western Irish Sea. Interestingly, Quéméré et al. (2015) suggest that the genetic structure of sea trout populations within the English Channel appears to be shaped by the spatial arrangement and quality (in respect of feeding opportunities) of marine habitats, which promotes a clinal variation in migratory behaviour, which in turn determines the level of gene flow among neighbouring streams. Genetic structure thus partly reflects micro-geographic responses to spatial variation in foraging conditions at sea. These results show that the marine environment, rarely considered previously, has an important role in combination with variation in freshwater environments in the evolution of life history in migratory aquatic animals.

The portfolio effect is an emerging paradigm that describes the reinforcing effect of multiple populations from rivers of contrasting environmental conditions which, through some level of recruitment exchange, maintains a higher level of overall species stability and productivity than had the populations been entirely independent (Schindler *et al*., 2010; Schindler et al. 2015). This has been well demonstrated in Pacific salmon population of Bristol Bay (Hilborn *et al*., 2003) in response to changing ocean conditions reflecting contrasting phases of the Pacific Decadal Oscillation (PDO). It is likely that such mechanisms also operate in sea trout in the Irish Sea and would be an important consideration in defining priorities for conservation. For example, small streams (say < 20km^2 catchment area) are by far the most abundant watercourse draining to sea and anecdotal information indicates strongly that most of them produce sea trout. Straying from small streams is thought to be higher than from large streams due to the attraction effect of higher river flows and the winter habitat opportunities of larger estuaries (Degerman et al., 2012). If it can be shown that this wandering of small stream sea trout is in fact comparatively high and gives rise to reproductive straying then they could collectively represent an important source population. Gene flow is more likely if the sea trout are fish, which are large, have long absence behaviours and have high marine survival; traits which are consistent with availability of productive and benign marine habitats as was found by Quéméré et al. (2015) in the English channel. We found considerably less genetic structuring (indicative of elevated gene flow) for sea trout in eastern sea board rivers compared to Irish populations with just two major genetic population groupings on the eastern side of the Irish Sea compared to at least five distinct regional groupings for rivers on the east coast of Ireland. In addition, there was substantially greater intra-regional structuring within the Irish regional groups compared to the levels of within region population structuring observed for English and Welsh rivers. So it would appear therefore from the genetic structure and life history data that similar processes to those observed in the English Channel are also in operation in the Irish Sea, i.e. superior feeding opportunities and waters less influenced by tidal currents, which prevail along the eastern part of the Irish Sea, give rise, on average, to larger, later maturing and higher surviving sea trout compared to their Irish cousins, which in turn has allowed greater levels of gene flow among Welsh and English sea trout populations. Small streams also experience inherently higher environmental variation (primarily flow-related) and are usually subject to less formal environmental monitoring and protection. In Ireland the future implemenation of the Water Framework Directive will involve integrated catchment management which will promote greater local stakeholder involvement (Daly et al, 2014). which is particularly appropriate for such watercourses. The trout populations in these channels would be expected to display greater variability. The converse could also apply: that sea trout from larger rivers support the populations of small streams. This is only speculation in the absence of a genetics study in a group of contiguous stream of contrasting size and this is a recommendation for a future study. The CSTP data can now inform how that might be designed.

Genetics and microchemistry cannot describe the actual routes and residencies of migrating fish, as the sample location represents only a single point in time, and that remains crucial missing information. The study of movements is best carried out by tracking studies, and modern equipment and methods make this entirely feasible (e.g. see review by Hussey et al. 2015; Lacroix, 2013; Jensen & Rikardsen, 2012). Integrated tracking programmes have been recommended several times recently. The knowledge benefits apply to many other migrating taxa and are valuable to several applications such as environmental impact assessment, coastal infrastructure design, fishery protection and research. The CSTP results focus attention on some key questions which would strengthen the design of such programmes from a sea trout perspective.

Sea Trout Stock Sizes and Trends

Rod catches were used as indices of stock abundance and were pooled at various scales to investigate synchronous variation. The quality of catch data varied greatly around the countries bordering the Irish Sea which limited some of the analysis and interpretation. It was considered only possible to use data after 1993 and there was insufficient information to examine within season or individual stock component variation on an Irish Sea scale. Nevertheless, the observed partial synchrony in rod catches is offered as evidence that sea trout stocks were responding to some common factor/s. This synchrony was observed even after fishing effort was accounted for, suggesting that it was an effect on stock abundance rather than the angling sampling method. Even so it was not possible to distinguish river flow effects (on river migration extent and timing) from genuine changes in the size of stocks resulting from altered survival. More sophisticated statistical analysis is needed to study such relationships, incorporating more environmental variables. One useful avenue for future research would be to look at the relationship between freshwater survival and sea trout performance and the effect of meteorological phenomena represented by such proxies as the NAO index (Piou and Prevost, 2013) on river flows and temperatures. It may well be that the principal determinant of abundance and most likely underlying cause of any apparent synchrony among populations and of disproportionately greater effect than freshwater factors can be found in the marine ecosystem. For example there are some encouraging correlative studies emerging on the biological impact on pelagic ecosystems of oceanic trends in sea surface temperatures represented by the Atlantic Decadal Oscillation (AMO) (Edwards et al. 2013; Globerville et al.2014; Friedland et al. 2014; Klower et al. 2014). A project to do this would be informative and valuable for further study of mechanism behind synchrony and for routine stock assessment; this is recommended.

The trends in sea trout abundance are of fundamental interest and rod catches were the only universal measure, but only in Wales were the data suitable for examining long terrn trends. Caution should still be applied and the uncertainties increase before the 1990s and even more before the 1976 when national organisation of fisheries management and catch recording was started in England and Wales.

Catches (and it is assumed returning stock sizes) have fluctuated in cycles, with a noticeable peak in the late 1970s; but on average in Welsh rivers, for which the best data were available, the post 1990 average catch has declined by 44% on the 1975-1990 average. It is unclear if this is due to reduction in average smolt productivity of rivers, or to an increase in marine mortality or to some combination of both. However, there have also been changes in the size structure with, in Welsh populations at least, an increase in proportions of smaller fish even though their numbers have declined. The cause is uncertain, but could be (a) an increase in overall mortality or (b), more likely, a decrease in the time of first return which would raise the abundance of .0+ fish at the expense of older maidens and bring about higher mortality.

Marine Ecology

Post-smolt and adult sea trout form part of the marine pelagic ecosystem competing in trophic webs of prey and predators quite different from those experienced in freshwater. A piscivorous diet prevails; but sea trout are opportunistic in that their preference for high protein/lipid prey can be met by sand eel or sprat, apparently depending on which is available. There was evidence that sprat form a more important part of their diet in the north east of the Irish Sea where they are more prevalent than sand eel. Furthermore, the distribution of sand eel was loosely associated with sandy sediment where they breed. Sea trout in the Irish Sea were shown to contribute only a small part of the total marine teleost biomass of their trophic level. Nevertheless they are dependent on the keystone prey species (sand eel and sprat), as are many other marine fish and bird species. A major gap lay in the lack of data on keystone species in the Irish Sea and it is advised that this component of marine monitoring be reviewed and enhanced.

Feeding history of sea trout is partly revealed in their scale growth patterns which in several cases showed that fish growth, and therefore feeding, persisted throughout the winter. The conventional notion of winter and summer annual growth checks may need to be revised. This question along with the re-interpretation of ambiguous checks in many scales using stable isotopes and microchemistry are important further items of work to which the CSTP archive lends itself.

A missing element of the CSTP was the impact of predation in estuaries and at sea. A variety of predators will contribute to mortality, including birds and other fish. The early post-smolt life, like that of salmon is expected to be one of high mortality from these causes; but these could not be assessed or quantified.

Two species of caligid copepod sea lice, namely *Lepeophtheirus salmonis* and *Caligus elongates,* which are natural parasites of sea trout, were recorded on fish taken at sea. Results from the CSTP, undertaken over a wide geographical area around the Irish Sea, correspond with natural background levels of sea lice reported in similar studies and provide a baseline dataset for future studies. Natural background sea lice levels are generally characterised by relatively high prevalence and low intensity.

The size of whitling revealed complex links between smolt age, size and timing with a result that whitling mean size tended to decrease for most of the run (approximately June to August) and to increase at the end. This gave the counter-intuitive result in which there was no apparent growth of this age group during its sea residence and demonstrated the importance of scale reading and of having full life history information to properly interpret this basic observation.

Life History Features

Anadromy defines sea trout, and partial migration of trout populations in general represents a phenotypic plasticity that is thought to confer resilience on the species (Jonsson and Jonsson, 2006). The CSTP was not intended to study the mechanics behind anadromy; but the importance of life history traits in determining fitness (as life time egg production) through determinants of alternative maturation and breeding schedules (e.g. age and size at smolting, age and time of first return, fecundity, multiple spawning) was a background to the project. The objective of modelling life cycles to provide a management tool was not fully achieved within the lifetime of the CSTP, but remains an important task and for some rivers the data collected will be of value in this respect.

However, it was possible to examine two key life history traits, marine growth and survival, and to compare these between rivers and over time. Growth is particularly important, being strongly tied to environmental factors of temperature and food, although genetic factors probably also operate. Freshwater growth rate is believed to be an important determinant of subsequent smolting and possibly also of marine performance (growth survival and maturation). These interactions between FW and marine growth were beyond the remit of the project and represent future research topics.

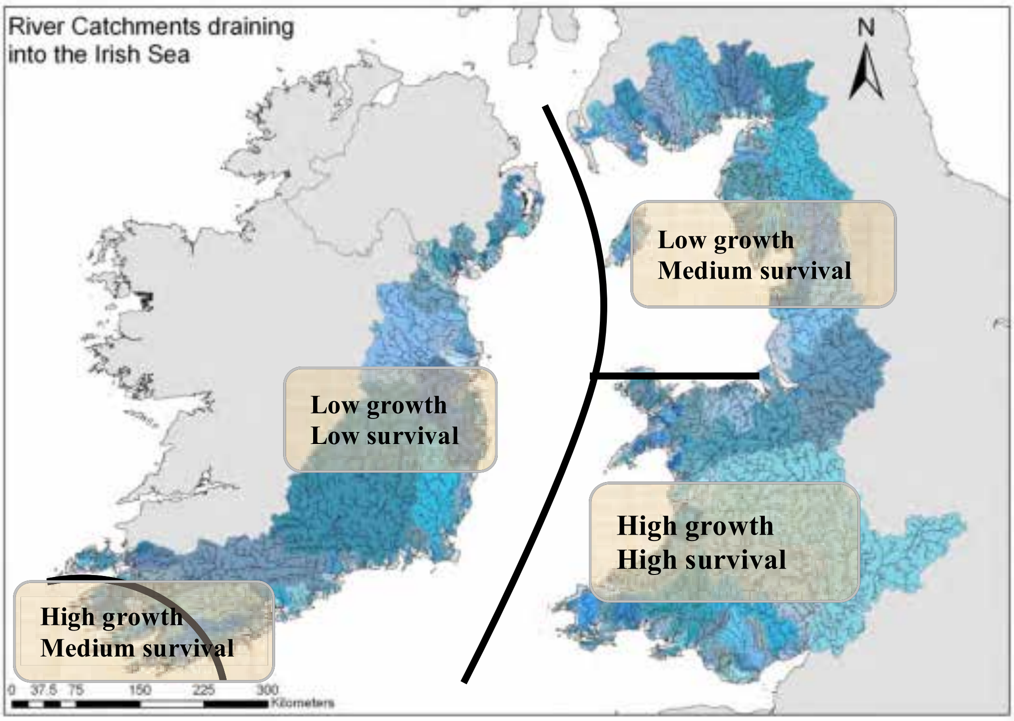

Figure 8.2.1 Diagrammatic representation of the principal geographical variation in marine growth and survival of sea trout in the Irish sea, showing four groupings based on tree regression. There is also clinal and river-specific variation within these major groups.

The spatial pattern of marine growth in sea trout sampled in eastern Irish Sea rivers (Wales up to Galloway) was significantly positively correlated with mean annual sea temperature. Fish from more northerly rivers were smaller at age .0+ and age .1+ than fish from southern rivers. Sea surface temperature (SST) was correlated with latitude, but with a noticeable regional variation in which the shallow areas of Cardigan Bay, Morecombe Bay and the Solway Firth had higher summer temperatures and lower winter SST. The location of fish during their marine growth was not known, therefore, as noted above, an assumption was made that their experienced SST were approximated by those close to their natal river mouths. The fact that average growth was related to the SST in the region of natal rivers suggests that on the eastern side of the Irish Sea at least, most fish do not move long distances, but remain reasonably close to their natal rivers. What this actually means in terms of the dispersal distance distribution is a crucial question which at present cannot be answered without tracking studies.

The movement patterns in the Irish Sea tentatively attributed to fish on the basis of genetics and hydrodynamic modelling distinguished between the UK and Irish coasts. The UK fish appeared to display less movement geographically than those from the Irish coast. The latter fish appeared to move further because of the residual current pattern, and if that was so their temperature experience would be less localised and resulting growth opportunity might be expected to be less as they move to northerly, cooler waters. The association between local SST on the west coast was the same direction as in the east but was not statistically significant, and was not inconsistent with the wider dispersal. There is much uncertainty in this: for example food availability and consumption were not known and the effect of river-specific genetic factors confounding growth (which has a high heritability in salmonids) cannot be entirely ruled out. However, it offers a working hypothesis open to further testing.

There was a significant difference in marine survival between east and west sides of the Irish Sea, with fish from the Irish coast rivers typically having lower survival. But in the case of the Currane in south west Ireland, growth and survival were higher than in the other Irish rivers, and this catchment is well known as a producer of large sea trout smolts and adults.

An important general conclusion to come from the observations on growth and survival, from the feeding results, the descriptions of the biotopes and from the interpretation of the HDM is that habitat and ecosystems in the sea are strongly structured. The sea is not some black box which sea trout simply enter and leave. The combinations of current, depth, seasonal fronts, temperature and probably salinity, appear to have influence on productivity and growth opportunity for post-smolt and adult sea trout.

In conclusion we return to the portfolio effect as a means to structure questions about the nature and role of population exchange, stability and resilience; these being central management concerns identified during the CSTP. For the portfolio effect to apply the stock variation needs to be partially asynchronous and the catch analyses indicated that this was the case. The methods used do not allow quantification of the exchange and thus potential for metapopulations to exist, or portfolio processes to operate. However, the CSTP has demonstrated that they are feasible; but it would be of great value to model these processes in order to describe the interdependencies amongst stocks. The methodologies exist and have been applied to related species (e.g. Hilborn et al.2003; Schindler et al. 2015 for review).

8.3 Management Recommendations and Future Research Recommendations

The aim of this section is to focus the outputs of CSTP tasks onto areas that were of priority concern. Reviews of the key issues or questions facing managers have been done through the 2004 Sea Trout Conference, the AST Sea Trout Working Group (AST, 2011) and within the CSTP by consulting the principal partners. These surveys inevitably involved a lot of common agencies and personnel and drew out the same issues repeatedly. The concerns occupying managers fell into three categories.

1) Risks to sea trout from current or future factors.
2) How to manage the risk factors.
3) How to assess the condition of sea trout stocks and to monitor their responses to changing pressures or to management interventions.

Over the course of the project, considerable weighting was placed on potential management advice that would emerge as an output. A table of potential advice was drawn up following informal consultations with various principle stakeholders (angling groups and government). Each of these categories has sub-issues and the approaches to how the key ones can be addressed by the CSTP are summarised in Appendix 8.1, with an indication of the nature of the potential action or advice.

Each of the various tasks identified implications for sea trout management and further research needs. These are presented below together with summary conclusions and general strategic recommendations.

- The CSTP provided a review of available information from published and unpublished sources on the sea trout fisheries in each of the four geographical regions of the Project Area bordering the Irish Sea (i.e. Scottish Solway, Northwest England, Wales and the east and south coast of Ireland). These comprehensive baseline data on catches and stocking history and the review of the economic value of sea trout and the analyses undertaken in Task 2 (Fisheries Inventory, Socio-Economic Value and Stocking History) provide a reference point for managers which underpins the value of sea trout at multiple scales. Additionally the output provides managers with these data, in an accessible format, which facilitates analysis of current and future fishery performance. Such baseline data are fundamental to any risk analysis particularly where anthropogenic impacts (direct and indirect) need to be assessed.

- Detailed descriptions of sea trout fisheries and catch records, including commercial and angling fisheries, angling regulations and data collection methods are provided. The principal conclusions were that the catch recording systems differed substantially between the regions due to legislative and administrative circumstances. It was identified that neither catch effort nor seasonal catch distribution data are collected in Scotland or Ireland and that finnock dominate catches in Ireland. The current Irish catch recording system significantly underestimates the scale of sea trout rod catches as only sea trout > 40cm are required to be recorded in the tagging and log book system. Adopting a standardised comprehensive approach to recording catch data in sea trout fisheries throughout the Irish Sea would substantially enhance sea trout assessment and management functions in this relatively confined waterbody. Existing sea trout recording schemes such as those operating in England and Wales, combined with current schemes operating in Scotland and Ireland, would provide a solid basis to develop enhanced recording.

- The genetics and microchemistry tasks reported that sea trout in the Irish Sea originate from a large number of rivers and are distributed widely within the waterbody. Nine major genetically distinct regional and phylogeographic groups within the British and Irish database were identified. Genomic DNA was extracted from 1,099 adult trout captured at sea. The genetic data show that sea trout in the Irish Sea originate from a large number of rivers and are distributed widely. Although the majority occurred in the proximity of their natal river long range feeding migrations up to 300km were recorded for some individuals. Otolith microchemistry and ecological profiling provided complementary estimates of reliability of genetically based assignments and provide strong corroborating support for the veracity of the microsatellite (GSI) based designations. Both tasks also demonstrated that there is potential for sea trout from different systems to be caught in any fisheries operating in coastal waters in most areas of the Irish Sea. The potential for both coastal and estuarine fisheries to exploit mixed stocks of sea trout supports a need to conduct further genetic studies of sea trout caught in estuary and in-river fisheries to determine and quantify the extent of mixing.

- The utility of genetic stock identification (GSI) was well demonstrated in the CSTP and the development of a comprehensive genetic baseline represents a major advance for further stock assignment and ultimately for management. Additional research is recommended to refine the juvenile genetic database which demonstrated some evidence of the presence of non-migratory trout in the samples. In addition, the quality of the baseline is, to a large extent, a function of the sampling design (e.g. its comprehensiveness). Thus it is important to ensure that all potential contributing rivers-populations are sampled. The genetic structuring observed in the larger rivers discharging into the Irish Sea supports the proposition of homing and high levels of reproductive isolation.

- A novel panel consisting of 152 mtSNP markers has been developed within the project and are readily available for future brown/sea trout studies. It is anticipated that both nuclear and mtDNA SNP marker will provide a valuable addition to the molecular toolbox for the monitoring of sea trout and the basis for new sea trout research initiatives. For management further assignment of existing samples of marine caught sea trout to river level would provide quantitative area-specific advice necessary to develop local conservation management plans for sea trout and its habitat thus contributing to an integrated resource management plan for sea trout in the Irish Sea.

- A substantial focus for CSTP, and a strategic priority for sea trout (Harris & Milner, 2006), is the marine ecology of sea trout. As reported in Task 7, the synchronous variation amongst widely dispersed sea trout stocks is evidence that sea trout were responding to some common factors operating across the Irish Sea. It was not possible to determine what these factors were or at what stage in the life cycle they operate. Arguments can be presented for impacts acting at sea, in freshwater (affecting smolt production) or both. Long-term changes in size at ages and size composition of catches suggest that marine stage influences acting through post-smolt growth are involved, but that does not rule out other factors. Further analyses on the factors contributing to synchrony, particularly climate change, are recommended.

- The direct effects of temperature change and indirect effects arising from changing food availability are likely features of climate change impacts on sea trout at sea. Investigations of impacts on salmonids in freshwater have demonstrated change and complementary studies, using the available CSTP marine sea trout scale samples, would allow investigation of such effects and of the links between growth and subsequent life history variation. More detailed analyses of the complex relationships between broad scale climate drivers and stock features, over an extended time–series, are warranted.

- Hydrodynamic modelling of the Irish Sea demonstrated that the simulated distributions of sea age 0/0+ fish appear broadly consistent with the information obtained from the genetic and microchemistry assignments and suggest that sea trout adopt a behaviour which tends to keep them in coastal waters close to their river of origin. More detailed tracking studies of sea trout in coastal waters will be required to determine the precise behaviours of the fish.

- The sea is not a black box into which sea trout migrate and disappear in their adult feeding phase. Marine habitats are highly variable and structured in the Irish Sea. Task 7 identified a research priority whereby marine habitats need to be better described, understood and managed as important determinants of sea trout stock well-being, just as freshwater habitats are for juvenile production.

- Task 6 dealt with identifying factors that are important to sea trout production in freshwater. Models were developed which account for some of the variability in production and provide useful indicative tools for managers to evaluate fishery performance and identify potentially influential environmental factors. These showed that generally, shorter rivers of low alkalinity in catchments which are relatively poor in nutrients and less-intensively farmed, with good spawning and nursery areas easily accessible from the sea, tend to be the better sea trout rivers. Conversely larger rivers whose headwaters are distant from the sea, with calcareous geology and productive, more intensively-farmed catchments are more likely to be salmon and/or brown trout dominated. Other exploratory analyses highlighted the importance of lower productivity and calcium availability in creating favourable conditions for good runs of sea-trout. However, as observed for rod catch data, the absence of standardised environmental datasets across the project area hindered modelling. Developing capacity for standardising data categories and sampling protocols, which would to facilitate integration of datasets for modelling, will be important to harmonise in order to allow for cohesive management of the sea trout resource in the Irish Sea. Better understanding of the influence of environmental features on sea-trout production will only be gained by undertaking catchment-specific, detailed studies of trout production and movement using a combination of marking and trapping, stable isotope analysis, scale microchemistry and genetics. In this way catchment-specific nursery habitat could be identified and more detailed studies of those areas undertaken to elucidate key features relevant to sea trout production and anadromy.

- Life history models that can simulate population responses to environmental pressures or changes in fishing regulations are at an early stage of development for sea trout due to the complexities of their life cycle. Matrix projection models were developed using stage specific approaches with stages defined by the re-created life history based on the scale reading. Eigen analysis was used to estimate several population parameters including population growth rate (λ), net reproductive rate (R_0), generation time, stable stage distribution and stage specific reproductive value. Although there were commonalities, sea trout populations from rivers draining into the Irish and Celtic Seas were heterogeneous and followed different population dynamics patterns. For example, population growth rate (λ) ranged from slightly negative values in rivers on the North East of the Irish Sea to strongly positive values for most rivers in Wales while the strongest population growth rate was found in the Isle of Man. The outcomes of the population dynamics analysis of the sea trout population of each of 22 rivers, where sufficient data were available, were summarized into individual river outputs and provide a potential basis for future assessments of the impacts of fisheries exploitation on population growth and resilience. However, the CSTP data and preliminary development of such approaches enhances the use and further development of practicable models. Progression is feasible but will require more time and investment.

- Attempts to model growth in the sea using a conventional trout growth model were unsuccessful, as others have found. This might be due to the effects of a predominantly high protein and lipid fish diet, salinity or other confounding environmental and physiological factors and the comparatively large size of the fish. The possibility of compensatory growth remains, but the evident variation in growth between regions, suggests that if it occurred it was not a major factor. Although temperature was shown to be an important influence on growth, the absence of a process-based growth model that adequately describes marine growth of trout (conditions of high salinity and typically high lipid fish diet) remains a knowledge gap.

- Sea trout fed mainly on fish, principally sand eel and sprat and some diet partitioning was evident. The complexity of the Irish Sea biotopes in terms of varying hydrography and trophic status, combined with limited routine stock assessment of the key prey species (for sea trout and many other marine fish and birds), constrained any evaluation of biotopes in this project. To build on the progress in sea trout dietary analysis achieved in the project and to increase understanding for management enhanced monitoring of sand eel and sprat populations in the Irish Sea is recommended. The lack of knowledge about coupling in sea trout food webs and the mechanisms governing them is also a significant research need.

- Prey species monitoring and food web investigations are priorities in the context of increasingly intensive use of coastal waters of the Irish Sea for a wide range of activities such as shipping, aggregate extraction, renewable energy infrastructures. It is a topic that points to the need for enhanced and common approaches to marine ecosystem monitoring to support consistent Strategic Environmental Assessment.

- Sea trout are vulnerable to human activities in the sea, by virtue of their coastal occupancy and dependency of their life histories on marine ecosystem health. Marine spatial planning and the implementation of the EU Marine Strategy Framework Directive offer routes for integrated environmental protection that could benefit sea trout. However at present these policy processes do not appear to register the environmental dependencies of sea trout, which should therefore be promoted more explicitly.

- From a technical perspective, within the CSTP, scale reading was an important technique but the difficulties in ensuring common interpretation across multiple readers in different locations were significant. Moreover, collection of adequate unbiased samples from rivers by volunteers was also problematic. Protocols and some new scale reading terminology were introduced in the CSTP, but if this potentially valuable technique is to be used routinely in assessment, it requires significant further development and validation. Given the importance attributed to life history variation, a more robust and long-term protocol for sea trout scale collection and analysis is needed to make the method suitable for scientific assessment. The CSTP collection and other historical collections are invaluable resources and need careful curating to preserve and use for this purpose. Further research on these scale interpretation questions and on the use of combined microchemistry and scale reading is recommended.

- The diversity of sea trout stocks is high in the Irish Sea. Some of this variety probably arises in smaller catchments that could not be covered in the CSTP surveys. Nevertheless they are discrete elements contributing to overall biodiversity and stability in productivity. A knowledge gap area lies in how these might combine with the populations from larger watercourses to provide a wider portfolio function around the Irish Sea. The potential for interdependencies within putative meta-populations of sea trout was not testable with current information but is important management information. Nonetheless, on a precautionary basis, management should target wide scale conservation of their freshwater and marine habitats.

- The extensive CSTP sampling programme and analyses undertaken has provided valuable insight into many of the important research needs identified at the 1st International Symposium on Sea Trout, held in 2004, and will contribute to improving sea trout management in the freshwater and marine environments. It is likely that CSTP outputs will function as a baseline and important reference point for other studies. In the future these baselines will be refined, modified and enhanced at local and broad scale levels to increase understanding of sea trout in the Irish Sea and further afield.

- Increasing the limited understanding of the marine ecology of sea trout throughout the Irish Sea was a major focus of the CSTP. Valuable new information on stock discrimination, life histories, marine growth, stock structure and general marine ecology has been elucidated over the course of the project which can contribute to informing management policy. Previous sea trout research has focussed primarily on the role of freshwater factors as a driver of anadromy. This project has demonstrated that marine habitat can also influence life histories which may be reflected in the stock structure and other facets of sea trout populations. Therefore, if common marine factors are influencing sea trout stock composition, as may be observed through life history changes, these factors must be a shared concern for marine environmental planners in all jurisdictions. Understanding of broad scale marine factors will only come from enhanced, targeted long-term monitoring and collaborative research into the variation in marine ecosystem components, for example, keystone prey species, and its causes. For sea trout the sea is shown to be a highly structured and dynamic habitat, exerting a strong influence on population dynamics, and the future of sea trout stocks depends as much upon understanding and protecting it as the freshwater environment.

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8.4 Appendices

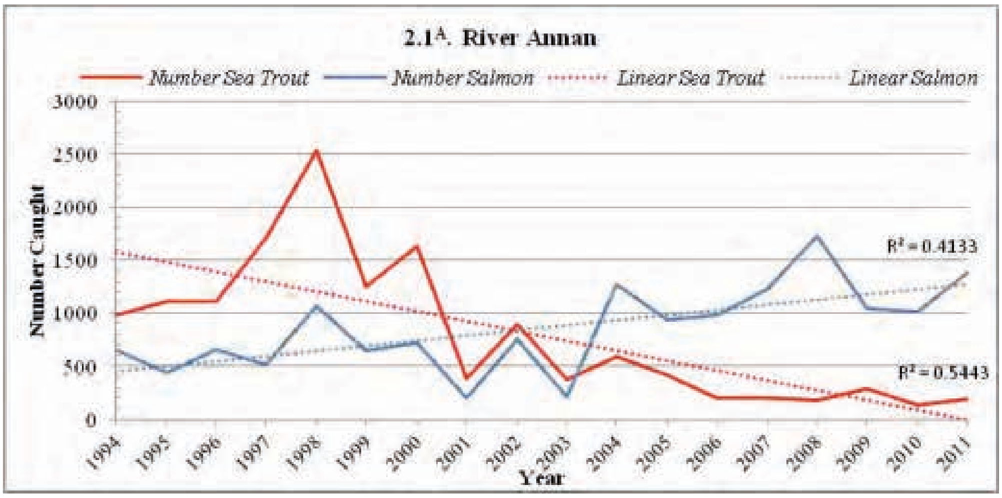
Appendix 1

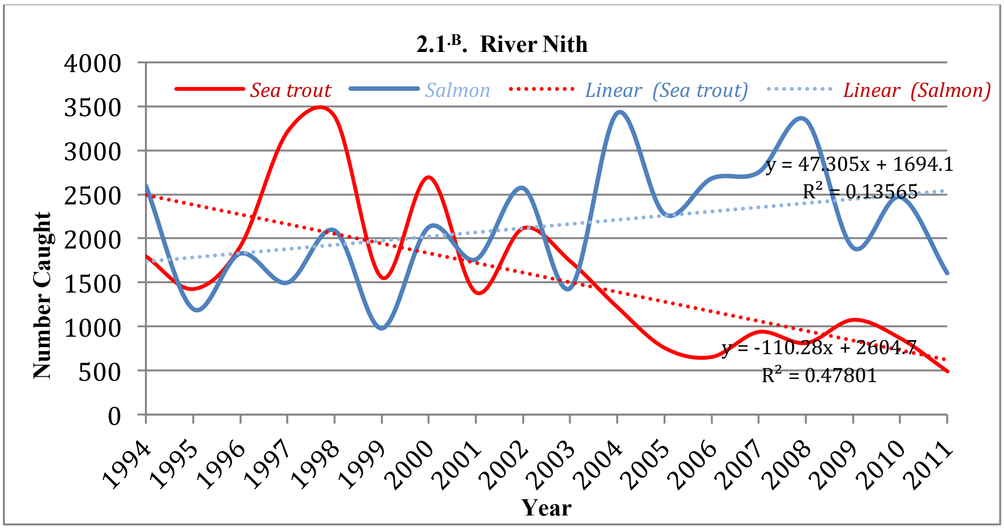
Letters of support for the CSTP funding bid were received from:

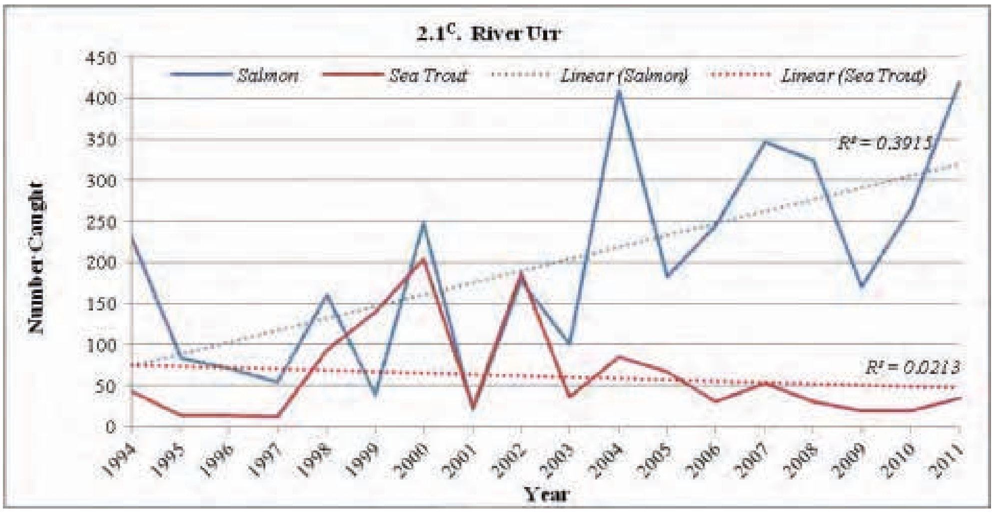
1. Afonydd Cymru
2. Angling Council of Ireland
3. Annan District Salmon Fishery Board
4. Arklow Flyfishers Club
5. Association of Rivers Trusts
6. Atlantic Salmon Trust
7. Bann River Angling Club
8. Brian Rooney
9. Carmarthenshire County Council
10. Carmarthenshire Fishermens Federation
11. The Carmarthenshire Rivers Trust
12. Clwb Godre'r Mynydd Du
13. The Clwyd and Conwy Rivers Trust
14. Countryside Council for Wales
15. Dargle Anglers Club
16. Dee and Glyde Fishing Development Association
17. Dublin and District Salmon Anglers Association Ltd.
18. Dundalk and District Brown Trout Anglers Association
19. Dundalk Salmon Anglers Association
20. Fred Burton, Angling Journalist
21. Galloway Fisheries Trust
22. Gormanston & District Anglers
23. Irish Federation of Sea Anglers
24. The Liffey River Trust
25. The New Dovey Fishery Association (1929) Ltd.
26. Nith District Salmon Fishery Board
27. Rathdrum Trout Anglers and Environmental Club
28. Salmon And Trout Association
29. Slaney River Trust Limited
30. Welsh Assembly Government
31. Welsh Salmon and Trout Angling Association
32. Wexford County Partnership

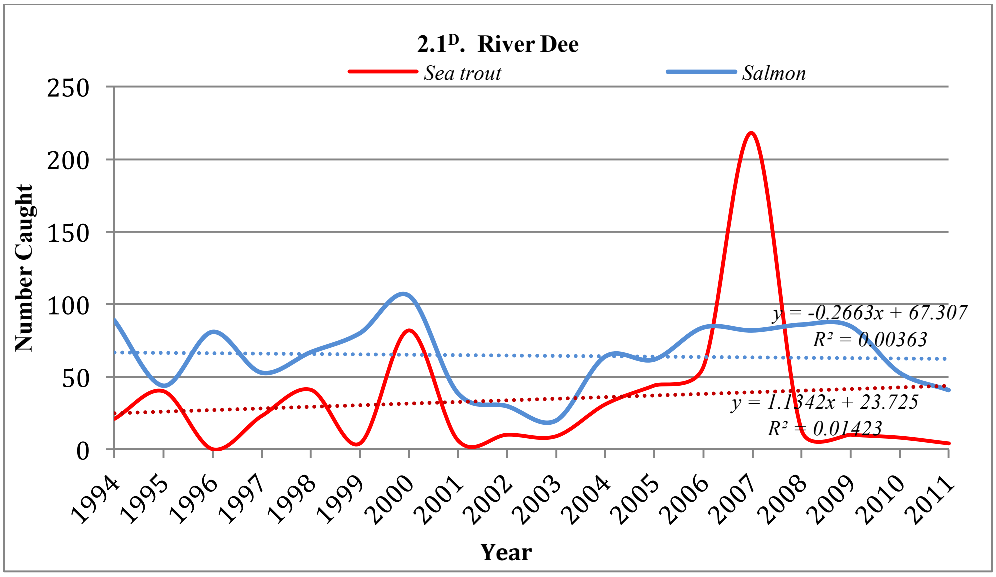
Appendix 2

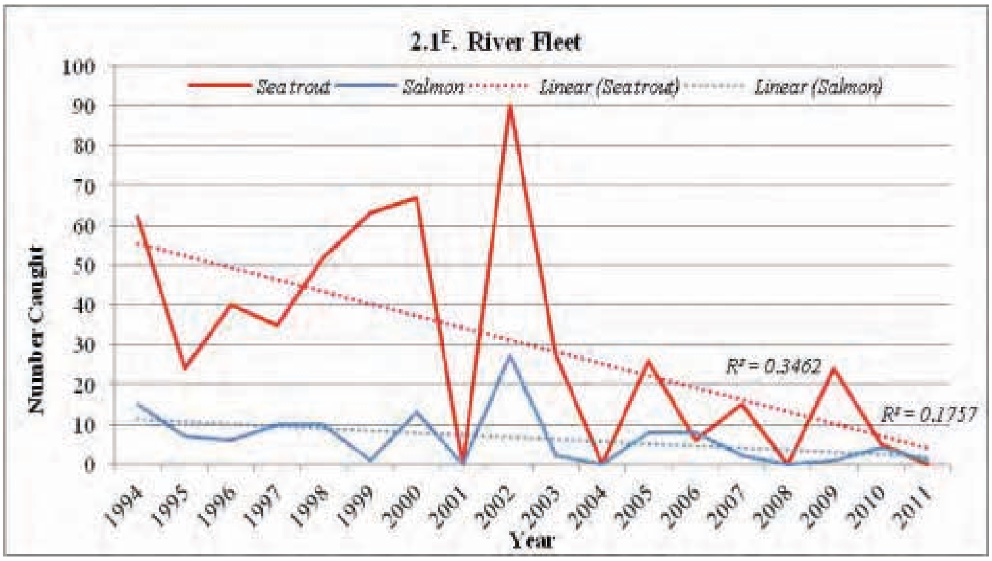
Section 2.1 Reported Rod Catches of Sea Trout & Salmon from the 8 Salmon Fishery Districts in the Solway Region: 1994-2011.

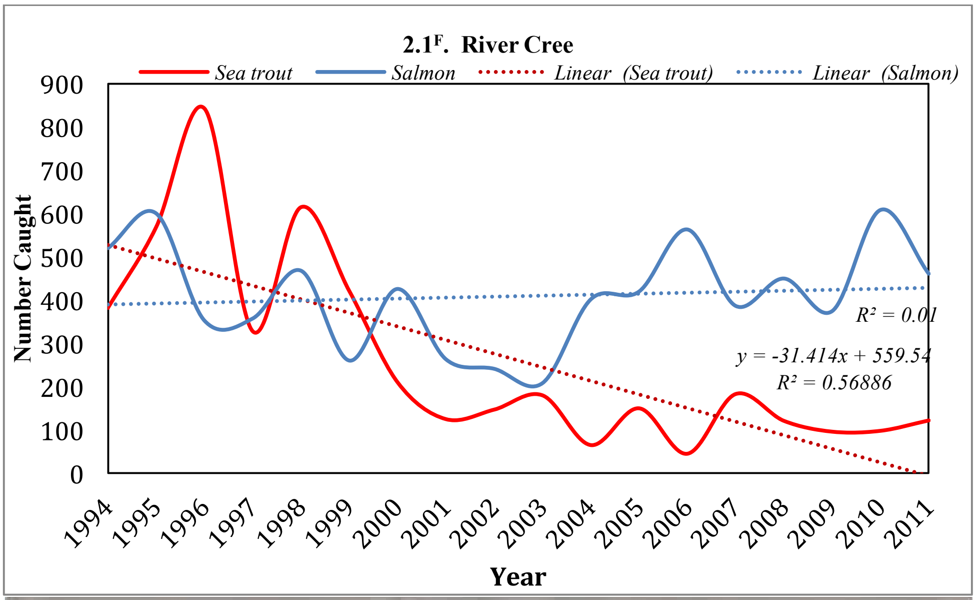


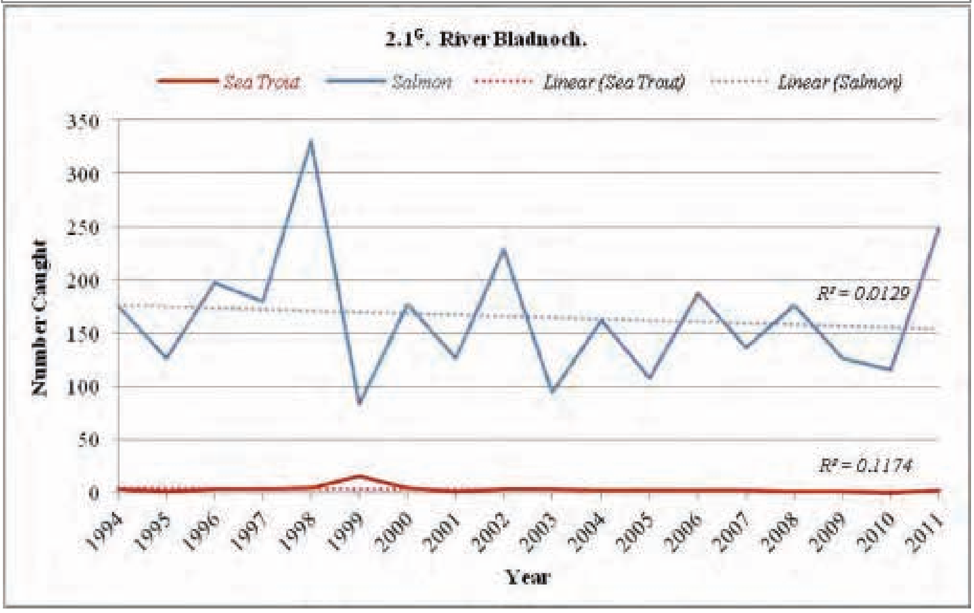


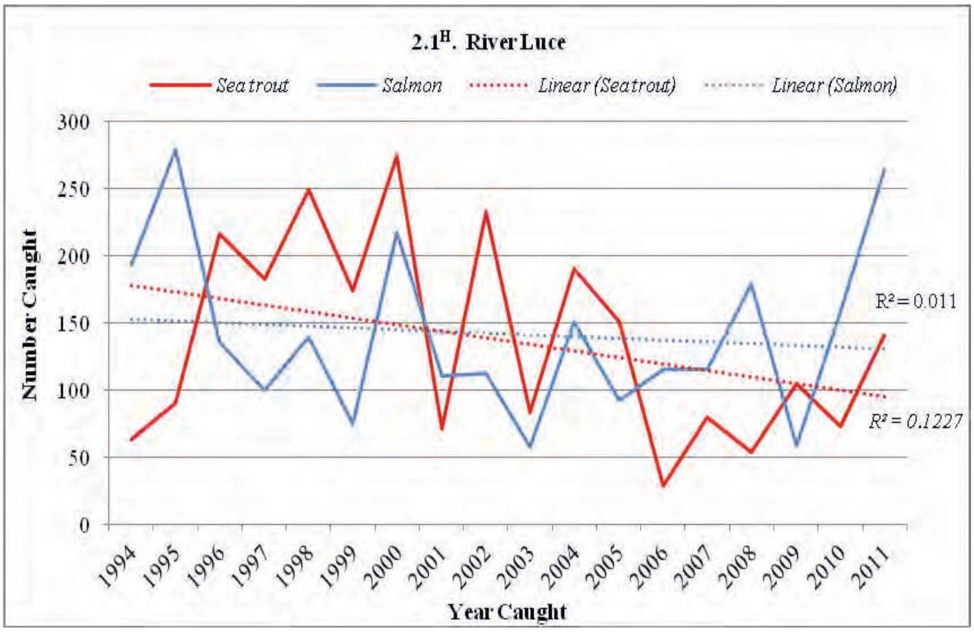

2.1C. River Urr
Salmon
Sea Trout
Linear (Salmon)
Linear (Sea Trout)
R² = 0.3915
R² = 0.0213
Number Caught
Year
450
400
350
300
250
200
150
100
50
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011


2.1D. River Dee
Sea trout
Salmon
y = -0.2663x + 67.307
R² = 0.00363
y = 1.1342x + 23.725
R² = 0.01423
Number Caught
Year
250
200
150
100
50
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011

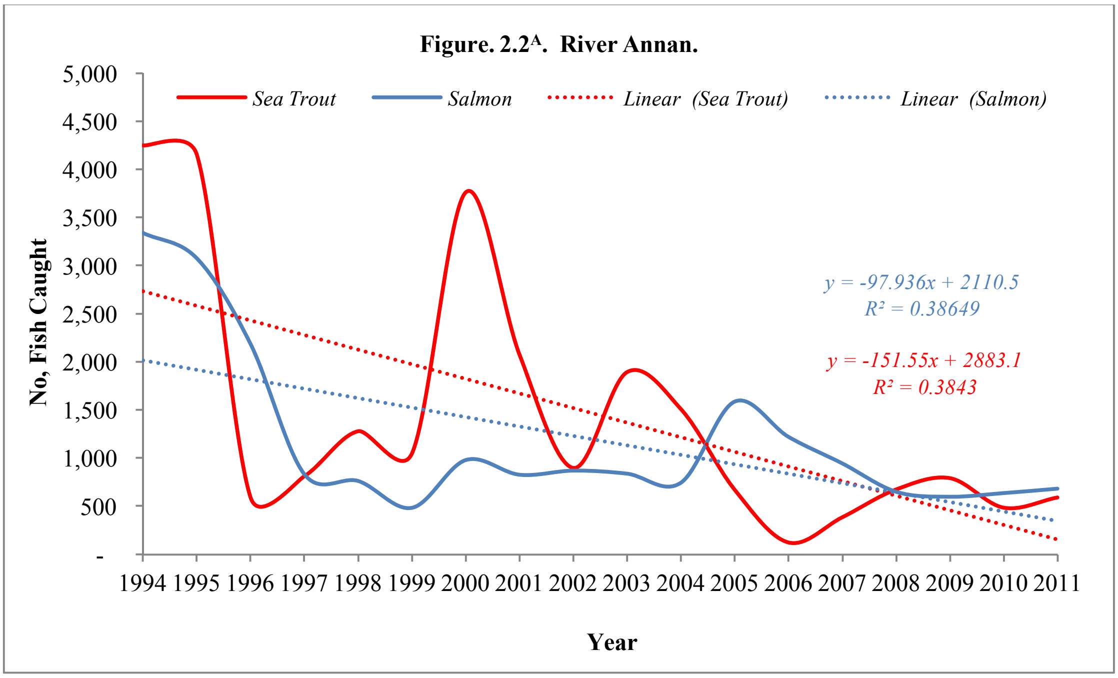

2.1E. River Fleet
Sea trout
Salmon
Linear (Sea trout)
Linear (Salmon)
R² = 0.3462
R² = 0.1757
Number Caught
Year
100
90
80
70
60
50
40
30
20
10
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011


2.1F. River Cree
Sea trout
Salmon
Linear (Sea trout)
Linear (Salmon)
Number Caught
900
800
700
600
500
400
300
200
100
0
R² = 0.01
y = -31.414x + 559.54
R² = 0.56886
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Year


2.1G. River Bladnoch.
Sea Trout
Salmon
Linear (Sea Trout)
Linear (Salmon)
Number Caught
350
300
250
200
150
100
50
0
R² = 0.0129
R² = 0.1174
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Year


2.1H. River Luce
Sea trout
Salmon
Linear (Sea trout)
Linear (Salmon)
Number Caught
300
250
200
150
100
50
0
R² = 0.011
R² = 0.1227
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Year Caught

Section 2.2. Salmon and Sea Trout Catches from the 4 Principal Commercial Net Fishing Districts in the Solway Region (1994-2010).



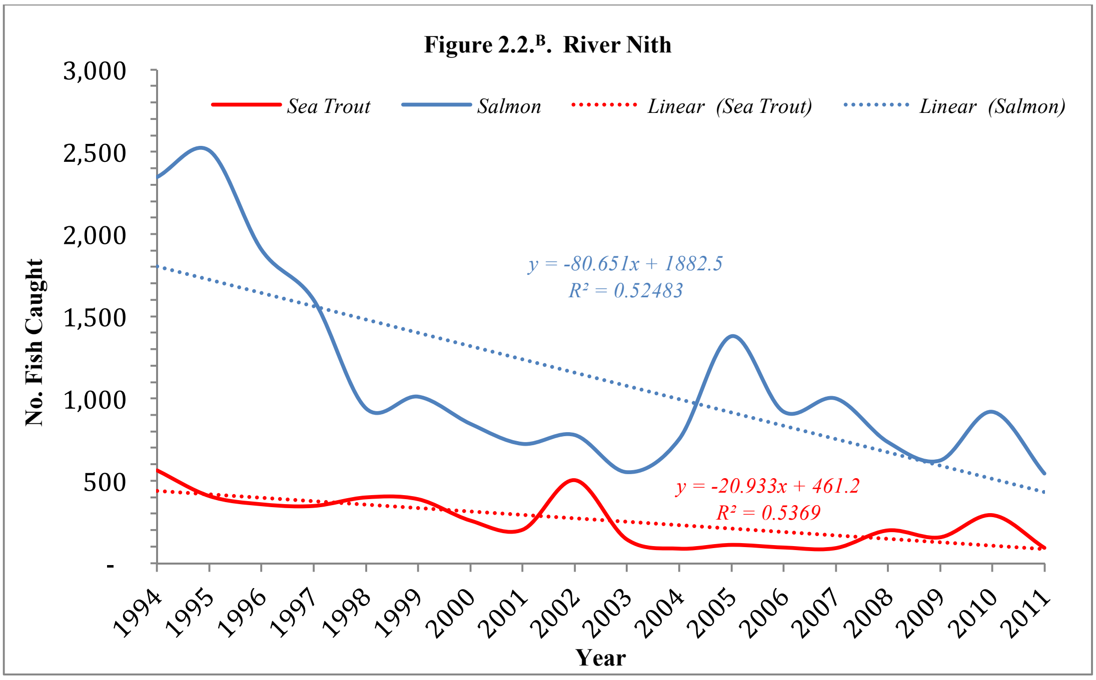


Figure 2.2.C. River Cree

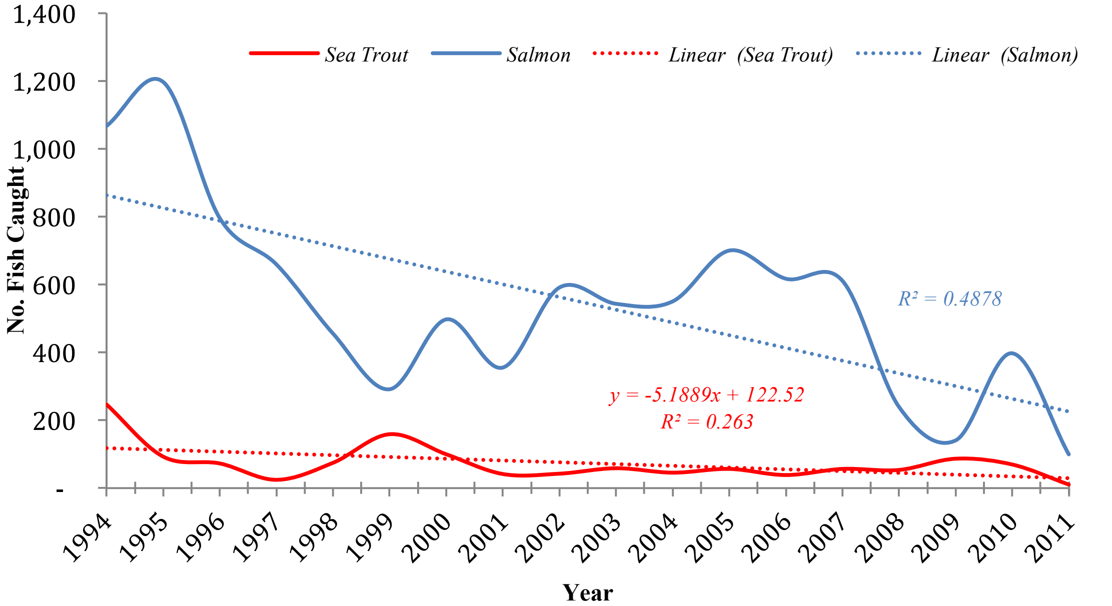
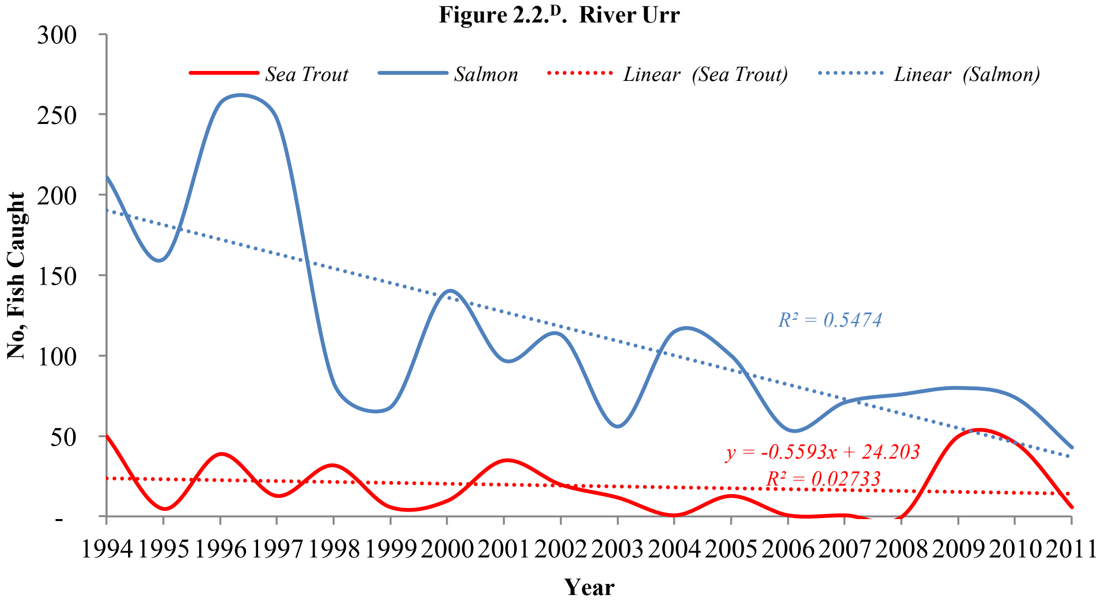


Figure 2.2.D. River Urr



Section 2.3 Details of Releases of Reared Sea Trout and Brown Trout in Welsh Rivers and Stillwaters by the Welsh Water Authority and Private Fishery Interests in 1977. [From Welsh Water Annual Fishery Report for 1977.]

This summary digest excludes any stocking with brown trout eggs or fry. No sea trout were reared beyond the early feeding stage before release and no sea trout eggs were imported into region.

Details given are: 1) All consented stocking with brown trout by private interests. 2) All stocking by Welsh Water Authority with sea trout and brown trout into rivers and the many reservoirs under its control, and 3) All sea trout and brown trout eggs laid down in 1977 at Authority hatcheries and culture units to support future stocking programmes.

1. Private Stocking

a) Sea Trout - No sea trout were stocked by private owners or angling clubs or other third parties.

b) Brown Trout - A total of 194 separate consents for the release of (97,650) brown was issued (including multiple consents for the same site on different dates but excluding transfers between commercial fish farms and any fry stocking). All fish were all supplied by 20 separate commercial fish farms, including 16 in various parts of England. Details for each (former) district are:-

Wye: 46 consents issued covering the introduction of 5,750 trout with a size range of 6-14 ins supplied by 6 commercial farms. Of these, 2,950 were stocked into private lakes and ponds and 2,800 were released into the River Wye and tributaries.

Usk: 25 consents issued covering 16,350 trout (5-12 in) from 8 commercial fish farms. Of these, 1,850 were released into lakes and ponds and 14,450 into two local rivers, the Usk (10,350) and tributaries and the Llwyd. (4,100).

Glamorgan: 41 consents for 24,250 trout (5-12 ins) from 7 fish farms. Of these, 5,750 were stocked into private lakes and ponds and 18,500 into 6 rivers: principally 3,100 (7-14 ins) into the Ogmore, 2,500 (7-12 ins) into the Neath and 6,000 (6-12 ins) into the Taff.

South West Wales: 20 consents issued for 12,500 fish (5-10 ins) from 3 fish farms. Of these 2,500 were stocked into small lakes and ponds and 10,000 were released into two rivers: as 9,000 (5-12 ins) into the Tawe and 1,000 (9 ins) into the Llan.

Gwynedd: 33 consents issued for 11,450 trout (8-13 ins) from 12 fish farms. Of these, some 10,200 were stocked into small ponds and 11 natural lakes in Snowdonia (notably, Conwy and Elsi with 2,500 fish (9-12 ins) and 500 (2-4 lbs) in the Conwy catchment) and 1,250 into two rivers as 750 (9-12 ins) into the Dysynni and 500 (9-11 ins) into the Erch and Rhydhir.

Dee & Clwyd: 29 consents for 11,000 trout (8-16 ins) from 2 fish farms (one farm providing 10,500 fish). Of these, 3,500 (8- 16 ins) were released into lakes and ponds and 7,500 into rivers: namely 1,500 (9-15 ins) into the Clwyd and tributaries and 6,000 (9-14 ins) into the Dee and tributaries.

2. Welsh Water Authority Stocking

In 1997, Welsh Water Authority operated 5 culture units rearing salmon, sea trout and brown trout to advances life-stages: three in Gwynedd (Cae Ddu, Felin Fach and Garreg Felin), one in South West Wales (Dolbantau) and one in Dee & Clwyd (Maerdy). It also maintained three separate trout culture units at reservoir sites in South Wales (Cantref and Wentwood) and on Anglesey (Alaw). Salmon and some sea trout were reared to support statutory fishery protection schemes (Tywi, Eastern Cleddau and Dee), river restoration projects and fish-kill mitigation. Brown trout were reared principally for stocking some 20 put-and-take reservoir fisheries under its ownership and for river restoration.

a) Sea Trout Stocking

Glamorgan. 90,000 unfed fry (from Gwynedd and West Wales rivers) released into 5 recovering industrial rivers in South Wale: including the Ogmore (10,000) and the Afan (30,000).

South Wales. 47,000 fry from Dolbantau stocked into 5 rivers: as Teifi and tributaries (12,600), Eastern Cleddau (17,000), Western Cleddau (10,000) and 2 other minor rivers.

Gwynedd. 320,000 fry released from three rearing units released into 17 rivers within area: principally Dyfi catchment (63,000), Glaslyn (44,000), (Conwy 36,000), Dwyfawr (62,000 and Seiont, Gwyrfai and Llyfni (20,000).

Others Districts: No sea trout were released in the Wye, Usk and Dee & Clwyd districts.

b) Brown Trout (excluding eggs and fry)

Wye: 5,250 brown trout (10-14 ins) provided by 2 commercial fish farms and released the Elan Valley reservoir complex.

Usk: 23,300 (trout (7-13 ins) provided by 6 commercial fish farms. Of these, 17,300 (7-13 ins) released into 5 reservoirs and 6,000 released into two rivers as 2000 (9-10 ins) into Lwyd and 4,000 (9-10 ins)) into Sirhowy.

Glamorgan: 12,200 trout (6-14 ins) provided by 4 commercial farms. Of these, 10,700 (6-14 ins)and released into 9 reservoirs in the Taff catchment and 1,520 fish (8 ins) from 1 commercial fish farm released into Rivers Taff, Ogmore and Neath.

South West Wales: 7,700 trout (9-14 ins) supplied by own unit and 3 fish farms. Of these, 5,700 released into stillwaters, as 3,700 (9-12 ins) two reservoirs in headwaters of Eastern Cleddau and 2,000 trout (9-10 ins) and 2,300 (9-14 ins) released into 4 natural lakes in headwaters of the River Teifi, and with 2,000 (9-10 ins) stocked into River Taf (pollution fish-kill compensation fund).

Gwynedd. 10,200 trout (3-11 ins) from Alaw unit released into Alaw reservoir and 25,000 fry stocked into River Conway and tributaries.

Dee & Clwyd. 38,200 fish (3-10 ins) from own unit and three commercial growers. Of these, 22,800 (3-12 ins) released into 7 reservoirs in Dee catchment and 9,250 (5-8 ins) released into River Clwyd - from one fish farm and 8,000 (3-10 ins) from one fish farm released into the Dee catchment.

3. Hatchery Incubation

During the autumn, a total of 424,000 sea trout eggs and 224,000 brown trout eggs were laid down in Authority hatcheries as: -

a) Sea Trout.

Glamorgan: 83,000 eggs into Cantref unit from West Wales and one local stream.
South West Wales: 103,000 at Dolbantau from local rivers by trapping (Teifi) and electro-fishing at spawning time.
Gwynedd: 233,000 eggs at three units from electro-fishing in 10 local rivers (including 63,000 eggs from Dyfi and 66,000 eggs from Glaslyn)
Dee: 5,000 eggs from electro-fishing on River Clwyd.

b) Brown Trout.

Usk: 50,000 eggs from River Llwyd.
South West Wales: 50,000 eggs from one commercial fish farm on Rheidol.
Gwynedd: 94,000 eggs from traps and nets in Alaw reservoir.
Dee & Clwyd: 30,000 eggs from traps in Brenig reservoir and 54,500 from commercial fish farm.

Appendix 3

Anglers who collected scale samples listed by River or Marine Zone:

Annan: Chris Berry, Joe Black, Rob Brannan, Michael Fearns, Eric Garthwaite, George Husband, GJ Keighley, A Kirkpatrick, D Newson, Ali Nockell, Roger Pascoe, David Scott, Roman Soltys, Anthony Steel, Rob Wardrope. **Argideen** Hugh Barry, Colin Bateman, John Bennett, G Braithwaite, Mark Corps, Frank Crowley, Patrick Deigne, John Higgins, Paul Higgins, Dennis Kerrigan, Gerard McCarthy, Martin McCarthy, D McDonnell, Greg Miller, Tim Miller, John Murphy, Queva Olivier, Guy Pitcher, Jeremy Smith, Julian Smith, Gordon Thompson, Brendan Walsh, Philip Ward, J Whittaker, Peter Wolstenholme. **Avoca:** Robert Doyle, Denis O'Toole. **Bandon:** William Finn, David Forde, Stephen Hanley, Peter O'Connell, Michael O'Neill, Mike O'Neill. **Bladnoch**: J Haley. **Boyne:** John Bagnall, Mark Campbell, Joe Colman, Michael Conagty, Jimmy Condra, Pat Dend, Paul Dennis, Pat Dowd, Ronan Formley, Bernard Halpenny, John Harmon, Brendan Jervis, Michael Kirby, Michael McMahon, Kieran Meaghen, John Murray, Vincent Smart, Mal Woods. **Castletown**: Matt Campbell, Stephen Gilliand, Paul Gilliand, Chris McCully, Brian McShane. **Clwyd**: George Coventry, Harry Coventry, Max Coventry, Allan Cuthbert, John Davidson, Shaun Ellis, R Craig Evans, George Hattersley, Paul Hughes, Dyfed Wyn Jones, Andy Kay, Ian MacDonald, David Pearson, Ian Roberts, Richard Owen Roberts, William Sharp, M Way, David Paul Williams, Paul Williams. **Colligan**: Mark Hayden. **Conwy:** Malcolm Adshead, Mike Cashell, Graham England, Tony Godbert, WK Jones, Mr Knowles, Stephen Last, Frank Lysar, Ian May, A Nixon, Kevin Parry, Paul Simpson, Roger Thomas, JL Thompson, Nick Webster, Bob Wilson. **Cree:** Robin Ade, Glen Alabaster, D Bailie, Murdo Crosbie, Terence Flanagan, J Forrester, Robert Greenhill, J Hyslop, Bob Kenyon, Roger Sharples, S Smith. **Currane**: Joe Barry, M Brush, Darragh Collins, Dennis Collins, Frank Donnelly, Ciaran Earley, Liam Ellis, Shane Fanning, Nick Kennedy, R Johnston, James Lyons, D Malcolmson, Dominic Mcgillicuddy, Jan Mertens, Neil O'Shea, Tom O'Shea, Kevin O'Shea, Denis O'Sullivan, Michael O'Sullivan, Bob Priestley, Constance Qvaring, James Sayers, Brod Sullivan, P Tunks, Jeffery Williams. **Dargle**: Joseph Bonnie, John Chaney, Declan Harrington, Gerard Roe, Jim Travers, Malachy Travers. **Dee (Wales)**: Gwilym Hughes, Peter Weir. **Dee (Ire):** Jim Curley, Gerry Keenan, James Kerin, Stephen Kerin, Peter MaCaughley, Martin McKenny, Roddy Minogue, Alan Wallace. **Dwyfor**: A Bailey, Jan DeBoorder, Ken Jones, RL Pemberton, Rich White, Gwyn Williams, M Williams. **Dyfi**: Melwyn Arnold, P Chomaik, J Clifford, PCJ Cooke, John Eardley, Richard Evans, Alys Fowler, J Glantz, AJ Gordon, Illtyd Griffiths, Kevin Haskey, Gareth Owen Hughes, Phil Jones, B Kettle, E Lewis, Emyr Lewis, Jeiman G Owen, Sean Potter, William Garry Pugh, Chris Randel, HL Rees, John Rees, Geoff Rothwell, Alex Yorke, Dick Yorke. **Ehen**: John Michael Allonby, Sam Flay, DA Gaythwaite, Ian Hurst, J Mills. **Border Esk**: Jackie Allan, John Allan, A Phil Ashworth, John Ashworth, Arthur Bell, Iain Bell, M Bell, Mick Benson, Iain Blackett, Julian Blincoe, JG Blinloe, Mark Burke, TR Carruthers, GS Clayton, Mr Collett, Alan Cooper, Brian Cooper, Martin Coulthard, M Craven, Andrew Croft, Robert Cumming, Rory Cumming, Michael Currie, Ross Currie, Bill Dockray, A Dorrian, J Ferguson-Davie, E Gouge, S Graham, Geoff Harvey, Kelvin Hay, Ian Hewartson, M Horner, Lee Jokes, Tim Jones, Rodney Kaye, Tim Lea, Barry Leeson, Mr Lockhart, S Lockhart, Robin Masterson, Mr McMullan, Stephen Moore, Terry Murphy, Mr Oliver, RM Parks, Scott Peak, Phillip Pearce, Alan Peet, George Potts, Ian Pugh, Gary Robinson, Colin Rutherford, J Scott, C Selstrom, Robert Shaw, M Skipsey, Bob Smith, Paul Stafford, C Storey, T Swires, Peter Thompson, Mr Tower, Bill Wightman, H Wilkinson, Nick Willcox, Dewi Winkle. **Fleet**: AW Gilbey, Mark Hannay, Tom McMillan, Andrew Wolffe. **Glaslyn**: WG Jones. **Glashaboy:** John Buckley. **Glass:** Jim Ramsay, Paul Surgeon, Geoff A Walmsley, Kevin Walmsley. **Kent**: Chris Dickinson. **Luce**: Shaun Bythell, Duncan Chapman, Peter Crawford, Brian Ferguson, Joe Fraser, Brian Goupillot, Andrew Innes, Tom Loch, Martin Lock, R McCreadie, Stuart McDowall, Roger McIntyre, Eric McLean, Corrie Nichol, Jim Nichol, Mary Nicholson, Mr Spicer. **Lune**: Mike P Barker, Duncan Berry, Edward Greenhalgh, W Greenwood, Ray Harrison, B Hollinworth, A Hurst, David Jacks, David Kirk, David G Kirk, CR Leach, D Ledgard, John P Rigby, Robert Rusby, Hans Smith, M Smith, David Wood, George Wood, Michael Woods. **Mawddach:** Stephen Campbell, Carl Clewley, H Dawson, Paul Fox, D Hodson, Ken Parnell, Ken Pollard, Ian G Shaw, Jim Walker. **Moneycarragh**: Martin Thomson. **MZ01**: Ken Whelan. **MZ04:** Sean Jordan. **MZ06:** Alan McEwen, Juergen Skwirbat, Stephen Kennedy. **MZ08**: Terry Jackson. **MZ09:** Walter Davidson. **MZ13:** Nigel Milner. **MZ16**: Vaughn Thomas. **Neath**: TM Evans. **Neb**: Robert Ashbridge, Dave Callow, John Griffiths, Owen Griffiths, Roy Moore, Terry Shepherd, Alan Stone. **Nith**: C Adair, Brian Bell, Michael Black, R Cunningham, Peter Fiohda, Jim Henderson, Tam Hill, William Jones, Scott Kerr, T Littlejohn, Alex Saville, John Stainby, Roderick Styles, B Young. **Ogmore:** Geoff Thompson. **Ogwen**: Vallen Astley, Mike LeHave. **Rheidol:** Gareth Evans, Robert Evans, David Lloyd, Andrew Selly, Chris Truckle. **Ribble**: P Entwistle, M Greenhalgh, Al Griffiths, JS Halford, Gareth Jones, Neil Kennedy, J Ketchell, AT Lawrenson, JP Lord, David Massam, G Murray, Keith Ogden, D Rawkins, Mark Rudd, Terry Semeraz, Jack Speed. **Shimna**: David Hamilton, Paul Harper, Richard Kennedy, Colm Murray, Mark Murray, Norman Patmore, William Robinson, Joe Strain, David Torney. **Slaney**: Nick Ashe, W Atkinson, Mr Buels, John Carroll, John Coyne, F Cullinane, David Dobbs, M Donohoe, J Griffin, Brian Hanley, Brian Harvey, Andy Kelly, John Kelly, Mick Kelly, John Leacy, Dominic Murphy, Sean O'Brien, W O'Connor, Shane O'Reilly, Patrick Power, Mr Stephens, Gavin Sullivan, Joe Tumilson, Billy Tunner, A Walsh. **Suir**: Patrick Lyons. **Sulby**: KH Creccin, Mr Irwain, Rodney Parton. **Tawe**: Ian Govier, John Graham, Roger Harris, Kerry Jones, Gary Lewis, R Lockyer, Malcolm Scutchings.**Teifi**: Claude Belloir, Eon Bowden, Jim E Burrows, H Butt, R Butt, K Checkley, Colin Gentle, Paul Gregory, JT Groves, Jean Claude Guennec, S Reeves, Raymond Turner. **Tywi:** Melwyn Bromham, William Counsell, Clive Davies, Phil Davies, T Davies, WJ Davies, Tyrone Edwards, Colin Evans, H Evans, Graeme Harris, David Harry, Charles Hinds, Rob Jenkins, Brian D

Jones, Frank H Jones, Mark Jones, Steve Jones, Dan King, Lynnford Martinson, Bruce McGlashan, Dave Mee, Paul Metcalf, Richard Norman, Mr Price, Roger Price, Raymond Rees, TJ Rees, Dylan Roberts, Michael Smits, Greg Smitt, Shane Stanley, P Theophilus, Dai Thomas, DW Williams, Ellis Williams, Ben Wilson. **Western Cleddau:** Jack James. **Wye**: David Edmonds.

Section 3.1 CELTIC SEA TROUT PROJECT genetic & microchemistry baseline sampling survey methodology

An important component of the genetics workpackage for the CSTP project was to establish a genetic baseline for sea trout to service a number of aspects of the programme including support the identification of the region and river/tributary of origin of sea trout captured in the Irish Sea, quantify levels of genetic variation in Welsh and Irish river populations, describe the scale and extent of genetic population structuring, at both local and regional level and genotyping sea trout caught at feeding locations in the Irish and Celtic Seas. Developing the baseline will include optimisation and development of a suite of molecular markers which can identify sea trout to region of origin, and optimisation and validation of the database and the assignment methodology. The potential of trout scale microchemistry will also be investigated to identify potentially different chemical signatures in scales from the different systems and tributaries within these systems.

A juvenile sampling programme to collect tissue samples from 0+ fry and1+ trout parr is required to provide material to develop the genetic database. Scale samples will be collected from 1+ parr for microchemistry. The electrofishing sampling programme has been designed to sample juvenile trout in the principal trout spawning area in each catchment. It is envisaged that the majority of systems will be sampled in Year 1 (2009) to allow the baseline to be developed and tested as soon as is feasible. Additional targeted sampling can be conducted subsequently where shortfalls or anomalies arise.

The aim of each sampling team should be to collect high quality tissue samples (tail fin clip) and scale samples from 1+ trout from the principal sea trout spawning area(s) in each system, from as many of the target systems as is feasible, within the available budget. The sampling opportunity should also be used to collect tissue samples (circa ¼ of body length including tail fin) of 0+ trout to allow for determination of genetic temporal stability. Ideally all nominated systems will be sampled over the course of the project.

Sampling strategy: to statistically describe a population characteristic with a high level of confidence, sample size must increase proportionately with the variance of the characteristic. In this instance, as the population characteristic (genetic variance) at regional, river system or local level is unknown it can be reasonably assumed that variance is likely to increase based on key factors including individual abundance and the extent of habitat occupancy. In the absence of other indices, recorded or estimated rod catch will be used as an indicator of sea trout abundance to prioritise sampling and maximise benefits from the available sampling and analytical resource. Wetted area (or catchment size) will also provide some guidance in terms of sampling prioritisation. Geographical distribution of systems will also drive the prioritisation process and will be important for determination of a regional signal. Finally biodiversity will be included as a lower priority driver.

1st filter	Rod catch	Prioritise sampling in catchments with high rod catch
2nd filter	Wetted area accessible to sea trout	Prioritise sampling in catchments with greatest accessible wetted area
3rd filter	Geographical distribution of system	Following sampling of 50% of the above site distribution should be assessed to ensure sufficient samples are taken to assess any regional signal
4th filter	Biodiversity	

Identification of the principal sea trout spawning areas in each system and sampling juvenile populations in these areas will be of paramount importance. In the absence of specific information on sea trout spawning areas, sampling in known salmon spawning areas is likely to cover sea trout spawning area and yield juvenile trout. It has been observed in some catchments that the first major tributary in a large riverine system can be the most prolific or important sea trout sub-system. Such observations may be significant when selecting sites for sampling.

Salmonid spawning areas are not evenly distributed throughout a river system but generally occur in identifiable spawning zones. The distribution of these zones is related to river gradient and availability of gravels. The primary interest for this project is to identify these spawning areas, particularly those that are capable of accommodating significant numbers of spawning sea trout as these areas are likely to be important in identifying discrete populations/structure. These zones can be identified as fairly continuous lengths (ranging from a few hundred metres to a number of kilometres) of river with typical gravel dominated riffle (spawning ford) and pool sequences. There is no necessity to distinguish or locate separately the spawning fords from the pools (these should all be considered as part of the spawning zone). These spawning areas or zones are typically low gradient, meandering channels with eroding banks and point bars and probably suitable for both spawning salmon and trout. These zones will usually be separated from each other by long sections (many kms) of river, which have high gradient consisting of mainly boulder or are long continuous, deep stretches of low gradient silt or sand dominated river, or lakes.

Ideally all sea trout spawning areas in each system should be sampled to provide a comprehensive genetic baseline. Selection and sampling of the major spawning area in a system will be key to delivering this project within the scope of available sampling and laboratory resources. It is likely that a single sample will suffice for linear rivers (very limited complexity) whereas large complex systems may demand two or three disparate samples. The latter will include systems with lakes where population structure may be very discrete.

Resident trout will undoubtedly contribute juveniles to the samples. To assess the potential contribution of residents it may be useful to sample trout upstream of an impassable barrier in a small number of catchments to provide tissue material for comparison between migrants and non-migrants.

Survey methodology: Sampling to be carried using an electrofishing backpack to allow for mobility to and withing sites. Sampling should be conducted consistently over a distance of 500 to 1,000 m within a spawning zone to ensure that multiple families are sampled. It should be feasible to sample two sites per day. **Backpack settings:** Note all agency safety procedures and safety features on the backpack before commencing operations. Pulsed DC to be used. Where any fish mortalities are being observed reduce the power setting appropriately. **Sample target:** 0+ and 1+ trout will be collected at all sites to allow for assessment of temporal variation. Fry and parr (50 of each) to be killed using a lethal dose of clove oil or similar anaesthetic (as described below) and transported in cooler box to the laboratory for processing.

For fry being processed in the field a solution of clove oil (0.8 ml of 10% clove oil-ethanol mixture per litre of water) should be placed in a holding bin and the entire fry sample immersed in the anaesthetic –water solution and observed. Anaesthesia is assumed when fish cease swimming, lose equilibrium and display no reaction to external stimulation or agitation. Prolonged exposure will result will result in mortality. Where anaesthetic is not available fry can be dispatched by cutting the spinal cord directly behind the head with a sharp scissors.

Each 0+ fish to be measured (forklength mm) and the entire tail fin removed, using a scissors, and transferred to a wide-necked plastic screw- capped sample bottle containing high grade ethanol (> 95% concentration) for a bulk sample collection. SARSTEDT 120 ml polypropylene tube with screw cap (product code 60.597) recommended. The volume of ethanol should be at least three times the 50-sample target fin clip mass volume. The vessel has to be tightly screw capped and sealed with parafilm to prevent loss of ethanol and sample desiccation. The number of clips in each sample to be noted (recording of fish lengths on survey sheet will aid this process). A waterproof label with site code, sampling date and sampler to be attached to the sample and an additional paper label to be placed inside the vessel. Example of Site Code No. format 09/IR/Dee/1. 1 denotes individual site number. Date and sampler to be included also.

Batches of 5 x 1+ trout parr to be anaesthetised in a separate holding bin using the same clove oil/ethanol concentration and to be observed closely up to the point of being anaesthetised. Following immobilisation, a tissue sample (15-20% of tail fin) to be clipped from the tail of each fish using a sharp scissors. Fish to be returned to a recovery bin and released once fully recovered. Up to 50 samples per site to be collected and bulked in a wide-mouthed 120 ml plastic bottle as per fry. Where parr are required for otolith microchemistry prolonged exposure will lead to mortality as described for fry. These fish should be individually wrapped in plastic bags or Clingfilm, to prevent any contamination of scales, and transported to the laboratory in a cooler box to be stored at -18C for procesing. A bulk sample, as recommended for field sampling, is suitable for the genetics task and will ensure sampling speed and efficiency. Where individual fish are brought to the laboratory individual samples can be taken.

Catchment coverage: A minimum of one spawning site per river system should be sampled in the priority rivers but large complex systems may demand additional samples. First order and higher order (major tributaries and main channel) channels may contribute to the available spawning habitat in a particular zone and should be sampled if necessary as part of the overall site. **Sampling period:** June to end September. **Survey sheets:** Survey sheets are provided and should be filled out for all sites fished. This includes sites where no trout were recorded.

SCALE SAMPLING FOR MICROCHEMISTRY

- Scales should be collected from 30 x 1+ trout parr per river/spawning area over a range of fish sizes. Scales to be sampled from the dorsal flank below the dorsal fin.
- 20-30 scales should be taken to ensure sufficient material available (original and not replacement scales) to work with, and for any repeat analysis.
- Samples to be taken with individual plastic knife – one per fish. The knife must be totally clean (no scales/mucus/dirt etc) before taking scale sample. The sample (20-30 scales) should be taken by running the knife across the sampling area in the direction of the head to

loosen scales and then lifted with the tip of the knife and transferred to the scale envelope and left to dry. Repeat until the desired number of scales obtained. Skin sections should not be cut out. Bangor University can supply plastic knives (picnic knife from supermarket) and will supply acid washed plastic knives (packed in bags of 40) for repeat use.

- As far as practicable, the scales should be spread across the inside of the envelope to prevent clumping. Clumping and poor storage can lead to fungal growth and scale degradation.
- Scale samples or filled envelopes should not be stored in plastic bags as the scales will rot. Filled scale envelopes should be stored in dry conditions as soon as possible to ensure that the scales will remain viable for the different analyses. Once fully dry the scales will provide microchemistry material for many decades if stored under good conditions.
- When sampling trout samples stored in a bag with other sea trout/fish run the back of the knife over the sampling area in the direction of the tail to remove loose scales from the other fish which may be sitting on the skin/mucus of the fish to be sampled. Then clean the knife thoroughly and take the sample as detailed above.

Some notes on specific fields in survey form:

Water levels (or gauge reading): Ideally water levels should be low when sampling is being carried out. High water levels would make sampling very difficult/dangerous. If a gauge is present please take a reading. **Conductivity/temperature:** conductivity is a useful measure in that it provides an indication of likely productivity and the likely rate of current transfer through the water. The conductivity instrument provided is sensitive and it is recommended to measure conductivity as follows: "fresh" sample of water to be collected in the fish sampling bucket upstream of where efishing was carried out to prevent possibility of disturbed substrate contributing to the reading. Hang meter from the handle of the bucket to allow for coverage of the probe (about 4 cm). Allow reading to stabilise and take water temperature also. **Fish measurement:** all juvenile trout captured should be measured from the tip of the nose to the middle of the fork in the tail to the nearest cm and registered on the survey sheet as shown below to provide a preliminary assessment of size/age frequency distribution and numbers retained/clipped. Where fish are suspected to be large fry or small parr (from length frequency distribution) take a scale sample and transfer to scale envelope with details, particularly accurate forklength (to nearest mm). **Disinfection:** use your agency's standard operating procedure to prevent transfer of algae, higher plants, invasives etc between systems. Proprietary disinfectants or long-term drying or freezing will have the desired effect. However, vigilance is essential if moving between catchments to avoid any possibility of transfer.

Section 3.2

CELTIC SEA TROUT PROJECT
- genetics/microchemistry juvenile sampling survey sheet

System name:

Country: ENG/IOM/IRE/SCOT/WAL

Main channel: Y/N
OR Trib name:

Site Code No:

Date:

Agency & operator:

Location section accessed at:

Local assistance (names & agency):

E/F time start:

E/F time finish:

E/F gear used:

Water levels (or gauge reading):

Conductivity (low water only): µS
GPS (u/s limit):

Photographs: Y/N

Known sea trout spawning zone:
Y/N/Do not know

GPS (d/s limit):

MSW salmon spawning zone: Y/N
1 SW salmon spawning zone: Y/N

Juvenile trout forklengths (cm)		
cm	Measured & fin clipped	Measured BUT NOT fin clipped
3-3.9		
4-4.9		
5-5.9		
6-6.9		
7-7.9		
8-8.9		
9-9.9		
10-10.9		
11-11.9		
12-12.9		
13-13.9		
14-14.9		
15-15.9		
16-16.9		
17-17.9		
18-18.9		
TOTALS		

Other fish species (State if Present (1-10), Common (11-50) or Abundant (>51)):				
Salmon:	Eel:	Stickleback:	Minnow:	Stoneloach:

Back of Sea trout Genetics sampling sheet

OBSERVATIONS

Stocking information (give details of trout stocking to include date, life stage, numbers, source (i.e. native or non-native):

Sampling site conditions:

Electrofishing observations (gear function etc):

Presence of precocious salmon parr:

Other samples taken:

Summary sampling protocol – see methodology document for further information

Sample target: Trout fry (0+) and parr (1+) to be retained.

Sample size: 50 trout fry (1/4 of body incl tail fin) and 50 tail fin clips will be required from each known spawning area. **STORE IN SEPARATE BOTTLES.**

Sampling unit: Minimum sampling unit should be > 500m of trout spawning area.

Fish sampling method: Collect juvenile fish using electrofishing apparatus. Sharp scissors to be used to clip fish. Scissors must be cleaned (dip in alcohol and tissue wiped) before taking another fin clip.

Sample storage: For each site the fin clips are to be stored in one vessel with ethanol (95% concentration). The volume must be three times the fin clip mass volume and the vessel has to be screw capped tightly and parafilmed to ensure no drying out of the sample. The number of clips in each sample should be noted. Sample label should ideally be waterproof paper with details pencilled and put into the vessel. An adhesive label should also be put on the outside of the sample bottle.

Example of sample label:
Example of Site Code No. format 09/IR/Dee/1. 1 denotes individual site number. Date to be included also.

Genetic baseline survey sampling sheet v2

Section 3.3. THE CELTIC SEA TROUT PROJECT 2009-2012

GUIDANCE FOR ANGLERS ON COLLECTING SCALE SAMPLES

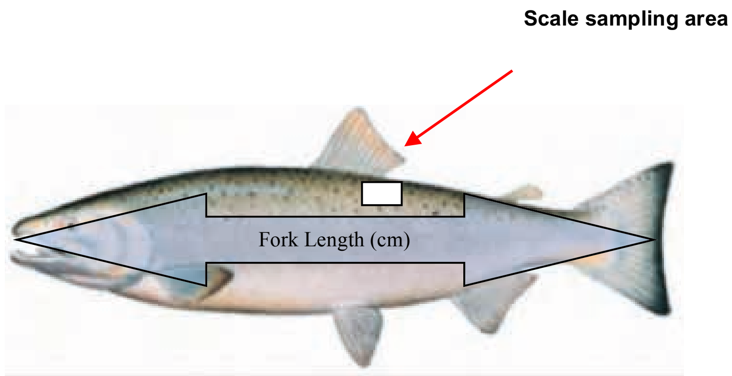
One of the most important parts of the CSTP programme is the collection of sea trout scale samples (juvenile and adult) from about 100 rivers and selected estuaries, coastal waters and further offshore, over the three years of the project, around the Irish Sea. Approximately 25 rivers have been targeted for detailed sampling (Priority Rivers) and this protocol is designed to assist anglers in accurate collection of scales for use in subsequent scientific analysis, e.g. stock structuring and distribution (from genetics and scale micro-chemistry) and features such as age and sex composition, life history, growth and survival.

For scale samples the target is 300+ sets of scales per river, to be collected over a two year period, starting in 2009. The samples must be collected in a scientifically unbiased way to ensure that the sample is representative of the stock. This means that fish of all sizes (smallest to largest) and spread throughout the entire angling season should be sampled.

Anglers are being asked to collect scales and take a length measurements and other relevant information from each sea trout that they catch according to the protocol below. The sample required for analysis is about 10scales per fish which should be placed in an individual scale envelope/scale packet. Specially designed CSTP scale envelopes are included in the sampling packs which also include a measuring tape, pencil, plastic knife and laminated sampling instructions.

<u>Step 1 – taking a sea trout scale sample</u>

- To measure length place the fish flat on top of the measuring device (board, tape etc). Ensure tape is fully extended and taut **under** the fish to record length accurately. Measure from the **tip of the snout** to the end of the **middle** rays of the tail (i.e. fork length), preferably in centimetres. Fork length to the nearest mm is preferable but to the nearest 0.5 cm is acceptable.
- Scales should be sampled from the left side just behind the dorsal fin and above the lateral line. The scale sample must be taken with a clean knife or forceps, to prevent the possibility of mixing of scales from other fish.



- The plastic knife (supplied with the sampling kit) used must be totally clean (no scales/mucus/dirt etc) before taking scale sample. The sample (10-15 scales) should be taken by running the knife across the sampling area in the direction of the head to loosen scales and then lifted with the tip of the knife and transferred to the scale envelope and left to dry. Repeat until the desired number of scales obtained. Skin sections should not be cut out.

- As far as practicable, the scales should be spread across the inside of the envelope to prevent clumping. Clumping and poor storage can lead to fungal growth and scale degradation.
- Scale samples or filled envelopes should not be stored in plastic bags as the scales will rot. Filled scale envelopes should be stored in dry conditions as soon as possible to ensure that the scales will remain viable for the different analyses. Once fully dry the scales will provide genetic material for many decades if stored under good conditions.
- When sampling sea trout stored with other sea trout/fish cross-contamination must be avoided by removing any loose scales adhering to the skin of the fish. Run the back of the knife over the sampling area in the direction of the tail to remove loose scales from the other fish which may be sitting on the skin/mucus of the fish to be sampled. Then clean the knife thoroughly and take the sample as detailed above.

Step 2 – information to be recorded on each scale envelope

Details to be included are:

1. **Name of fish** (i.e. finnock, sea trout etc)
2. **Length** refers to fork length (in centimetres) from tip of snout to fork in tail. Please r**ecord to the nearest 0.5cm**. State measurement unit used, if not centimetres.
3. **Weight** (if measured): whole fish, preferably weighed on electronic balance (to nearest gram, or state other units if applicable).
4. **Sex (external or internal examination, note Int or Ext)**
5. **Location of capture**: Name of tributary/fishery, river or lake, Region, Country
6. **Captor name and contact No.**
7. **How caught** – fishing gear used (fly, lure, bait etc)
8. **Date of capture-** day/month/year

The minimum details required are 1, 2, 5 and 8 above

Step 3 – scale envelope forwarding

Retain envelopes in dry conditions to prevent scale deterioration. Do not store in refrigerator. On a regular basis please post any scale samples you have to your regional or river coordinator, or use whatever arrangements have been made locally:

Postage costs will be reimbursed to all participants at the end of the sampling season.

Feedback

The project aims to give feedback on results as practicable and all participants will receive updates on progress. Thank you for your help. Your assistance is extremely important to the success of this project and is very much appreciated. Check project website for updates: www.celticseatrout.com

Contacts

The contact list on a separate sheet provides the names and details of your regional/river coordinator.

Section 3.4 CSTP angler scale envelope

Celtic Sea Trout Project

Angler caught sea trout scale collection

IRELAND WALES 2007 – 2013

Reference/Code No.

Scale Reading..............

River name..

Capture location.................................Tidal: yes ☐ no ☐

Fish returned alive: yes ☐ no ☐......... fresh-run ☐ **OR** stale ☐

Forklength (to nearest ½cm)..

Weight (to nearest 10g or oz)...................................grams

OR..................lbs..................ozs

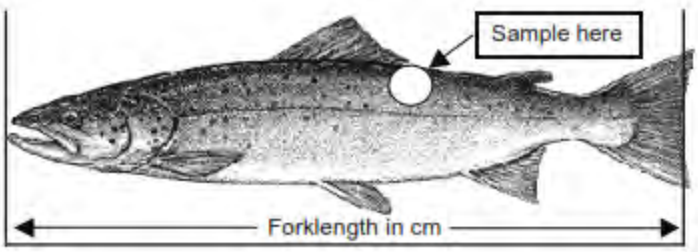
Method of capture: fly ☐ spin ☐ bait ☐

Date of capture............................Time: day ☐ night ☐

Sex: male ☐ female ☐ unknown ☐

Internal examination: yes ☐ no ☐

Please remove 10-15 scales from fish from area shown in drawing overleaf, place in this envelope, fill in details above & return envelope(s) to your regional co-ordinator regularly. Ensure knife is thoroughly clean before scaling another fish.



Angler/Sampler name..

Angler/Sampler contact number..

Other observations (parasites, damage, etc.).....................................

....

THANK YOU FOR YOUR INTEREST & SUPPORT

www.celticseatrout.com

Section 3.5 Celtic Sea Trout Project – Scale collection by anglers

Anglers can catch sea trout in the sea as well as in rivers

NB CAUTION - STAY LEGAL! Please note that fishing with the intention of contributing to the CSTP does not exempt you from fishing regulations. Local regulations are outlined below.

On the Welsh and English coast...

Regulations apply to sea trout angling in the sea as well as in rivers, but these vary around the Irish Sea. In areas managed by the Environment Agency, out to 6 miles offshore in England and Wales, you must have an EA migratory salmonid rod license, just as when fishing in freshwater. Also you must adhere to any byelaws that apply regarding size limits, seasons and quotas etc. You can check these on http://www.environment-agency.gov.uk/homeandleisure/recreation/fishing/31465.aspx

On the Irish coast...

Legislation regarding sea trout in Ireland

In the sea the season extends from January 1st to October 12th. If fishing in a specific river estuary, then the close season for that particular river will apply. A number of fishery estuaries are closed or fished on a catch & release basis for sea trout of 40cm or over. Anglers fishing for sea trout must make themselves fully aware of the regulations.

Licence (RoI)

- A State Salmon Rod License is required to fish for sea trout
- You must carry your license, logbook and tags with you at all times
- All sea trout retained, that is fish 40cm or over, must be tagged and the logbook filled out accordingly
- It is prohibited to sell rod caught sea trout over 40cm.

On rivers that are closed or not classified as salmon rivers angling for salmon (any size) and sea trout (over 40cm) is prohibited. For comprehensive information on fisheries in RoI click on this link: http://www.fisheriesireland.ie/Notices/salmon-and-sea-trout-angling-regulations-2012.html

For information about sea trout regulations in Northern Ireland click on this link: http://www.nidirect.gov.uk/index/information-and-services/leisure-home-and-community/leisure-and-recreation/outdoor-recreation/angling/game-and-coarse-angling/angling-licences-and-permits.htm

On the Galloway coast….

Anglers catch sea trout when fishing in the coastal waters around the shores of Scotland. No offence is committed if these fish are captured unintentionally and returned safely to the water. Under the Salmon and Freshwater Fisheries (Consolidation) (Scotland) Act 2003 section 6 (1) an angler is required to obtain written permission from the proprietor of the salmon fishing rights if he/she wishes to fish for or take sea trout (sea trout and salmon are classified as the same under Scots law). This law applies to inland waters and the sea up to 1.5 kilometres seaward from mean low water springs.

Section 3.6 Sampling location and date for 0+ and 1+ trout

Country	River Name	Trib Name	Country-River Code	Sampling Date	GPS Lat	GPS Long	0+ Fry	1+ Parr	Sample storage
England	Calder	Main River - Calder	E-CALD	21/09/2009	54.440461	-3.4767569		17	Ind.
		Main River - Calder			54.448052	-3.4569251		5	Ind.
		Main River - Calder		13/10/2010	54.448052	-3.4569251	24		Ind.
		Main River - Calder		19/10/2010	54.447179	-3.4577424	26	50	Ind.
		Worm Gill		21/09/2009	54.46824	-3.4418726		5	Ind.
	Derwent	Marron	E-DERW	21/10/2009	54.601755	-3.4349464	48	46	Ind.
		Marron			54.624362	-3.4594412		4	Ind.
		Marron		27/08/2010	54.601755	-3.4349464	50	37	Ind.
		Marron		06/09/2010	54.572646	-3.4475368		33	Ind.
		Marron			54.624362	-3.4594412		5	Ind.
	Duddon	Appletree Worth Beck	E-DUDD	21/09/2010	54.317337	-3.1717943	6	21	Ind.
		Black Sike Beck		21/09/2010	54.342296	-3.2153452	38		Ind.
		Lickle		16/09/2010	54.298018	-3.2086622	4	19	Ind.
		Lickle		21/09/2010	54.298018	-3.2086622	4	6	Ind.
		Lickle		16/10/2010	54.327423	-3.1725578		4	Ind.
	Eden	Sunnygill Beck	E-EDEN	26/10/2009	54.728866	-2.6246047	50	50	Ind.
		Sunnygill Beck		07/07/2010	54.728866	-2.6246047	50	50	Ind.
	Ehen	Kirk Beck	E-EHEN	27/10/2009	54.465959	-3.4978791	50	50	Ind.
		Kirk Beck		19/10/2010	54.465467	-3.4983549	51	50	Ind.
	Cumbrian Esk	Blea Beck	E-ESKC	17/09/2010	54.398229	-3.2425686	27	6	Ind.
		Eel Beck		22/10/2009	54.395868	-3.2707615		3	Ind.
		Eel Beck		17/09/2010	54.395878	-3.2707002	12	30	Ind.
		Spothow Gill		17/09/2010	54.395656	-3.2287054	11	14	Ind.
		Stanley Ghyll Beck		22/10/2009	54.390272	-3.274716		27	Ind.

		Whillan Beck		22/10/2009	54.393337	-3.2798167	53	20	Ind.
		Whillan Beck		30/09/2010	54.398229	-3.2425686	16		Ind.
	Irt	Bleng	IRT	22/10/2009	54.430014	-3.4153244	35	20	Ind.
		Bleng		27/10/2009	54.434744	-3.4120648	14	4	Ind.
		Cinderdale Beck		27/10/2009	54.42315	-3.3442635		11	Ind.
		Cinderdale Beck		13/10/2010	54.423431	-3.3440723	55	29	Ind.
		Kid Beck		27/10/2009	54.428954	-3.3661123		11	Ind.
		Main River - Irt		21/09/2009	54.38846	-3.4147407		4	Ind.
		Mecklin Beck		21/09/2010	54.405759	-3.3690232	21	21	Ind.
	Kent	Lambrigg Beck	KENT	27/10/2009	54.359545	-2.6400841		8	Ind.
		Lambrigg Beck			54.360655	-2.6690631	50	42	Ind.
		Lambrigg Beck		16/09/2010	54.360784	-2.6684805		38	Ind.
		Mint		01/09/2010	54.355455	-2.7093077	51	12	Ind.
	Lune	Austwick Beck	LUNE	24/09/2010	54.104986	-2.3667503	50	48	Ind.
		Ellergill Beck		23/09/2010	54.44194	-2.5564415	50	50	Ind.
	Ribble	Dunsop	RIBB	22/09/2010	53.967939	-2.5313306	48	50	Ind.
		Twiston Beck		21/09/2010	53.89686	-2.2985364	50	50	Ind.
Ireland	Argideen	Main River - Argideen	ARGI	16/06/2011	51.647603	-9.024843	53	66	Bulk
		Reanagar		16/06/2011	51.684585	-8.854021	57	28	Bulk
	Avoca	Avonmore	AVOC	29/07/2010	52.886895	-6.23108	14	14	Bulk
		Derry		29/07/2010	52.851806	-6.333803	9	41	Bulk
	Bandon	Bridewell	BAND	15/06/2011	51.723024	-8.762923	37	58	Bulk
		Brinney		14/06/2011	51.78271	-8.7024794		46	Bulk
	Boyne	Mattock	BOYN	28/07/2009	53.712726	-6.461226	50	52	Bulk
		Trimblestown		02/08/2009	53.563776	-6.8601636	52	53	Bulk
	Bride	Douglas	BRID	10/06/2011	52.076341	-8.1692991		55	Bulk
		Glenaboy		10/06/2011	52.089987	-8.008883		59	Bulk
	Campile	Main River - Campile	CAMP	07/10/2010	52.288624	-6.9369072	43	51	Bulk
	Castletown	Creggan	CAST	11/08/2010	54.034573	-6.457142	32	42	Bulk

	Colligan	Main River - Colligan	COLL	18/10/2010	52.170536	-7.6634195	52	23	Bulk
	Cooley	Main River -Cooley	COOL	21/09/2009	53.997276	-6.2236179	53		Bulk
	Corock	Main River - Corock	CORO	06/10/2010	52.376051	-6.7552251	53	48	Bulk
	Currane	Capall	CURR	31/08/2010	51.827788	-10.032519	51	3	Bulk
		Cappamore		31/08/2010	51.818946	-10.08888	49		Bulk
		Cloughvoola		27/08/2010	51.836119	-10.07684	53	10	Bulk
		Comavanniha		01/09/2010	51.887841	-9.98529	42		Bulk
		Comavoher		01/09/2010	51.896096	-10.000464	43		Bulk
		Commeragh		26/08/2010	51.878086	-10.061453	50	1	Bulk
		Finglas		26/08/2010	51.80314	-10.141027	52	11	Bulk
		Halliseys		31/08/2010	51.82023	-10.069766	48	4	Bulk
	Dargle	Main River- Dargle	DARG	16/10/2009	53.15523	-6.195615	14		Bulk
		Main River- Dargle		20/07/2010	53.155192	-6.195684	51	50	Bulk
	Dee (White River)	Main River - Dee White River	DEWR	10/08/2010	53.841088	-6.398388	51	15	Bulk
	Dodder	Main River - Dodder	DODD	18/08/2010	53.316622	-6.236037	50	13	Bulk
	Duncormick	Main River - Duncormick	DUNC	29/09/2010	52.271197	-6.6806168	52	47	Bulk
	Fane	Main River - Fane	FANE	04/08/2010	53.96837	-6.494794	42	4	Bulk
	Flurry	Main River - Flurry	FLUR	03/08/2010	54.07624	-6.349831	50	14	Bulk
	Glashaboy	Cloughnagashen	GLSH	22/06/2011	51.988167	-8.4797696	66	53	Bulk
	Glyde	Main River - Glyde	GLYD	12/08/2010	53.899181	-6.50959	59	54	Bulk
	Ilen	Renagh	ILEN	15/06/2011	51.647818	-9.268002	52	34	Bulk
	Inch	Main River - Inch	INCH	26/07/2010	52.740384	-6.2405736	50	50	Bulk
	Inny	Kealnenachrie	INNY	21/06/2011	51.87876	-10.159199	54	10	Bulk
		Toorcladine		21/06/2011	51.932312	-10.018711	49	17	Bulk
	Liffey	Rye	LIFF	19/08/2010	53.366449	-6.490911	15	4	Bulk
		Rye			53.379847	-6.5296901	15	4	Bulk
		Rye			53.381895	-6.5483007	13	4	Bulk
	Mahon	Main River - Mahon	MAHO	12/10/2010	52.211946	-7.4847216	53	50	Bulk

	Moygannon	Main River - Moygannon	MOYG	31/07/2009	54.104703	-6.2290106	28	10	Bulk
		Main River - Moygannon		18/08/2009	54.104703	-6.2290106	30	4	Bulk
		Main River - Moygannon		10/09/2009	53.996732	-6.223374		3	Bulk
		Main River - Moygannon		15/09/2009	54.104703	-6.2290106		24	Bulk
		Main River - Moygannon		14/10/2009	54.104703	-6.2290106		17	Bulk
	Nanny	Main River - Nanny	NANN	14/08/2009	53.66517	-6.3576172	25	3	Bulk
	Nore	Ballygallon Stream	NORE	09/06/2011	52.498942	-7.0620335	2	55	Bulk
	Owenboy	Aughnboy	OWBY	(blank)	51.799731	-8.642772	49	63	Bulk
	Owenacurra	Main River - Owenacurra	OWCA	19/10/2010	51.93896	-8.199376	39	50	Bulk
	Owenduff	Main River - Owenduff	OWDF	06/10/2010	52.331287	-6.8482549	51	41	Bulk
	Owenavarragh	Main River - Owenavarragh	OWVR	15/10/2010	52.605745	-6.2986273	54	6	Bulk
	Potters	Main River - Potters	POTT	26/07/2010	52.921915	-6.1097878	52	52	Bulk
	Redcross	Main River - Redcross	REDC	27/07/2010	52.856855	-6.1031372	52	49	Bulk
	Ryland	Main River - Ryland	RYLA	15/09/2009	54.079005	-6.2511093	56	59	Bulk
	Slaney	Boro	SLAN	01/01/2009	52.484947	-6.726187		47	Bulk
		Boro - Aughnagappal		01/01/2009	52.472297	-6.709001	48		Bulk
		Urinn		10/02/2010	52.503031	-6.60927	48		Bulk
	Sow	Main River - Sow	SOWi	29/09/2010	52.395977	-6.4720895	51	26	Bulk
	Suir	Blackwater	SUIR	06/06/2011	52.303604	-7.1651954	60	31	Bulk
	Tay	Main River - Tay	TAYi	13/10/2010	52.174945	-7.516597	48	30	Bulk
	Three Mile Water	Main River - Three Mile Water	TMWR	30/07/2010	52.947435	-6.0980262	50		Bulk
	Turvey	Main River - Turvey	TURV	17/08/2010	53.50806	-6.1955695	10	35	Bulk
	Vartry	Main River - Vartry	VART	22/07/2010	53.012773	-6.117919	40	52	Bulk
	Womanagh	Main River - Womanagh	WOMA	19/10/2010	51.910667	-8.053671	51		Bulk
N. Ireland	Ghan	Main River - Ghan	GHAN	31/08/2010	54.101324	-6.194601	52	51	Bulk
	Monecarragh	Main River - Monecarragh	MONN	25/09/2009	54.262071	-5.853086		41	Bulk

	Shimna	Main River Shimna	SHIM	01/01/2008	54.222317	-5.9232328	48	45	Bulk
	Strangford Blackwater	Ballinrae	STBL	01/01/2008	54.474889	-5.691822	24	24	Bulk
Scotland	Annan	Dryfe Water	ANNA	09/09/2010	55.262224	-3.3028377		25	Ind.
		Dryfe Water		14/09/2010	55.262224	-3.3028377	50	25	Ind.
		Water of Ae		08/07/2009	55.194524	-3.6005158		7	Ind.
		Windyhill Burn		04/09/2008	55.212686	-3.6182826		50	Ind.
		Windyhill Burn		27/05/2010	55.211742	-3.6170184		26	Ind.
		Windyhill Burn		13/07/2010	55.212669	-3.6182348		25	Ind.
		Windyhill Burn		16/09/2010	55.211742	-3.6170184	53		Ind.
	Cree	Palnure Burn	CREE	19/10/2010	54.998445	-4.38559	12		Ind.
		Penkiln Burn		01/12/2011	55.019236	-4.425154	39	32	Ind.
		Penkiln Burn		11/12/2011	55.019236	-4.425154	36	1	Ind.
	Border Esk	Black Esk	ESKB	11/09/2009	55.249754	-3.2483449	54	18	Ind.
		Black Esk		18/09/2009	55.23188	-3.2185287		12	Ind.
		Black Esk		23/09/2009	55.230149	-3.2523567		5	Ind.
		Black Esk			55.239252	-3.2484514		10	Ind.
		Black Esk			55.249754	-3.2483449		5	Ind.
		Boyken Burn		15/10/2009	55.187069	-3.0984125		30	Ind.
		Caddroun Burn		29/09/2010	55.278869	-2.6564006		4	Ind.
		Caddroun Burn		04/10/2010	55.268704	-2.689377		12	Ind.
		Different Beck		16/09/2009	55.199918	-2.8738863		10	Ind.
		Ewes Water		15/09/2009	55.243171	-2.9678093		50	Ind.
		Kirk Beck		14/10/2009	55.062894	-2.686429		50	Ind.
		Liddel Water		13/09/2009	55.277708	-2.6568694		30	Ind.
		Liddel Water		24/09/2009	55.274935	-2.6371331		20	Ind.
		Liddel Water		05/10/2010	55.226152	-2.7331003		24	Ind.
		Liddel Water			55.226439	-2.7316435		9	Ind.
		Little Beck		16/09/2009	55.195759	-2.9226565		2	Ind.

		Meggat Water		12/09/2009	55.238798	-3.1060033		50	Ind.
		Meggat Water		28/09/2010	55.238798	-3.1060033	50	5	Ind.
		Meggat Water		06/10/2010	55.224487	-3.094507		17	Ind.
		Meggat Water			55.228416	-3.0832789		26	Ind.
		Meggat Water			55.240718	-3.0597391		8	Ind.
		Roughley Burn		13/09/2009	55.260935	-2.7555652		15	Ind.
		Roughley Burn		24/09/2009	55.245781	-2.7718403		35	Ind.
		Tarras Water		16/09/2009	55.156225	-2.9372805		11	Ind.
		Tarras Water			55.202523	-2.9218231		9	Ind.
		Tarras Water			55.207502	-2.9193454		18	Ind.
		Tinnis Burn		16/09/2009	55.147719	-2.8548467		50	Ind.
		Wauchope Water		15/09/2009	55.140968	-3.0252152		20	Ind.
		Wauchope Water		23/09/2009	55.140968	-3.0252152		30	Ind.
		White Lyne		14/10/2009	55.078816	-2.7193598		50	Ind.
	Fleet	Barley Burn	FLEE	16/10/2009	54.895131	-4.2164996		32	Ind.
		Barley Burn		15/11/2010	54.895131	-4.2164996	34	14	Ind.
		Barley Burn		16/11/2010	54.895131	-4.2164996	17	35	Ind.
	Luce	Lady Burn	LUCE	13/10/2009	54.878343	-4.8103434		39	Ind.
		Lady Burn		13/10/2010	54.878343	-4.8103434	50	50	Ind.
	Nith	Mennock Water	NITH	19/08/2009	55.373965	-3.8180239		80	Ind.
		Mennock Water		05/08/2010	55.366576	-3.8332642	50	50	Ind.
		Wanlock Water		03/08/2010	55.414226	-3.8169745	50	50	Ind.
Wales	Aeron	Mydr	AERO	13/10/2010	52.198428	-4.2310067		42	Ind.
		Mydr			52.220289	-4.2339866	50	8	Ind.
	Clwyd	Deunant	CLWY	17/06/2010	53.191546	-3.5619802	50	50	Ind.
	Conwy	Roe	CONW	17/06/2010	53.214411	-3.8475389	50	50	Ind.
	Dee(Wales)	Ceiriog	DEEw	14/10/2010	52.887025	-3.2532065		17	Ind.
		Ceiriog			52.8997	-3.2090014		19	Ind.
		Ceiriog			52.930853	-3.1873598	50	14	Ind.

		Eglwyseg		11/10/2010	52.985036	-3.1853747	52	50	Ind.
	Dwyfor	Dwyfach	DWYF	16/06/2010	52.966256	-4.2624981	50	23	Ind.
		Dwyfach		27/09/2010	52.978493	-4.2676908		30	Ind.
	Dwyryd	Teigl	DWYR	14/06/2010	52.965126	-3.9433581	54	50	Ind.
	Dyfi	Cerist	DYFI	15/06/2010	52.725721	-3.7051243	50	50	Ind.
	Glaslyn	Nant Colwyn	GLAS	16/06/2010	53.036891	-4.1250349	50	50	Ind.
	Llyfni	Nant Tal-y-mignedd	LLYF	18/06/2010	53.054706	-4.2005605	50	50	Ind.
	Loughor	Aman	LOUG	09/09/2010	51.803991	-3.8983024	39	40	Ind.
		Aman		10/09/2010	51.803381	-3.9039263	3	2	Ind.
		Aman		16/09/2010	51.803349	-3.9039086	9	8	Ind.
	Mawddach	Nant Pwll-y-gele	MAWD	15/06/2010	52.761652	-3.8411973	50	50	Ind.
	Nevern	Brynberian	NEVE	13/10/2010	51.992703	-4.7433403	50	50	Ind.
	Ogwen	Ffydlas	OGWE	18/06/2010	53.17836	-4.0558896	50	50	Ind.
	Rheidol	Melindwr	RHEI	14/10/2010	52.401646	-3.9740205		28	Ind.
		Melindwr			52.414141	-3.9504177	53	22	Ind.
	Taf	Main River - Taf	TAF	16/09/2010	51.909494	-4.6471504	52	50	Ind.
	Tawe	Main River - Tawe	TAWE	17/09/2010	51.801364	-3.7069214	50	50	Ind.
	Teifi	Cerdin	TEIF	11/10/2010	52.049531	-4.3032868	11	3	Ind.
		Cych		28/04/2010	51.983138	-4.4875777		60	Ind.
		Nant Bargod		11/10/2010	52.026135	-4.3992821	50	50	Ind.
	Tywi	Sawdde	TYWI	09/09/2010	51.897522	-3.8053477	50	50	Ind.
	Western Cleddau	Anghof	WCLE	04/10/2010	51.899462	-4.9685005	50	25	Ind.
		Anghof			51.917429	-4.9359009		25	Ind.
Isle of Man	Glass	Main River- Glass	GLSS	16/09/2010	54.153928	-4.5018436	16	24	Ind.
		Main River- Glass			54.164289	-4.4944224	25	3	Ind.
		Main River- Glass		28/09/2010	54.183321	-4.5017341	9		Ind.
		Main River- Glass		17/08/2011	54.155248	-4.5018627	20		Ind.
		Main River- Glass		18/08/2011	54.164198	-4.4942986	21		Ind.

		Main River- Glass			54.183233	-4.5015145	9		Ind.
	Neb	Main River - Neb	NEB	08/09/2010	54.208006	-4.6382961	20	2	Ind.
		Main River - Neb		09/09/2010	54.203841	-4.65934	16	14	Ind.
		Main River - Neb		17/09/2010	54.21118	-4.6931151	14	9	Ind.
		Main River - Neb		27/07/2011	54.203483	-4.6590169	20		Ind.
		Main River - Neb		22/08/2011	54.211132	-4.6931144	20		Ind.
		Main River - Neb		23/08/2011	54.207979	-4.6385704	10		Ind.
	Sulby	Glen Auldyn	SULB	24/09/2010	54.320409	-4.4053257	25	23	Ind.
		Glen Auldyn		04/08/2011	54.319703	-4.4055619	19		Ind.
		Main River - Sulby		21/09/2010	54.31561	-4.4859958	16	7	Ind.
		Main River - Sulby			54.323332	-4.4335855	8	5	Ind.
		Main River - Sulby		20/07/2011	54.315952	-4.4876062	20		Ind.
		Main River - Sulby			54.32317	-4.4352611	11		Ind.

Section 3.7 Rivers, tributaries/sites and numbers of 0+ trout fry and 1+ parr retained for growth studies and microchemistry analysis.

Country Code	River Name	Trib Name	Fry	Parr
England	**Calder**	Main River - Calder	50	
	Cumbrian Esk	Blea Beck	27	
		Eel Beck	12	
		Spothow Gill	11	
		Whillan Beck	69	
	Derwent	Marron	98	25
	Duddon	Appletree Worth Beck	6	
		Black Sike Beck	38	
		Lickle	8	
	Eden	Sunnygill Beck	100	
	Ehen	Kirk Beck	101	25
	Irt	Bleng	49	
		Cinderdale Beck	55	
		Mecklin Beck	21	
	Kent	Lambrigg Beck	50	25
		Mint	51	
	Lune	Austwick Beck	50	25
		Ellergill Beck	50	25
	Ribble	Dunsop	48	25
		Twiston Beck	50	25
Ireland	**Argideen**	Main River - Argideen		22
		Reanagar		3
	Avoca	Derry		25
	Bandon	Brinney		25
	Castletown	Creggan		25
	Currane	Capall		3
		Cloughvoola		10
		Commeragh		1
		Finglas		11
		Halliseys		4
	Dargle	Main River- Dargle		25
	Dee (White River)	Main River - Dee White River		15
	Mahon	Main River - Mahon		25
	Sow	Main River - Sow		15
N. Ireland	**Ghan**	Main River - Ghan		7
Scotland	**Annan**	Dryfe Water	50	25
		Windyhill Burn	53	26
	Border Esk	Black Esk	54	18
		Caddroun Burn		16
		Liddel Water		8
		Meggat Water	50	31
	Cree	Palnure Burn	12	
		Penkiln Burn	75	33
	Fleet	Barley Burn	51	25
	Luce	Lady Burn	50	25
	Nith	Mennock Water	50	55
		Wanlock Water	50	25
Wales	**Aeron**	Mydr	50	
	Clwyd	Deunant	50	25
	Conwy	Roe	50	25
	Dee(Wales)	Ceiriog	50	25
		Eglwyseg	52	25

	Dwyfor	Dwyfach	50	
	Dwyryd	Teigl	54	
	Dyfi	Cerist	50	25
	Glaslyn	Nant Colwyn	50	
	Llyfni	Nant Tal-y-mignedd	50	25
	Loughor	Aman	51	25
	Mawddach	Nant Pwll-y-gele	50	25
	Nevern	Brynberian	50	
	Ogwen	Ffydlas	50	
	Rheidol	Melindwr	53	25
	Taf	Main River - Taf	52	
	Tawe	Main River - Tawe	50	25
	Teifi	Cerdin	11	
		Cych		60
		Nant Bargod	50	25
	Tywi	Sawdde	50	25
	Western Cleddau	Anghof	50	25
Isle of Man	**Glass**	Main River- Glass	50	25
	Neb	Main River - Neb	50	25
	Sulby	Glen Auldyn	25	13
		Main River - Sulby	24	12
Total			2611	1138

Section 3.8 Numbers of sea sampled by year from rivers for the CSTP (2007-2012)

River Name	2007	2008	2009	2010	2011	2012	Total
Annan				8	69	26	103
Argideen			70	130	133	16	349
Artro					4		4
Avoca		2	6	1	11	6	26
Bandon			9	27	57	9	102
Blackwater			11				11
Bladnoch						1	1
Border Esk	3	2	178	154	125	76	538
Boyne			16	10	172	119	317
Broadmeadow			2	14			16
Campile				1			1
Castletown		6	161	117	282	48	614
Clwyd			2	40	40	8	90
Colligan		8		4	14		26
Conwy			37	11	25	9	82
Cree			11	12	45	24	92
Currane		8	72	54	267	6	407
Dargle			21	31	77		129
Dee (White River)			8	69	420	107	604
Dee(Scotland)					21		21
Dee(Wales)				115	15		130
Derwent				5			5
Dodder		1	5	7	2		15
Dwyfor				12	5	12	29
Dyfi			2	39	191	43	275
Eden				2			2
Ehen				96	161	1	258
Fane			14				14
Fleet			82	5	98	2	187
Glashaboy			4				4
Glaslyn					13		13
Glass			4	5	6	2	17
Glyde				56	1	60	117
Ilen		2					2
Inch			12				12
Kent					1		1
Liffey				4	2	1	7
Loughor					3	2	5
Luce			5	26	129	92	252
Lune				257	117	58	432
Mahon	1	9		2	22		34
Mawddach					54	23	77
Monecarragh			15				15
Neb			61	31	16	1	109
Nevern				1			1
Nith			127	78	64	55	324
Nore					1		1
Ogwen			3	1	1		5
Owenavarragh		5	5	1	4		15

Owenduff				3			3
Potters			15	3			18
Redcross			5	4		4	13
Rheidol						15	15
Ribble				13	74		87
Shimna		4	76	42	138	430	690
Slaney		22	81	34	185		322
Sow				31			31
Suir				3			3
Sulby			57	13	1	1	72
Tawe				11	46	5	62
Tay				4			4
Teifi		3		2	69	57	131
Three Mile Water			2				2
Turvey			3				3
Tywi			8	62	371	50	491
Urr						1	1
Vartry		4	14	5			23
Western Cleddau				1	6		7
Total	**4**	**76**	**1204**	**1657**	**3558**	**1370**	**7869**
% by year	0.05	0.97	15.30	21.06	45.22	17.41	7869

Section 3.8 Numbers of sea sampled by month by year from rivers for the CSTP (2010-2012). Non-priority rivers highlighted.

	River	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
ENG	**Ehen**	2010								2				2
		2011							1	4		1		6
		2012								1				1
	Kent	2011						1						1
	Lune	2010						1	8	1	2			12
		2011						41	30	5	2			78
		2012					4	22	24	7	1			58
	Ribble	2010							7	6				13
		2011						19	27	11	1	13		71
IRE	**Argideen**	2009						1	20	19	18	13		71
		2010			1	16	44	13	3	32	12	4		125
		2011				9	18	16	31	42	13	4		133
		2012					1	1	2		12			16
							130							
	Avoca	2010									1			1
		2011							1	8	1			10
		2012							4		2			6
	Bandon	2009						3			6			9
		2010				1	5	10	3	8				27
		2011						6	27	23	1			57
		2012					1			1	7			9
	Boyne	2009							8	8				16
		2011		1					81	46	38			166
		2012					2	3	21	33	60			119
	Campile	2010										1		1
	Castletown	2008						1	3	2				6
		2009						4	49	50	53			156

		2010						11	54	36	10			111
		2011						41	122	77	41			281
		2012						8	19	13	8			48
	Colligan	2011						7	5	1	1			14
	Currane	2008						4	5					9
		2009					1		38	26	9			74
		2010				1	9	4	35	2	2			53
		2011				3	37	130	46	18	25	14		273
		2012			1						5			6
	Dargle	2010									1			1
		2011					2		1	5	3			11
	Dee	2009							2	6				8
		2010					1	14	21	23	6			65
		2011				6	3	53	194	51	113			420
		2012						5	13	3	81			102
	Dodder	2011								2				2
	Fane	2009							13		1			14
	Glashaboy	2009									1	3		4
	Glyde	2010						4	8	16	16			44
		2011								1				1
		2012						1	8	11	40			60
	Liffey	2012					1							1
	Mahon	2010									1			1
		2011								10	12			22
	Nore	2011									1			1
	Redcross	2012							4					4
	Slaney	2008						20				1		21
		2009						28	20	5				53
		2010						6	27	1				34
		2011					1	83	63					147
	Suir	2010				1	1				1			3
NIRE	**Monecarragh**	2009								2	8	4	1	15

	Shimna	2008											4	4
		2009	1						1	43	17	13	1	76
		2010						1	16	17	2		4	40
		2011							18	61	40	13		132
		2012				56	44	17	155	92	25	32		421
SCOT	**Annan**	2011						22	10					32
		2012		4	11		2	3	2	1				23
	Bladnoch	2012		1										1
	Border Esk	2007					1	2						3
		2008							2					2
		2009					8	65	72	22	1			168
		2010					2	19	69	3				93
		2011					3	36	22	7	2			70
		2012					4	41	19	1				65
	Cree	2009							2	3	2	3		10
		2010				1			2	5	2	1		11
		2011						2	11	16	8			37
		2012						2	3	3	7	8		23
	Fleet	2009						3	1	4	1			9
		2010						1	3					4
		2011								2				2
		2012							2					2
	Luce	2009							4					4
		2010							22	2	1			25
		2011						8	41	55	11	6	1	122
		2012						18	40	15	4	2		79
	Nith	2009						6	20	3	4			33
		2010						7	4					11
		2011				1		4	8	1	7	11		32
		2012				1	14	14		3	2			34
WAL	**Artro**	2011							3					3
	Clwyd	2009								2				2

		2010					1	6	13	9	6	2		37
		2011						1	16	6	13	3	1	40
		2012						2	4	2				8
	Conwy	2009					1	9	11	10	3	1		35
		2010						1	7	2	1			11
		2011					3	7	7	6	2			25
		2012						1	5	3				9
	Dee(Wales)	2010							1					1
		2011						1	7	4	3			15
	Dwyfor	2010								9	1			10
		2011						4		1				5
		2012						2	8	2				12
	Dyfi	2009							2					2
		2010						3	21	8				32
		2011					3	50	57	20	5			135
		2012						15	20	4				39
	Glaslyn	2011						6	7					13
	Loughor	2011									2			2
		2012							1	1				2
	Mawddach	2011						11	37	2				50
		2012						11	10	2				23
	Ogwen	2009							3					3
		2010							1					1
		2011					1							1
	Rheidol	2012						12	3					15
	Tawe	2010						1	4	4	1	1		11
		2011					1	10	8	8	13	6		46
		2012					1		2	2				5
	Teifi	2011					7	9	17					33
		2012							10					10
	Tywi	2009					1	2	2	1		2		8
		2010				1		16	26	14	4			61

		2011				2	7	40	58	14	12			133
		2012				1	3	18	11	9	1			43
	WCleddau	2011						5	1					6
IOM	**Glass**	2009								3	1			4
		2010										4		4
		2011								2	1			3
		2012						1						1
	Neb	2009								6	3			9
		2010							2	1	2			5
		2011							3	2	1	3		9
	Sulby	2009							1	2	1			4
		2010								1	2	5		8
		2011								1				1
		2012								1				1
	Total		**1**	**6**	**13**	**100**	**238**	**1076**	**1986**	**1141**	**830**	**174**	**12**	**5577**

Section 3.10 Marine survey sampling sheet

CELTIC SEA TROUT PROJECT
Marine sea trout sampling survey sheet

PLEASE FILL OUT EVEN WHEN NO SEA TROUT ARE RECORDED

Survey type (circle)
Estuarine
Inshore (<1km from coast)
Marine

Country: ENG/IOM/IRE/SCOT/WAL

County:

Date:

Location name:

Location section accessed at:

Nearest river mouth:

GPS (sampling starting point)..
GPS (sampling starting point)..
GPS (sampling starting point)..
GPS (sampling starting point)..

Gear type: gill net/draft net/ seine net/ trawl other (specify)..

Wind direction:

Weather conditions:

Sampling time start (net deployment):

Sampling course (e.g. E to W)

Sampling depth (m):

Salinity: **ppt**

Known sea trout habitat: Y/N/Do not know

CSTP box:

Site Code No:

Agency & operator:

Vessel type/length:

Local assistance (names & agency):

GPS (sampling finish point)..
GPS (sampling finish point)..
GPS (sampling finish point)..
GPS (sampling finish point)..

Tide: Ebbing/flooding

Gear details: length, depth, mesh size(s), composition:

Net orientation from shore: (where applicable)
parallel, perpendicular, diagonal

Wind speed:

Time finish (netting effort finish):

Photographs: Y/N

Substrate types:

Water temperature: **°C**

Sampling site selection criteria:
(local knowledge, random etc)

Where sample retained: ....

Additional Comments: ie Anchor points, net condition post survey, problems (weed, crab, etc)

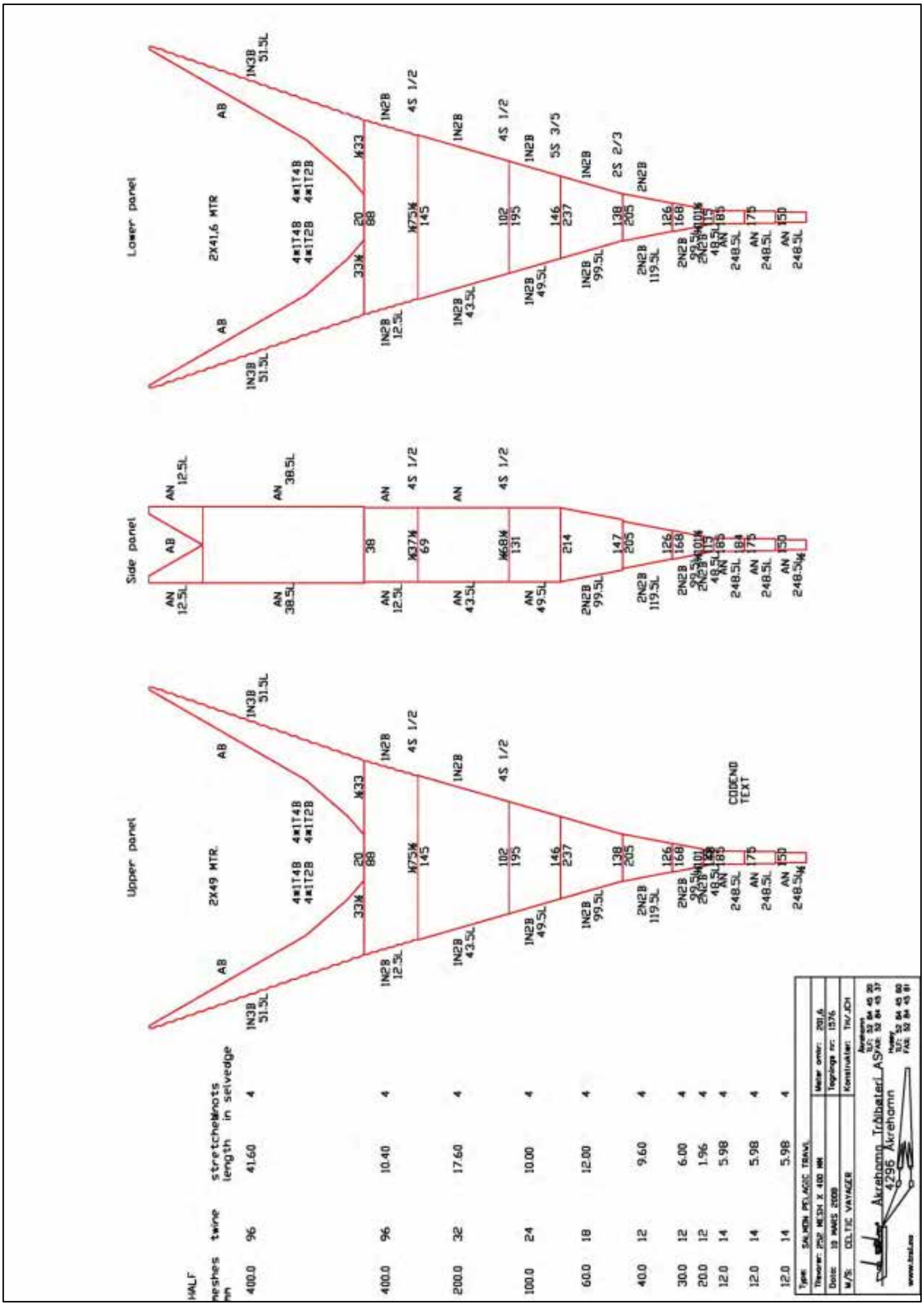
Sampling location.. **Date**..
Method.. **Sampler**..

Species and numbers of fish captured per Net/Shot:

Sea trout:	**Dogfish:**	**Mullet:**	**Bass:**	**Flounder:**
Plaice:	**Ray:**			

Net/ Shot No.	Fish No.	Mesh Size (cm)	Species	Fork Length (mm)	Weight (g)	Net/ Shot No.	Fish No.	Mesh Size (cm)	Species	Fork Length (mm)	Weight (g)

Section 3.11 SALSEA-Merge trawl design



Section 3.12 Marine Zone sampling details and principal fish species captured

CSTPMarineZone	Country	County	Date	StartLat	StartLong	SamplingCatchMethod	SandSmelt	SeaTrout	ThickLippedMullet	Flounder	Bass	Salmon	LesserSpottedDogfish	Plaice	Whiting	Sandeel	Mackerel	Herring	Weever	Turbot	Sole	Garfish
MZ01	Ireland	Kerry	8/2012	52.1	-9.9	Draft Net		1														
MZ01	Ireland	Kerry	4/9/2012	51.8	-10.2	Draft Net				10	1									2		
MZ01	Ireland	Kerry	6/9/2012	52.1	-10.0	Draft Net																
MZ01	Ireland	Kerry	not provided	51.9	-10.4	Drift Net																
MZ01	Ireland	Kerry	not provided	52.1	-9.9																	
MZ03	Ireland	Cork	2012			Angling		2														
MZ03	Ireland	Cork	not provided	51.9	-8.2																	
MZ03	Ireland	Cork	not provided	51.6	-8.9																	
MZ04	Ireland	Waterford	4/9/2012	52.2	-7.1	Gill Net					1											
MZ04	Ireland	Waterford	4/9/2012	52.2	-7.1	Draft Net																
MZ04	Ireland	Waterford	11/8/2010	52.2	-7.0	Draft Net		5														
MZ04	Ireland	Waterford	23/7/2010	52.2	-7.0	Draft Net		1														
MZ04	Ireland	Waterford	11/10/2012	52.2	-7.1	Gill Net			6	2												
MZ04	Ireland	Waterford	11/10/2012	52.2	-7.1	Gill Net																
MZ04	Ireland	Waterford	11/10/2012	52.2	-7.1	Gill Net																
MZ04	Ireland	Waterford	11/10/2012	52.2	-7.1	Draft Net																
MZ04	Ireland	Waterford	11/10/2012	52.2	-7.1	Draft Net																
MZ04	Ireland	Waterford	11/10/2012	52.2	-7.1	Draft Net																
MZ04	Ireland	Waterford	not provided	52.2	-7.0	Drift Net																
MZ04	Ireland	Wexford	not provided	52.2	-6.7																	
MZ05	Ireland	Wicklow	28/2/2012	52.9	-6.0	Draft Net		3	3	4												
MZ05	Ireland	Wicklow	28/2/2012	52.9	-6.0	Draft Net		5														
MZ05	Ireland	Wexford	20/2/2012	52.3	-6.1	Trawl Net		1														

MZ05	Ireland	Wicklow	25/7/2011	52.9	-6.0	Draft Net		20	3	6	7											
MZ05	Ireland	Wicklow	3/6/2011	52.9	-6.0	Draft Net		5														
MZ05	Ireland	Wicklow	3/6/2011	52.9	-6.0	Draft Net		10														
MZ05	Ireland	Wicklow	3/6/2011	52.9	-6.0	Draft Net		36	3	1	1	1										
MZ05	Ireland	Wexford	13/4/2011	52.2	-6.3	Gill Net				2	8											
MZ05	Ireland	Wexford	13/4/2011	52.2	-6.3	Gill Net		3	1	1	9			1								
MZ05	Ireland	Wexford	21/5/2010	52.4	-6.3	Gill Net		2	5		1											
MZ05	Ireland	Wexford	21/5/2010	52.4	-6.3	Gill Net		3	2		1											
MZ05	Ireland	Wicklow	24/6/2010	52.9	-6.0	Draft Net		15														
MZ05	Ireland	Wicklow	24/6/2010	52.9	-6.0	Draft Net		11														
MZ05	Ireland	Wexford	8/4/2010	52.2	-6.3	Gill Net					7											
MZ05	Ireland	Wexford	8/4/2010	52.2	-6.3	Gill Net					6											
MZ05	Ireland	Wexford	8/4/2010	52.2	-6.3	Gill Net					4											
MZ05	Ireland	Wexford	8/4/2010	52.2	-6.3	Gill Net				3	4			1						2		
MZ05	Ireland	Wexford	2/6/2010	52.5	-6.3	Gill Net			14		1											
MZ05	Ireland	Wexford	2/6/2010	52.5	-6.2	Gill Net				2	1											
MZ05	Ireland	Wexford	2/6/2010	52.5	-6.2	Gill Net		4			1											
MZ05	Ireland	Wicklow	20/7/2009	52.9	-6.0	Draft Net		18	6		43											
MZ05	Ireland	Wicklow	25/7/2011	52.9	-6.0	Draft Net			5	5	4											
MZ05	Ireland	Wicklow	25/7/2011	52.9	-6.0	Draft Net			8	6	4											
MZ06	Ireland	Wicklow	24/6/2010	53.0	-6.0	Gill Net																
MZ06	Ireland	Wicklow	29/5/2012	53.0	-6.0	Draft Net		29														
MZ06	Ireland	Dublin	28/2/2012	53.4	-6.1	Gill Net		6							1							
MZ06	Ireland	Dublin	23/2/2012	53.4	-6.1	Gill Net		1														
MZ06	Ireland	Dublin	23/2/2012	53.4	-6.1	Gill Net																
MZ06	Ireland	Dublin	23/2/2012	53.4	-6.1	Gill Net		1														
MZ06	Ireland	Dublin	23/2/2012	53.4	-6.1	Gill Net		2														
MZ06	Ireland	Dublin	23/2/2012	53.4	-6.1	Gill Net																
MZ06	Ireland	Wicklow	13/3/2012	53.0	-6.0	Draft Net		21	2	4												
MZ06	Ireland	Wicklow	13/3/2012	53.0	-6.0	Draft Net		29														
MZ06	Ireland	Wicklow	13/3/2012	53.0	-6.0	Draft Net		21														
MZ06	Ireland	Dublin	1/6/2011	53.4	-6.1	Gill Net		3	1													
MZ06	Ireland	Dublin	1/6/2011	53.4	-6.1	Gill Net																

MZ06	Ireland	Dublin	2/6/2011	53.4	-6.1	Gill Net		2	1	3							1					
MZ06	Ireland	Dublin	2/6/2011	53.4	-6.1	Gill Net																
MZ06	Ireland	Dublin	20/5/2011	53.4	-6.1	Gill Net		2														
MZ06	Ireland	Dublin	20/5/2011	53.4	-6.1	Gill Net		1														
MZ06	Ireland	Wicklow	19/4/2011	53.1	-6.0	Draft Net		5	3		2											
MZ06	Ireland	Wicklow	19/4/2011	53.1	-6.0	Draft Net		16	3													
MZ06	Ireland	Wicklow	19/4/2011	53.1	-6.0	Draft Net		1	2													
MZ06	Ireland	Dublin	5/4/2011	53.4	-6.1	Gill Net			2		1											
MZ06	Ireland	Dublin	5/4/2011	53.4	-6.1	Gill Net		2	2													
MZ06	Ireland	Dublin	5/4/2011	53.4	-6.1	Gill Net		1	1													
MZ06	Ireland	Dublin	22/3/2011	53.4	-6.1	Gill Net		4										1				
MZ06	Ireland	Dublin	22/3/2011	53.4	-6.1	Gill Net		2	1	2												
MZ06	Ireland	Dublin	22/3/2011	53.4	-6.1	Gill Net		2										1				
MZ06	Ireland	Dublin	22/3/2011	53.4	-6.1	Gill Net				2												
MZ06	Ireland	Dublin	22/3/2011	53.4	-6.1	Gill Net		2										1				
MZ06	Ireland	Dublin	24/3/2011	53.4	-6.1	Gill Net		3														
MZ06	Ireland	Wicklow	16/3/2011	53.1	-6.0	Draft Net		12		1												
MZ06	Ireland	Wicklow	16/3/2011	53.1	-6.0	Draft Net				1												
MZ06	Ireland	Wicklow	16/3/2011	53.1	-6.0	Draft Net		4														
MZ06	Ireland	Wicklow	16/3/2011	53.1	-6.0	Draft Net		6														
MZ06	Ireland	Wicklow	2/3/2011	53.0	-6.0	Draft Net		3														
MZ06	Ireland	Wicklow	2/3/2011	53.0	-6.0	Draft Net		2														
MZ06	Ireland	Wicklow	2/3/2011	53.0	-6.0	Draft Net		2														
MZ06	Ireland	Wicklow	1/6/2010	53.1	-6.0	Draft Net			3													
MZ06	Ireland	Wicklow	1/6/2010	53.0	-6.0	Draft Net		1			1											
MZ06	Ireland	Wicklow	21/5/2010	53.1	-6.0	Draft Net		6														
MZ06	Ireland	Wicklow	21/5/2010	53.0	-6.0	Draft Net		12	1													
MZ06	Ireland	Wicklow	21/5/2010	53.0	-6.0	Gill Net		2	1		1											
MZ06	Ireland	Dublin	13/4/2010	53.4	-6.1	Gill Net		3														
MZ06	Ireland		8/8/2011	53.3	-6.0	Trawl Net							5		10	2	12		70			
MZ06	Ireland		8/8/2011	53.4	-6.0	Trawl Net							1			6	6		3			
MZ06	Ireland	Dublin	not provided	53.5	-6.2																	
MZ06	Ireland	Dublin	not provided	53.4	-6.1																	

MZ06	Ireland	Louth	not provided	54.0	-6.3																	
MZ07	Ireland	Meath	3/9/2010	53.7	-6.3	Draft Net		7														
MZ07	Ireland	Meath	21/9/2010	53.7	-6.3	Draft Net		2														
MZ07	Ireland	Meath	16/9/2010	53.7	-6.3	Draft Net		1														
MZ07	Ireland	Meath	7/9/2010	53.7	-6.3	Draft Net		13														
MZ07	Ireland	Meath	3/8/2010	53.7	-6.3	Draft Net		8														
MZ07	Ireland	Meath	9/8/2010	53.7	-6.3	Draft Net		4														
MZ07	Ireland	Meath	0/8/2012	53.7	-6.3	Draft Net		11														
MZ07	Ireland	Louth	22/3/2011	54.0	-6.3	Drift Net		1														
MZ07	Ireland	Louth	22/3/2011	54.0	-6.3	Drift Net		5										2				
MZ07	Ireland	Louth	3/6/2011	54.0	-6.3	Drift Net		1	48		10							2				
MZ07	Ireland	Louth	14/5/2011	54.0	-6.3	Drift Net							1									
MZ07	Ireland		8/8/2011	53.5	-6.0	Trawl Net																
MZ07	Ireland		9/8/2011	53.6	-6.1	Trawl Net											6					
MZ07	Ireland		9/8/2011	53.7	-6.2	Trawl Net						1					6					
MZ07	Ireland		9/8/2011	53.8	-6.2	Trawl Net									30							
MZ07	Ireland	Louth	14/8/2011	54.0	-6.3	Trawl Net		5								40	3					4
MZ07	Ireland	Meath	14/8/2011	53.8	-6.2	Trawl Net		1														
MZ07	Ireland	Meath	14/8/2011	53.7	-6.2	Trawl Net		1														
MZ07	Ireland	Louth	not provided	53.7	-6.3																	
MZ07	Ireland	Louth	not provided	53.7	-6.3																	
MZ07	Ireland	Louth	not provided	53.7	-6.3																	
MZ07	Ireland	Louth	not provided	53.7	-6.3																	
MZ08	N. Ireland	Down	30/8/2012	54.0	-6.1	Draft Net		16					1									
MZ08	N. Ireland	Down	9/8/2011	54.0	-6.1	Draft Net		22				1										
MZ08	N. Ireland	Down	4/8/2011	54.1	-6.0	Draft Net		8														
MZ08	N. Ireland		9/8/2011	54.0	-6.0	Trawl Net																
MZ08	N. Ireland		9/8/2011	54.2	-5.8	Trawl Net																
MZ08	N. Ireland	Down	not provided	54.3	-5.5																	
MZ08	N. Ireland	Down	not provided	54.4	-5.6																	
MZ08	N. Ireland	Down	not provided	54.2	-5.9																	
MZ08	N. Ireland	Derry	not provided	55.2	-6.8																	
MZ08	N. Ireland	Derry	not provided	55.2	-6.8																	

MZ08	N. Ireland	Down	29/9/2012	54.0	-6.1	Draft Net		8					1									
MZ08	N. Ireland	Down	21/9/2012	54.0	-6.1	Draft Net		14					1									
MZ09	Scotland	Dumfries & Galloway	15/6/2011	54.9	-4.2	Gill Net																
MZ09	Scotland	Dumfries & Galloway	16/6/2011	54.9	-4.2	Gill Net		3														
MZ09	Scotland	Dumfries & Galloway	15/7/2011	54.7	-4.5	Gill Net																
MZ09	Scotland	Dumfries & Galloway	15/7/2011	54.8	-4.2	Gill Net		1														
MZ09	Scotland	Dumfries & Galloway	2/8/2011	54.9	-4.8	Gill Net		3														
MZ09	Scotland	Dumfries & Galloway	2/8/2011	54.9	-4.8	Gill Net																
MZ09	Scotland	Dumfries & Galloway	4/8/2011	54.9	-4.8	Gill Net		1														
MZ09	Scotland	Dumfries & Galloway	4/8/2011	54.9	-4.8	Gill Net																
MZ09	Scotland	Dumfries & Galloway	13/10/2011	54.9	-4.8	Gill Net		2														
MZ09	Scotland	Dumfries & Galloway	1/10/2011	54.7	-4.5	Gill Net		1														
MZ09	Scotland	Dumfries & Galloway	2/8/2012	54.9	-4.8	Gill Net		2														
MZ09	Scotland	Dumfries & Galloway	2/8/2012	54.9	-4.8	Gill Net																
MZ09	Scotland	Dumfries & Galloway	2/8/2012	54.9	-4.8	Gill Net		1														
MZ09	Scotland	Dumfries & Galloway	not provided	54.9	-4.4	Unknown																
MZ09	Scotland	Dumfries & Galloway	not provided	54.8	-4.2	Stake Net																
MZ09	Scotland	Dumfries & Galloway	not provided	54.7	-4.5	Coastal Net																
MZ09	Scotland	Dumfries & Galloway	not provided	54.9	-4.4																	
MZ09	Scotland	Dumfries & Galloway	not provided	54.9	-4.4																	
MZ09	Scotland	Dumfries & Galloway	not provided	54.9	-4.4																	
MZ09	Scotland	Dumfries & Galloway	not provided	54.9	-4.4																	
MZ09	Scotland	Dumfries & Galloway	not provided	54.8	-3.8																	
MZ09	Scotland	Dumfries & Galloway	not provided	54.8	-5.0																	
MZ10	Scotland	Dumfries+ Galloway	9/3/2011	55.0	-3.6	Gill Net																
MZ10	Scotland	Dumfries+ Galloway	10/3/2011	55.0	-3.6	Gill Net				1												
MZ10	Scotland	Dumfries+ Galloway	10/3/2011	55.0	-3.6	Gill Net																
MZ10	Scotland	Dumfries & Galloway	10/3/2011	55.0	-3.6	Gill Net																
MZ10	Scotland	Dumfries & Galloway	not provided	55.0	-3.2	Stake Net																
MZ10	Scotland	Dumfries & Galloway	not provided	55.0	-3.2	Haaf Net																
MZ10	Scotland	Dumfries & Galloway	not provided	55.0	-3.2	Haaf Net																
MZ10	Scotland	Dumfries & Galloway	not provided	54.9	-3.2	Haaf Net																
MZ10	Scotland	Dumfries & Galloway	not provided	55.0	-3.2	Haaf Net																

MZ10	Scotland	Dumfries & Galloway	not provided	55.0	-3.2	Haaf Net															
MZ10	Scotland	Dumfries & Galloway	not provided	55.0	-3.1	Haaf Net															
MZ10	Scotland	Dumfries & Galloway	not provided	55.0	-3.1	Stake Net															
MZ10	Scotland	Dumfries & Galloway	not provided	55.0	-3.3	Gill Net															
MZ10	Scotland	Dumfries & Galloway	not provided	54.9	-3.7	Stake Net															
MZ10	Scotland	Dumfries & Galloway	15/3/2011	54.9	-3.6	Gill Net															
MZ10	Scotland	Dumfries & Galloway	15/3/2011	55.0	-3.6	Gill Net															
MZ10	Scotland	Dumfries & Galloway	22/4/2011	54.9	-3.6	Gill Net			4	6											
MZ10	Scotland	Dumfries & Galloway	28/4/2011	54.9	-3.6	Gill Net															
MZ10	Scotland	Dumfries & Galloway	28/4/2011	54.9	-3.5	Gill Net					1		1								
MZ10	Scotland	Dumfries & Galloway	28/4/2011	54.9	-3.6	Gill Net		1		2			1	1							
MZ10	Scotland	Dumfries & Galloway	4/6/2011	55.0	-3.6	Gill Net															
MZ10	Scotland	Dumfries & Galloway	4/6/2011	55.0	-3.6	Gill Net															
MZ10	Scotland	Dumfries & Galloway	4/6/2011	55.0	-3.6	Gill Net															
MZ10	Scotland	Dumfries & Galloway	7/6/2011	54.9	-3.6	Gill Net															
MZ10	Scotland	Dumfries & Galloway	7/6/2011	54.9	-3.5	Gill Net															
MZ10	Scotland	Dumfries & Galloway	7/6/2011	54.9	-3.5	Trammel Net															
MZ10	Scotland	Dumfries & Galloway	7/6/2011	55.0	-3.5	Gill Net															
MZ10	Scotland	Dumfries & Galloway	7/6/2011	55.0	-3.6	Gill Net															
MZ10	Scotland	Dumfries & Galloway	7/6/2011	55.0	-3.6	Gill Net															
MZ10	Scotland	Dumfries & Galloway	24/7/2011	54.9	-3.5	Gill Net				5											
MZ10	Scotland	Dumfries & Galloway	24/7/2011	55.0	-3.5	Gill Net				4											
MZ10	Scotland	Dumfries & Galloway	24/7/2011	55.0	-3.6	Trammel Net				6		1		1							
MZ10	Scotland	Dumfries & Galloway	24/7/2011	55.0	-3.6	Trammel Net				5		2									
MZ10	Scotland	Dumfries & Galloway	16/4/2012	55.0	-3.6	Trammel Net		2		5											
MZ10	Scotland	Dumfries & Galloway	21/5/2012	55.0	-3.6	Trammel Net		2		3											
MZ10	Scotland	Dumfries & Galloway	27/5/2012	55.0	-3.6	Haaf Net															
MZ10	Scotland	Dumfries & Galloway	not provided	54.9	-3.7	Gill Net															
MZ11	England	Cumbria	not provided	54.4	-3.5	Gill Net															
MZ11	England	Cumbria	not provided	54.3	-3.4	Gill Net															
MZ11	England	Cumbria	not provided	54.4	-3.5	Gill Net															
MZ11	England	Cumbria	not provided	54.5	-3.6																
MZ12	England	Lancashire	9/5/2011	51.6	-3.1	Gill Net															

MZ12	England	Lancashire	9/5/2011	53.6	-3.1	Seine Net				3				42						1		
MZ12	England	Lancashire	9/5/2011	53.6	-3.1	Seine Net				2				2						1		
MZ12	England	Lancashire	10/5/2011	53.7	-3.0	Gill Net			1	4	7											
MZ12	England	Lancashire	10/5/2011	53.8	-3.1	Gill Net				3	2											
MZ12	England	Lancashire	10/5/2011	53.7	-3.0	Gill Net				8												
MZ12	England	Lancashire	10/5/2011	53.7	-3.0	Gill Net			1	8												
MZ12	England	Lancashire	10/5/2011	53.7	-3.1	Gill Net				2	1											
MZ12	England	Lancashire	10/5/2011	53.7	-3.1	Gill Net																
MZ12	England	Lancashire	17/5/2011	53.9	-3.1	Gill Net		1														
MZ12	England	Lancashire	17/5/2011	53.6	-3.1	Gill Net			1	5	2							1				
MZ12	England	Lancashire	26/7/2011	53.7	-3.1	Gill Net				69	26		1						1		14	
MZ12	England	Lancashire	26/7/2011	53.7	-3.0	Gill Net				24	5										2	
MZ12	England	Lancashire	27/7/2011	53.7	-3.0	Gill Net		1		40	13								2		3	
MZ12	England	Lancashire	27/7/2011	53.7	-3.0	Gill Net				60	9			3					1		16	
MZ12	England	Lancashire	2/8/2011	53.6	-3.1	Gill Net								2								
MZ12	England	Lancashire	2/8/2011	53.9	-3.1	Gill Net																
MZ12	England	Lancashire	not provided	54.0	-2.9	Fish Kill																
MZ12	England	Lancashire	not provided	53.7	-3.1	Gill Net																
MZ13	Wales	Gwynedd	9/8/2010	53.3	-3.9	Gill Net							4									
MZ13	Wales	Gwynedd	9/8/2010	53.3	-3.9	Gill Net																
MZ13	Wales	Gwynedd	9/8/2010	53.3	-4.0	Gill Net																
MZ13	Wales	Gwynedd	9/8/2010	53.3	-4.0	Gill Net							4									
MZ13	Wales	Anglesey	14/2/2011	53.4	-4.3	Gill Net																
MZ13	Wales	Anglesey	14/2/2011	53.4	-4.3	Gill Net																
MZ13	Wales	Anglesey	14/2/2011	53.4	-4.3	Gill Net																
MZ13	Wales	Anglesey	14/2/2011	53.4	-4.3	Gill Net																
MZ13	Wales	Anglesey	14/2/2011	53.4	-4.3	Gill Net																
MZ13	Wales	Anglesey	14/2/2011	53.4	-4.2	Gill Net																
MZ13	Wales	Anglesey	17/2/2011	53.3	-4.2	Gill Net																
MZ13	Wales	Gwynedd	29/3/2011	53.2	-3.6	Gill Net																
MZ13	Wales	Anglesey	20/4/2011	53.4	-4.3	Gill Net				1												
MZ13	Wales	Clwyd	4/5/2011	53.3	-3.6	Gill Net																
MZ13	Wales	Anglesey	6/5/2011	53.2	-4.2	Gill Net							3					1				

MZ13	Wales	Anglesey	1/6/2011	53.4	-4.3	Gill Net			1								2	1				
MZ13	Wales	Conwy	3/6/2011	53.3	-3.6	Gill Net																
MZ13	Wales	Conwy	3/6/2011	53.3	-3.6	Seine Net				10												
MZ13	Wales	Conwy	3/6/2011	53.3	-3.6	Seine Net																
MZ13	Wales	Conwy	3/6/2011	53.3	-3.6	Seine Net																
MZ13	Wales	Gwynedd	4/7/2011	53.3	-3.9	Gill Net																
MZ13	Wales	Anglesey	8/7/2011	53.4	-4.3	Gill Net		1														
MZ13	Wales	Anglesey	12/10/2011	53.4	-4.3	Gill Net							2		1			4				
MZ13	Wales	Gwynedd	12/10/2011	53.3	-3.9	Gill Net												1				
MZ13	Wales	Gwynedd	22/10/2011	53.1	-3.9	Trawl Net		1														
MZ13	Wales	Anglesey	not provided	53.4	-4.3																	
MZ13	Wales	Anglesey	not provided	53.4	-4.2																	
MZ13	Wales	Flint	not provided	53.4	-3.3																	
MZ13	Wales	Conwy	not provided	53.3	-3.9																	
MZ14	Wales	Gwynedd	11/8/2010	53.2	-4.3	Gill Net																
MZ14	Wales	Gwynedd	11/8/2010	53.2	-4.3	Gill Net																
MZ14	Wales	Gwynedd	11/8/2010	53.1	-4.3	Gill Net																
MZ14	Wales	Gwynedd	31/8/2010	53.1	-4.3	Seine Net																
MZ14	Wales	Gwynedd	31/8/2010	53.1	-4.3	Seine Net																
MZ14	Wales	Gwynedd	31/8/2010	53.1	-4.3	Seine Net																
MZ14	Wales	Gwynedd	28/1/2011	53.0	-4.4	Gill Net																
MZ14	Wales	Gwynedd	28/1/2011	53.0	-4.4	Gill Net																
MZ14	Wales	Gwynedd	28/1/2011	53.1	-4.4	Gill Net																
MZ14	Wales	Gwynedd	28/1/2011	53.0	-4.4	Gill Net																
MZ14	Wales	Gwynedd	28/1/2011	53.1	-4.5	Gill Net																
MZ14	Wales	Gwynedd	28/1/2011	53.2	-4.5	Gill Net																
MZ14	Wales	Gwynedd	28/3/2011	53.1	-4.2	Gill Net																
MZ14	Wales	Gwynedd	7/4/2011	53.1	-4.3	Seine Net		1														
MZ14	Wales	Gwynedd	7/4/2011	53.1	-4.3	Seine Net																
MZ14	Wales	Gwynedd	7/4/2011	53.1	-4.3	Seine Net			1													
MZ14	Wales	Gwynedd	7/4/2011	53.1	-4.3	Seine Net								1								
MZ14	Wales	Gwynedd	7/4/2011	53.1	-4.3	Seine Net			2													
MZ14	Wales	Gwynedd	7/4/2011	53.1	-4.3	Seine Net			1													

MZ14	Wales	Anglesey	8/4/2011	53.4	-4.3	Seine Net				1				1								
MZ14	Wales	Anglesey	8/4/2011	53.4	-4.3	Seine Net				1				1								
MZ14	Wales	Anglesey	8/4/2011	53.4	-4.3	Seine Net				1				3								
MZ14	Wales	Anglesey	8/4/2011	53.4	-4.3	Seine Net				2				3								
MZ14	Wales	Gwynedd	14/4/2011	53.1	-4.3	Gill Net		2	4		4											
MZ14	Wales	Anglesey	18/4/2011	53.2	-4.5	Gill Net		1							1		6					
MZ14	Wales	Anglesey	18/4/2011	53.2	-4.5	Seine Net		1		5										1		
MZ14	Wales	Anglesey	18/4/2011	53.3	-4.3	Seine Net		5														
MZ14	Wales	Anglesey	18/4/2011	53.2	-4.5	Seine Net				7	1									3		
MZ14	Wales	Anglesey	18/4/2011	53.2	-4.5	Seine Net				3										6		
MZ14	Wales	Gwynedd	27/4/2011	52.9	-4.5	Gill Net							11							1		
MZ14	Wales	Gwynedd	2/6/2011	53.1	-4.3	Gill Net			2		1		4									
MZ14	Wales	Gwynedd	2/6/2011	53.1	-4.3	Seine Net					2			1						6		
MZ14	Wales	Gwynedd	2/6/2011	53.1	-4.3	Seine Net				2	6			6						3		
MZ14	Wales	Gwynedd	2/6/2011	53.1	-4.3	Seine Net				1					5					5		
MZ14	Wales	Anglesey	1/8/2011	53.2	-4.5	Seine Net		1		3				1						1		1
MZ14	Wales	Anglesey	1/8/2011	53.2	-4.5	Gill Net			1													
MZ14	Wales	Anglesey	1/8/2011	53.2	-4.5	Seine Net				2				1	1							1
MZ14	Wales	Anglesey	1/8/2011	53.2	-4.5	Seine Net				5	1											
MZ14	Wales	Gwynedd	5/8/2011	52.8	-4.7	Gill Net			1		1											
MZ14	Wales	Gwynedd	1/9/2011	53.1	-4.3	Gill Net		1			1			1			4					
MZ14	Wales	Gwynedd	1/9/2011	53.0	-4.3	Gill Net			1	1							12					
MZ14	Wales	Gwynedd	15/9/2011	53.1	-4.3	Gill Net																
MZ14	Wales	Anglesey	15/9/2011	53.2	-4.5	Gill Net																
MZ14	Wales	Gwynedd	19/10/2011	53.1	-4.3	Gill Net		2			4											
MZ14	Wales	Gwynedd	27/10/2011	53.1	-4.3	Gill Net			4		1		3									
MZ14	Wales	Gwynedd	4/11/2011	53.1	-4.3	Gill Net		2			4											
MZ14	Wales	Gwynedd	4/11/2011	53.1	-4.3	Seine Net		1			4			16								
MZ14	Wales	Gwynedd	4/11/2011	53.1	-4.3	Seine Net		1			1			20								
MZ14	Wales	Anglesey	7/11/2011	53.2	-4.5	Gill Net							1		1			28				
MZ14	Wales	Anglesey	7/11/2011	53.2	-4.5	Seine Net						1		2								
MZ14	Wales	Anglesey	7/11/2011	53.2	-4.5	Seine Net	2			1												
MZ14	Wales	Anglesey	7/11/2011	53.2	-4.5	Seine Net												10				

MZ14	Wales	Anglesey	7/11/2011	53.2	-4.5	Seine Net				2												
MZ14	Wales	Gwynedd	8/11/2011	53.1	-4.3	Gill Net						1						1				
MZ14	Wales	Gwynedd	8/11/2011	53.1	-4.3	Gill Net			1		1											
MZ14	Wales	Gwynedd	15/11/2011	53.1	-4.3	Gill Net				2	6											
MZ14	Wales	Gwynedd	15/11/2011	53.1	-4.3	Seine Net				2				3								
MZ14	Wales	Gwynedd	15/11/2011	53.1	-4.3	Seine Net				7				7								
MZ14	Wales	Gwynedd	12/1/2012	53.1	-4.3	Gill Net																
MZ14	Wales	Gwynedd	12/1/2012	53.1	-4.3	Gill Net																
MZ14	Wales	Gwynedd	12/1/2012	53.1	-4.3	Seine Net			1			1		2	8							
MZ14	Wales	Gwynedd	13/1/2012	53.1	-4.3	Gill Net		1			1							1				
MZ14	Wales	Gwynedd	31/1/2012	53.1	-4.3	Gill Net			6			1										
MZ14	Wales	Gwynedd	31/1/2012	53.1	-4.3	Gill Net			16													
MZ14	Wales	Gwynedd	31/1/2012	53.1	-4.3	Seine Net								2								
MZ14	Wales	Anglesey	12/3/2012	53.2	-4.5	Gill Net		1				1			2							
MZ14	Wales	Gwynedd	13/3/2012	53.1	-4.3	Seine Net						2		4						2		
MZ14	Wales	Anglesey	12/3/2012	53.2	-4.5	Seine Net			5	1				1								
MZ14	Wales	Anglesey	12/3/2012	53.2	-4.5	Seine Net			1	3				3		1						
MZ14	Wales	Anglesey	12/3/2012	53.2	-4.5	Seine Net							1									
MZ14	Wales	Gwynedd	13/3/2012	53.1	-4.3	Seine Net		1												4		
MZ14	Wales	Gwynedd	13/3/2012	53.1	-4.3	Seine Net								2								
MZ14	Wales	Gwynedd	13/3/2012	53.1	-4.3	Seine Net								2						1		
MZ14	Wales	Gwynedd	13/3/2012	53.1	-4.3	Seine Net			2	1				1								
MZ14	Wales	Gwynedd	13/3/2012	53.1	-4.3	Seine Net			10		1		1									
MZ14	Wales	Gwynedd	14/3/2012	53.1	-4.3	Gill Net			26													
MZ14	Wales	Gwynedd	14/3/2012	53.1	-4.3	Gill Net			18		1											
MZ14	Wales	Gwynedd	14/3/2012	53.1	-4.3	Seine Net		1	1					1								
MZ14	Wales	Gwynedd	14/3/2012	53.1	-4.3	Seine Net				1	1			1	1							
MZ14	Wales	Gwynedd	27/3/2012	53.1	-4.3	Gill Net			2													
MZ14	Wales	Gwynedd	8/5/2012	53.1	-4.3	Gill Net		2	3		3											
MZ14	Wales	Gwynedd	8/5/2012	53.1	-4.3	Gill Net			1		2		2									
MZ14	Wales	Anglesey	22/5/2012	53.2	-4.5	Gill Net		2	1		3						1					
MZ14	Wales	Anglesey	22/5/2012	53.2	-4.5	Seine Net				4				1						1		
MZ14	Wales	Anglesey	22/5/2012	53.2	-4.5	Seine Net					1								1	2		

MZ14	Wales	Anglesey	22/5/2012	53.2	-4.5	Seine Net					2			2						2		
MZ14	Wales	Anglesey	22/5/2012	53.2	-4.5	Seine Net			2	2				1						1		
MZ14	Wales	Anglesey	5/7/2012	53.2	-4.5	Gill Net			1	1	1		1				2					
MZ14	Wales	Anglesey	5/7/2012	53.2	-4.5	Seine Net				3										4		
MZ14	Wales	Anglesey	5/7/2012	53.2	-4.5	Seine Net					1									2		
MZ14	Wales	Anglesey	5/7/2012	53.2	-4.5	Seine Net				2				1						3		
MZ14	Wales	Gwynedd	9/7/2012	53.1	-4.3	Seine Net																
MZ14	Wales	Gwynedd	9/7/2012	53.1	-4.3	Seine Net																
MZ14	Wales	Gwynedd	9/7/2012	53.1	-4.3	Seine Net																
MZ14	Wales	Gwynedd	9/7/2012	53.1	-4.3	Seine Net			1											1		
MZ14	Wales	Gwynedd	9/7/2012	53.1	-4.3	Seine Net	20															
MZ14	Wales	Anglesey	2/9/2012	53.2	-4.5	Gill Net			1													
MZ14	Wales	Anglesey	2/9/2012	53.2	-4.5	Gill Net																
MZ14	Wales	Gwynedd	not provided	53.1	-4.3	Seine Net																
MZ14	Wales	Gwynedd	not provided	53.1	-4.3	Fish Kill																
MZ14	Wales	Gwynedd	not provided	52.8	-4.7	Gill Net																
MZ14	Wales	Gwynedd	22/9/2012	53.1	-4.3	Gill Net		1			4		2									
MZ14	Wales	Gwynedd	28/7/2012	53.1	-4.3	Gill Net		2														
MZ15	Wales	Ceredigion	15/11/2010	52.5	-4.1	Seine Net												1				
MZ15	Wales	Gwynedd	6/6/2011	52.9	-4.2	Gill Net																
MZ15	Wales	Gwynedd	6/6/2011	52.9	-4.2	Seine Net				3										1		
MZ15	Wales	Gwynedd	6/6/2011	52.9	-4.2	Seine Net																
MZ15	Wales	Ceredigion	14/7/2011	52.5	-4.1	Gill Net					1						1					
MZ15	Wales	Ceredigion	23/8/2011	52.5	-4.1	Gill Net			9		4						2	1				
MZ15	Wales	Gwynedd	not provided	52.8	-4.7	Gill Net																
MZ16	Wales	Cardiganshire	8/4/2011	52.0	-5.0	Gill Net							8		6			3				
MZ16	Wales	Cardiganshire	8/4/2011	52.0	-4.9	Gill Net							6		4			3				
MZ16	Wales	Cardiganshire	9/4/2011	52.0	-4.8	Gill Net																
MZ16	Wales	Cardiganshire	9/4/2011	52.1	-4.7	Gill Net																
MZ16	Wales	Pembrokeshire	14/6/2011	52.0	-4.8	Seine Net		1														
MZ16	Wales	Cardiganshire	22/10/2012			Trawl Net																
MZ16	Wales	Cardiganshire	23/10/2012	52.4	-4.2	Trawl Net											1					
MZ16	Wales	Cardiganshire	30/10/2012	52.4	-4.1	Trawl Net	1															

MZ16	Wales	Ceredigion	not provided	52.4	-4.1	Unknown																
MZ16	Wales	Pembrokeshire	not provided	52.1	-4.8	Gill Net																
MZ16	Wales	Ceredigion	not provided	52.1	-4.7	Gill Net																
MZ16	Wales	Pembrokeshire	not provided	51.9	-5.2	Not Recorded																
MZ16	Wales	Pembrokeshire	not provided	52.0	-5.1	Not Recorded																
MZ17	Wales	Pembrokeshire	10/5/2011	51.7	-5.0	Seine Net		1														
MZ17	Wales	Pembrokeshire	3/9/2012	51.6	-5.2	Trawl Net																
MZ17	Wales	Pembrokeshire	4/9/2012	51.6	-5.2	Trawl Net	100															
MZ17	Wales	Pembrokeshire	6/9/2012	51.6	-5.2	Trawl Net																
MZ18	Wales	Carmarthenshire	27/3/2011	51.7	-4.5	Gill Net																
MZ18	Wales	Carmarthenshire	27/3/2011	51.7	-4.5	Gill Net																
MZ18	Wales	Carmarthenshire	27/3/2011	51.7	-4.5	Gill Net																
MZ18	Wales	Carmarthenshire	27/3/2011	51.7	-4.5	Gill Net																
MZ18	Wales	West Glamorgan	28/5/2011	51.6	-3.9	Gill Net			2	1			4									
MZ18	Wales	West Glamorgan	28/5/2011	51.6	-3.9	Gill Net			1				2									
MZ18	Wales	West Glamorgan	1/4/2011	51.7	-4.3	Gill Net			4													
MZ18	Wales	West Glamorgan	1/4/2011	51.7	-4.3	Gill Net			2	1												
MZ18	Wales	Carmarthenshire	5/6/2011	51.7	-4.6	Gill Net		3														
MZ18	Wales	Carmarthenshire	16/6/2011	51.7	-4.3	Gill Net		1	19	1	11											
MZ18	Wales	Carmarthenshire	7/9/2012			Trawl Net																
MZ18	Wales	Carmarthenshire	8/9/2012	51.6	-4.8	Trawl Net	1000															
MZ18	Wales	Carmarthenshire	8/9/2012	51.6	-4.7	Trawl Net	500										10					
MZ18	Wales	Carmarthenshire	21/9/2012	51.6	-4.7	Trawl Net																
MZ18	Wales	Carmarthenshire	21/9/2012	51.6	-4.7	Trawl Net	5										6					
MZ18	Wales	Glamorgan	not provided	51.6	-4.0	Unknown																
MZ22	Isle of Man		10/8/2011	54.6	-4.3	Trawl Net										2		4				
MZ22	Scotland		10/8/2011	54.6	-5.1	Trawl Net																
MZ22	Scotland		10/8/2011	54.5	-4.7	Trawl Net										10						
MZ23	Isle of Man	Isle of Man	30/6/2010	54.4	-4.4	Gill Net																
MZ23	Isle of Man	Isle of Man	30/6/2010	54.4	-4.4	Gill Net																
MZ23	Isle of Man	Isle of Man	30/6/2010	54.4	-4.4	Gill Net																
MZ23	Isle of Man	Isle of Man	2/8/2010	54.4	-4.4	Gill Net		1	2													

MZ23	Isle of Man	Isle of Man	2/8/2010	54.4	-4.4	Gill Net		1	2				1		1							
MZ23	Isle of Man	Isle of Man	2/8/2010	54.3	-4.4	Gill Net		1	1				2		1			1				
MZ23	Isle of Man	Isle of Man	18/8/2010	54.4	-4.4	Gill Net		2	2		2		1									
MZ23	Isle of Man	Isle of Man	18/8/2010	54.4	-4.4	Gill Net		1		1			3		2							
MZ23	Isle of Man	Isle of Man	18/8/2010	54.3	-4.4	Gill Net		3	1				4		1		3					
MZ23	Isle of Man	Isle of Man	1/9/2010	54.4	-4.4	Gill Net		2					4				1					
MZ23	Isle of Man	Isle of Man	1/9/2010	54.4	-4.4	Gill Net			4		1		2									
MZ23	Isle of Man	Isle of Man	1/9/2010	54.4	-4.4	Gill Net		2	1						2		3					
MZ23	Isle of Man	Isle of Man	27/9/2010	54.3	-4.6	Gill Net					1		2									
MZ23	Isle of Man	Isle of Man	27/9/2010	54.3	-4.6	Gill Net			2	1	2											
MZ23	Isle of Man	Isle of Man	27/9/2010	54.3	-4.6	Gill Net					1		1									
MZ23	Isle of Man		11/8/2011	54.4	-4.5	Trawl Net										25		20				
MZ23	Isle of Man		11/8/2011	54.4	-4.4	Trawl Net									6	15		6				
MZ23	Isle of Man		11/8/2011	54.5	-4.4	Trawl Net									6		1					
MZ23	Isle of Man		11/8/2011	54.5	-4.4	Trawl Net									6		1					
MZ23	Isle of Man	Isle of Man	21/8/2011	54.4	-4.4	Gill Net		2	1													
MZ23	Isle of Man	Isle of Man	21/8/2011	54.4	-4.4	Gill Net		6			1	1	1									
MZ23	Isle of Man	Isle of Man	21/8/2011	54.4	-4.4	Gill Net		1	1		3		1									
MZ23	Isle of Man	Isle of Man	7/8/2011	54.4	-4.4	Gill Net		1														
MZ23	Isle of Man	Isle of Man	7/8/2011	54.4	-4.4	Gill Net		2	3													
MZ23	Isle of Man	Isle of Man	7/8/2011	54.4	-4.4	Gill Net		1	3						3		1					
MZ23	Isle of Man	Isle of Man	23/7/2011	54.4	-4.4	Gill Net		4	4		2											
MZ23	Isle of Man	Isle of Man	23/7/2011	54.4	-4.4	Gill Net		4	1													
MZ23	Isle of Man	Isle of Man	23/7/2011	54.4	-4.4	Gill Net		1	5		2											
MZ23	Isle of Man	Isle of Man	23/4/2011	54.4	-4.4	Gill Net							6									
MZ23	Isle of Man	Isle of Man	23/4/2011	54.4	-4.4	Gill Net			1				5		1							
MZ23	Isle of Man	Isle of Man	23/4/2011	54.4	-4.4	Gill Net			1				1									
MZ23	Isle of Man	Isle of Man	9/4/2011	54.3	-4.6	Gill Net							32									
MZ23	Isle of Man	Isle of Man	9/4/2011	54.3	-4.6	Gill Net		1					40									
MZ23	Isle of Man	Isle of Man	9/4/2011	54.3	-4.6	Gill Net		1					18									
MZ23	Isle of Man	Isle of Man	28/3/2012	54.4	-4.4	Gill Net		1	58				1									
MZ23	Isle of Man	Isle of Man	28/3/2012	54.4	-4.4	Gill Net			58													
MZ23	Isle of Man	Isle of Man	28/3/2012	54.4	-4.4	Gill Net		4	32													

MZ23	Isle of Man	Isle of Man	12/6/2012	54.4	-4.4	Gill Net		7														
MZ23	Isle of Man	Isle of Man	12/6/2012	54.4	-4.4	Gill Net							4									
MZ23	Isle of Man	Isle of Man	12/6/2012	54.4	-4.4	Gill Net											1					
MZ23	Isle of Man	Isle of Man	26/7/2012	54.4	-4.4	Gill Net		1	1		1		1									
MZ23	Isle of Man	Isle of Man	26/7/2012	54.4	-4.4	Gill Net			3		1		2									
MZ23	Isle of Man	Isle of Man	26/7/2012	54.4	-4.4	Gill Net		1			1		3				1					
MZ23	Isle of Man	Isle of Man	22/6/2010	54.4	-4.4	Gill Net					2											
MZ29	England		13/8/2011	54.0	-3.4	Trawl Net		3						1								2
MZ29	England		13/8/2011	53.9	-3.6	Trawl Net		1									3					1
MZ29	England		13/8/2011	54.0	-3.6	Trawl Net		12									3	2				4
MZ30	England		12/8/2011	54.7	-4.1	Trawl Net		16							6							
MZ30	England		12/8/2011	54.7	-3.9	Trawl Net		13														4
MZ30	Scotland		12/8/2011	54.7	-4.2	Trawl Net		10							1	5		1	2			
MZ30	Scotland		12/8/2011	54.7	-4.0	Trawl Net		8								5						3

Section 3.13 Protocols for fish carcass sampling

The fish sampling protocol is based primarily on the SALSEA MERGE (2011) template. Follow the modified colour coded sampling sequence (Appendix 3.13) and use CSTP LabSheet_v1.0 to collate sample data for each fish (Appendix 3.14).

1. **Record basic sampling data on sheet**
2. **Photograph both flanks of fish** – entire fish to be photographed
   a. Pins to be used to extend fins
   b. Take photo on measuring board or include ruler for scale
   c. Photo to be directly overhead and high quality resolution using camera mounted on tripod.

   Photo to be used for morphometrics, identification of damage (scale loss/physical injury), colour, parasites

3. **Sea Lice/parasites**
   External parasites – collection and reporting on sea trout

   Equipment
   i. Binocular microscope
   ii. Petri dishes
   iii. Forceps

   Method: individual fish (if frozen) to be thawed. Flush out plastic bag also to recover any detached parasites. Examine fish under binocular microscope and remove all visible parasites from fins and body to petri dish. Count (by species) all juvenile life stages on fins and other parts of body. Sort all parasites by species and life stage. Lice should be separated/reported in three life stages - copepods, chalimus and post- chalimus.

   Data analysis
   The infestation parameters described are as follows:
   Mean is the average number of lice per fish sampled.
   Standard deviation is a measure of how widely values are dispersed from the mean value.
   IQR (Inner Quartile Range) returns the quartile of a data set.
   Median returns the value in the middle of the dataset.
   Max returns the largest value from a set of values.
   Abundance relates to all fish in sample.
   Intensity relates to infested fish only in sample.

4. **Gill maggots**

   Check for presence by checking through gill filaments and enumerating gill maggots.

5. **Organ collection for external/internal parasites from adult sea trout**

   Same protocols can be applied to juveniles and smolts. (Guidance provided by Nikki Marks and Aaron Maule, QUB). As many different types of specimens are being harvested/examined from each fish, and tissue samples are also being collected, it may be necessary to harvest individual parasites and/or tissue for later analysis.

CS|TP will sample external and gill parasites. QUB samples will include harvested stomach parasites, whole hindgut and body cavity nematodes.

External parasites

Desirable that QUB receive as much of the intact fish as feasible to examine for parasites which encyst between the scales or on the fins. If possible retain some carcasses by refreezing for this purpose.

If fish are frozen and individual parasites being retained – individual parasites should be placed into "RNAlater" or 70% alcohol. If the parasites are the same species more than one specimen can be placed into tubes as long as there is enough liquid to cover them.

If fish are fresh and individual parasites being retained – collect parasites and place into either 4% PFA in PBS (paraformaldehyde), 70% ethanol and "RNAlater". (If same species more than one specimen per tube is acceptable).

Fixing solutions available from QUB

4% paraformaldehyde (PFA) solution in PBS Mix 0.4 g PFA in 1.0 mL dH2O and add 100 µL 1N NaOH, and then dilute to 10mL with PBS. (Heat this mixture until the PFA has dissolved)

RNA*later* is an aqueous, non-toxic tissue storage reagent that rapidly permeates tissues to stabilize and protect cellular RNA. RNA*later* eliminates the need to immediately process tissue samples or to freeze samples in liquid nitrogen for later processing. Tissue pieces can be harvested and submerged in RNA*later* for storage without jeopardizing the quality or quantity of RNA obtained after subsequent RNA isolation.

70% ethanol

Internal parasites

Gut samples desirable as this would allow QUB to check for the presence of tapeworms and nematodes.

Hindgut harvesting for parasite sampling

On opening cavity remove stomach and hindgut and separate. Weigh stomach, place in ziplock bag and refreeze for later analysis. Refreeze quickly if not being examined on the day. Put hindgut in preservative (70% alcohol) to limit degradation. Stomach parasites observed during stomach content analysis should also be retained (in 70% alcohol). QUB will work directly on hindgut.

Nematodes

Any nematodes present in the body cavity upon opening the fish should be harvested and stored in either 4% PFA, 70% alcohol or RNAlater. Nematodes will migrate to organs such as the liver within 1 hour of death of fish and will be very visible in body cavity and swim bladder.

Eye parasites (optional)

Collect fish eyes to examine for presence of eye fluke. Eyes to be dissected out and stored in 70% alcohol.

Section 3.14 CSTP – Sea Trout Laboratory Sampling Protocol – based on SALSEA MERGE (2011)

Sampling sequence	Type of sample	How to take sample	Conservation	Material for storage	Comments	Appendix No.
1	Photograph	Digital, with individual fish reference no, left side and right side	Digital	Digital images	Overhead shots with fins pinned on LHS picture with ruler for scale	No. 3
2	Scale loss	Percent scale loss by section and side		Info on database		
3	Sea lice count	Scan with binocular microscope and count sea lice (0 if absent)			Species, counts and lifestage	Initial pages of this document
4	Sea lice collection	Pick off sea lice – adults only?	Alcohol	Epindorff, Alcohol, Ref no.	Qualitative only – reference collection	Initial pages of this document
5	Length	Fork length in cm (precision 1 mm)		Info on database	Fresh length may already be taken. Thawed length will also be taken in lab.	
6	Whole weight	Weight in grammes (precision 1 g)			Fresh weight may already be taken. Thawed weight will also be taken in lab.	
7	Presence of scars	Note type of scar, location, comments on sampling form		Info on database		
8	Scale sample for ageing	Note on sheet, location scales removed	Dry	Scale Envelope, Ref no.		
9	Scale sample for SIA	Note on sheet location scales removed	Dry	Scale Envelope, Ref no.		
10	Tissue for genetics	Small piece of pectoral fin	Alcohol	Epindorff, Alcohol, Ref no.		
11	Sex determination	Male, female, unknown (if not identifiable)		Info on database		
12	Gonad weight/maturity status	Total weight of both gonads/classify maturity per Kestevan scheme	Frozen	Small sample bag, Ref no.	Gonads will be blotted initially then weighed	No.4
13	Stomach	Cut at the sphincter Muscle beside Pyloric Caecae (Ref to	Frozen	Small sample bag, Ref no.	Stomach fullness rating: 0 (empty) –	No.5

		Photo)			10 (full)	
14	Hindgut for parasites	Remove hindgut	Alcohol	25 ml universal, Alcohol, Ref no.		
15	Stable isotope tissues	Liver - small plug, lower tip	Frozen	Epindorff,Ref no.		
16	Stable isotope tissues	Dorsal muscle - small plug just below dorsal fin, no skin	Frozen	Epindorff,Ref no.	Remove muscle from Right side	
17	Stable isotope tissues	Adipose tissue - if present, small bit	Frozen	Epindorff,Ref no.		
18	Stable isotope tissues	Heart	Frozen	Epindorff,Ref no.	Entire heart	
19	Stable isotope tissues	Caudal fin - upper clip or punch	Frozen	Epindorff,Ref no.	Upper clip will be taken	
20	Viscera for parasites	Remove all gills, and retain remaining viscera	Alcohol	25 ml universal, Alcohol, Ref no.		
21	Individual nematodes in viscera/swim bladder	Harvest nematodes from viscera/organs	Alcohol	25 ml universal, Alcohol, Ref no	.	
22	Gutted weight	Weight in grammes		Info on database	Gills in but other organs removed	
23	Lipid condition	Remove about 1 cm wide strip of muscle middle of dorsal fin, down to vertebral column, along ribs, from left side, starting at dorsal fin down to ventral incision	Frozen	5 ml universal, Ref no.	Remove muscle from Left side.	
24	Head	Remove head for otoliths	Frozen	Ziploc bag		
25	Otoliths	Dissect out both otoliths	Dry	Otolith tray	Blot dry	No.6
26	Eye parasites	Dissect out both eyes	Alcohol	Epindorff, Alcohol, Ref no.		
27	Carcass - parasites	Place in plastic bag and freeze	Frozen	Ziploc bag, Ref no.	Add any loose tissues back in with carcass	Retain some carcasses for external parasites?

FISH CODE NO. –MZ - -

Celtic Sea Trout Project-Sampling Sheets

Sample Date:	
Catch Date:	
Gear Used:	
Net/Buoy No.	

- **Photograph:** Left side ______ Right side __________
- **% Scale Loss:** Left side _______ Right side __________
- **Sea lice count:** Left side _______ Right side __________
- **Fork length** (cm): ______ **Whole weight** (g): _______
- **Thawed length** (cm): _____ **Thawed weight** (g): _______

Comment on Scar Type:
Left Flank / Right Flank

- **Genetics-pectoral fin**:
- **Sex:**

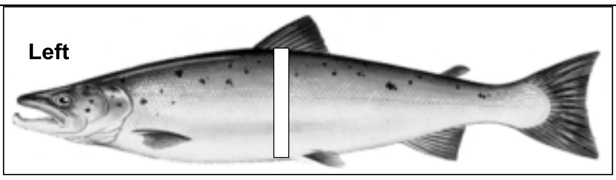
Male		Female		Unknown	

- **Total gonad weight:**(g) ____________________
- **Viscera for parasites:** 25ml Btl ,Label, Alcohol
- **Gutted weight:**(g) ________ **Stomach weight:**(g) _______
- **Stomach sample:** Small Ziploc, Label, Freeze

- **Tissues for stable isotope:** Individual Epindorffs, Label, Freeze

Liver		**Adipose fin**	
Caudal clip		**Muscle**	
Heart		**Scales**	

- **Muscle for lipid condition**
  5ml Btl, Label, Freeze



- **Remove otoliths:** Lennox Otolith Tray, Label, Dry
- **Carcass:** Ziploc bag, Label, Freeze
- **Comments:**

Sampler:	
Recorder:	
Other:	

Section 3.16 Eight-stage FAO maturity classification scheme for total spawners (from Maier (1908) in FAO (1974)).

Stage	State	Description
I	Virgin	Sexual organs very small, situated close to vertebral column. Testis and ovary transparent, colourless or grey. Eggs not visible to naked eye.
II	Maturing virgin	Testis and ovary translucent, grey- red. Length of gonads 1/2, or slightly more, of length of ventral cavity. Individual eggs can be seen with magnifying glass.
III	Developing	Testis and ovary opaque, reddish with blood capillaries. Occupy about 1/2 of ventral cavity. Eggs visible to naked eye as whitish granular material.
IV	Developed	Testis reddish-white, no milt produced under pressure. Ovary orange-red. Eggs clearly discernible, opaque. Testis and ovary occupy about 2/3rds of ventral cavity.
V	Gravid	Sexual organs fill ventral cavity. Testis white. Drops of milt produced under pressure. Eggs completely round, some already translucent and ripe.
VI	Spawning	Roe and milt run under slight pressure. Most eggs translucent with few opaque eggs left in ovary.
VII	Spent	Not completely empty, no opaque eggs left in ovary.
VIII	Resting	Testis and ovary red and empty. A few eggs in state of resorption.

Reference

FAO (1974). MANUAL OF FISHERIES SCIENCE Part 2 - Methods of Resource Investigation and their Application. Eds MJ Holden and DFS Raitt, FAO Rome.

Section 3.17 Stomach and hind gut analysis

Preparation

- Place the appropriate internal label inside the 120ml sample bottle, and stick the external label on the outside and cover it with tape after recording the scale envelope number that corresponds to the sample.
- Ensure fish is placed on a uniform coloured tray or stainless steel surface.
- Using a clean blade, make an incision from the anus to below opercular bone.
- Isolate the entire digestive tract (from beginning of oesophagus to the anal vent). Cut the oesophagus where it begins in the mouth, holding it closed with your thumb and forefinger to prevent items from inadvertently falling out. Hold it closed while you are isolating the stomach.
- Elevate the oesophagus and cut off any extra fat, tissue and organs (gall bladder, pyloric ceca, heart, liver, etc.
- DO NOT puncture oesophagus, stomach and the intestines while doing this.
- Isolate the digestive tract/hind gut. Cut the pyloric sphincter in the middle to separate the stomach and oesophagus from the intestine. If cut too distally, the parasites in the intestines will fall out.
- Place stomach in Ziploc bag for immediate freezing. Retain hindgut in 70% ethanol mixture for parasite analysis.

Note: Gill netting often causes regurgitation in salmonids - check stomachs to assess if they are truly empty or partially/completely regurgitated. Inspect for any signs of regurgitation (i.e. regurgitated food items in the gills, relatively large, distended stomachs, with thin walls and little internal ridging, etc.).

Recording

- Identify and categorise prey items.
- Photograph unknown prey items for further investigation.

Potential data analysis (per Prof Roger Baker)

- Estimate the *degree of fullness* (Fw) from the ratio of the total wet mass of the stomach to the wet mass of the fish x 100. This can be used as an index of feeding intensity between different sea trout populations (Rikardsen et al. 2006). It is vital however that the stomach is cut from the same location (Cut the gut at the anus and at the joint of the mouth/gut) to ensure consistency.
- Identify prey items and estimate % frequency of occurrence.
- Identify the frequency in which prey items occurred (empty stomachs excluded: from Amundsen et al. 1996).

Appendix 3.18. Otolith Removal for (sb)-ICP-MS Elemental Analysis

(Adapted from Marriott *et al* in Prep)

Equipment required

- 1 x chopping board, plastic (black for preference, available at RNIB online shop)
- 1 x Scalpel handle & scalpel blades
- 1 x Ceramic blade kitchen knife for bigger fish (available at amazon.co.uk)
- 4 x 100ml glass beakers (1 to contain 10% trace element grade nitric acid, & 3 to contain ultrapure water for triple rinse of forceps & cleaning brush)
- 1 x small Nylon painting brush to clean debris off otoliths
- 1 or 2 x plastic fine tipped forceps (available from farnell.co.uk)
- Acid washed petri dishes (1 as a general debris removal bath & 1 for each otolith for triple rinse)
- Acid washed & triple rinsed water bottle containing ultrapure water
- Acid washed eppendorfs-labelled (1 for each otolith)
- 1 x laminar flow cabinet
- Supply of ultrapure water

Acid-Washing

All equipment used in the extraction and storage of the juvenile and sub-adult otoliths were first bathed in a solution of 10% solution of diluted >69% trace metal grade nitric acid (HNO_3) made up with ultra pure Milli Q water (water purified to produce 18.2 MΩ.cm resistivity ultrapure water at 25 °C; www.millipore.com, 2003) and stored in polypropylene tubs (5 litre capacity) for a period of three days prior to use.

Non-powdered nitrile gloves are to be used due to the possibility of zinc contamination from small particles of powder (zinc contained within the glove powder, Batley, 1989; Dugan *et al*., 2008) becoming aerosolized when applying and removing the latex or nitrile gloves (see Batley, 1989; Friel *et al*., 1996; Dugan *et al*., 2008).

1.2 Otolith Removal

The sagittal otoliths were extracted from the fish using a pre-acid washed (see acid washing method above) polyamide carbon fibre very fine tipped plastic forceps (ideal-tek, Switzerland, www.farnell.co.uk part no **1227457 Tweezer Peek Replacable Tips Ideal Tek 5CPR.SA**).

- Label up enough eppendorf tubes as required one for each otolith, L + R
- Clean the bench down with ultrapure water.
- Set out the chopping board
- Set out scalpel & ceramic blade (if using).
- Remove 3 beakers from acid bath & triple rinse beakers with ultrapure water & part fill with clean ultrapure water
- Remove other beaker from acid bath but keep enough acid in the beaker to submerge the tip of the forceps
- Line the 4 beakers up above where you will place the chopping board (acid beaker, 1, 2, 3 containing ultrapure Water).
- Place 1 petri dish next to the chopping board & fill completely with ultrapure water for initial clean of otoliths

- Line up empty acid washed petri dishes & using water bottle place 3 spots of water in each petri for triple rinse of otoliths
- Place forceps & brush in acid to clean
- Using scalpel or knife cut open the cranium of the fish.
- Remove the forceps from the acid beaker & triple rinse in beakers, 1, 2 & 3.
- Use forceps to remove otoliths & place in cleaning petri dish, remembering which otolith is which, in BU left oto is placed at top of dish & right oto at bottom of dish
- Place forceps back in acid
- Take forceps & brush & triple rinse in water beakers
- Use forceps & brush to remove any adhering tissue from otoliths & place otolith in 1st spot of water in next petri dish, keeping otoliths in separate dishes
- Place forceps & brush back in acid beaker
- Take forceps & triple rinse in water
- Triple rinse each otolith in 3 spots of water & place in individually labelled acid washed eppendorf
- Trip away petri dishes with used 3 spots of water
- Once all extractions are complete place eppendorf tubes in a positive flow laminar cabinet on an eppendorf rack inside a plastic bag, open all tubes to allow air flow and leave to dry for 24 hours.
- After 24 hours check otoliths to see if they are dry by gently tapping tube, otolith should move around the tube freely.
- Remove from laminar flow. Close all tube lids & place otoliths in storage box ready for analysis.
- Petri dishes should be rinsed in distilled water & fully dried under the laminar flow. They can be used 3 times before being re-washed in the acid bath.

Section 3.19 Structure of the Celtic Sea Trout Project Database

Section 1 - Overview

The project has 7 major tasks: management and dissemination of information; Fishery inventory and description; Sampling; Stock discrimination and structuring (Genetics); Movements and distribution (Microchemistry); Freshwater production capacity; Marine ecology and life history variation. During this project a great deal of information was gathered from these tasks. In order to store the information in a single location a database has been developed using Microsoft Access 2007. The database initially covers all aspects of sampling.

Within Microsoft Access databases users can create tables, queries, forms and reports, and connect them together with macros. The naming convention for each item are as follows tbl = table, frm = form, rpt = report and qry = query. Data can be input directly into the database or imported from templates in a variety of other formats, including Microsoft Excel. Data can be stored in tables with a similar appearance to MS Excel, which many users are familiar with, and joined to a number of other tables with related information by creating relationships between key information. Databases can be very large entities; therefore many tables are linked by numeric identifications which take up less byte space than text. Good database practice means that spaces are not used in Field headers.

The database was created by Carys Ann Davies based on information on the recording forms and discussion with John Coyne. The database was stored on the online file sharing service Dropbox. Whilst the database was being populated only CAD and JC had direct access to it. Information was either input directly or uploaded from MS Excel template documents. Information request queries were created and sent out as MS Excel spreadsheets, primarily for ease of use/familiarity and secondarily not all have MS Access installed on their computers.

The CSTP database has information relating to sea trout at different life stages and their environment. The information has been gathered from recording forms provided at the start of the project. These can be viewed in Appendix 1. Databases do not work effectively if there is duplication of information, therefore information, such as that recorded on the forms or scale envelopes, was rationalised and common information was used as the basis of the recording tables. A cascade system was utilised. Two pieces of information were used to link tables, these are the Fish Reference Code (Figure 1) and the River – Marine Zone Code (Table 1); all ancillary information were linked to the "parent" information tables.

The following sections form the coding system for the CSTP. The CSTP would like to acknowledge Katie Thomas, Salsea Merge, for help with developing the system.

Table 1 – List of River – Marine Zone codes, with country and full name

Country	Code	Name	Country	Code	Name
England	RIBB	Ribble	**Ireland**	BRID	Bride
England	WYRE	Wyre	**Ireland**	MBLK	Munster BW
England	LUNE	Lune	**Ireland**	WOMA	Womanagh
England	KENT	Kent	**Ireland**	OWCA	Owenacurra
England	LEVE	Leven	**Ireland**	GLSH	Glashaboy
England	DUDD	Duddon	**Ireland**	OWBY	Owenboy
England	ESKC	Cumbrian Esk	**Ireland**	BAND	Bandon
England	IRT	Irt	**Ireland**	ARGI	Argideen
England	CALD	Calder	**Ireland**	ILEN	Ilen
England	EHEN	Ehen	**Ireland**	CURR	Currane
England	DERW	Derwent	**Ireland**	INNY	Inny
England	ELLE	Ellen	**Ireland**	SHAN	Shanganagh
England	EDEN	Eden	**Isle of Man**	GLSS	Glass
Ireland	MOYG	Moygannon	**Isle of Man**	NEB	Neb
Ireland	RYLA	Ryland	**Isle of Man**	SULB	Sulby
Ireland	COOL	Cooley	**Marine Zone**	MZ01	
Ireland	FLUR	Flurry	**Marine Zone**	MZ02	
Ireland	CAST	Castletown	**Marine Zone**	MZ03	
Ireland	FANE	Fane	**Marine Zone**	MZ04	
Ireland	GLYD	Glyde	**Marine Zone**	MZ05	
Ireland	DEWR	Dee (White River)	**Marine Zone**	MZ06	
Ireland	TERM	Termonfeckin	**Marine Zone**	MZ07	
Ireland	BOYN	Boyne	**Marine Zone**	MZ08	
Ireland	NANN	Nanny	**Marine Zone**	MZ09	
Ireland	DELV	Delvin	**Marine Zone**	MZ10	
Ireland	TURV	Turvey	**Marine Zone**	MZ11	
Ireland	BROA	Broadmeadow	**Marine Zone**	MZ12	
Ireland	LIFF	Liffey	**Marine Zone**	MZ13	
Ireland	DODD	Dodder	**Marine Zone**	MZ14	
Ireland	DARG	Dargle	**Marine Zone**	MZ15	
Ireland	TMWR	Three Mile Water	**Marine Zone**	MZ16	
Ireland	VART	Vartry	**Marine Zone**	MZ17	
Ireland	POTT	Potters	**Marine Zone**	MZ18	
Ireland	REDC	Redcross	**Marine Zone**	MZ19	

Ireland	AVOC	Avoca	**Marine Zone**	MZ20	
Ireland	INCH	Inch	**Marine Zone**	MZ21	
Ireland	OWVR	Owenavarragh	**Marine Zone**	MZ22	
Ireland	BLAC	Blackwater	**Marine Zone**	MZ23	
Ireland	SOWi	Sow	**Marine Zone**	MZ24	
Ireland	SLAN	Slaney	**Marine Zone**	MZ25	
Ireland	DUNC	Duncormick	**Marine Zone**	MZ26	
Ireland	OWDF	Owenduff	**Marine Zone**	MZ27	
Ireland	CORO	Corock	**Marine Zone**	MZ28	
Ireland	BARR	Barrow	**Marine Zone**	MZ29	
Ireland	NORE	Nore	**Marine Zone**	MZ30	
Ireland	CAMP	Campile	**Northern Ireland**	MONN	Moneycarragh
Ireland	SUIR	Suir	**Northern Ireland**	STBL	Strangford Blackwater
Ireland	MAHO	Mahon	**Northern Ireland**	SHIM	Shimna
Ireland	TAYi	Tay	**Northern Ireland**	KILK	Kilkeel
Ireland	COLL	Colligan	**Northern Ireland**	WHIT	Whitewater
Northern Ireland	GHAN	Ghan	**Wales**	AERO	Aeron
Northern Ireland	KILB	Kilbroney	**Wales**	YSTW	Ystwyth
Northern Ireland	CLAN	Clanrye	**Wales**	RHEI	Rheidol
Scotland	ESKB	Border Esk	**Wales**	DYFI	Dyfi
Scotland	ANNA	Annan	**Wales**	DYSY	Dysynni
Scotland	NITH	Nith	**Wales**	MAWD	Mawddach
Scotland	URR	Urr	**Wales**	ARTR	Artro
Scotland	DEEs	Dee(Scotland)	**Wales**	DWYR	Dwyryd
Scotland	FLEE	Fleet	**Wales**	GLAS	Glaslyn
Scotland	CREE	Cree	**Wales**	DWYF	Dwyfor
Scotland	BLAD	Bladnoch	**Wales**	LLYF	Llyfni
Scotland	LUCE	Luce	**Wales**	GWYR	Gwyrfai
Scotland	ABBE	Abbey Burn	**Wales**	SEIO	Seiont
Wales	TAWE	Tawe	**Wales**	OGWE	Ogwen
Wales	LOUG	Loughor	**Wales**	CONW	Conwy
Wales	GWEN	Gwendraeth	**Wales**	CLWY	Clwyd
Wales	TYWI	Tywi	**Wales**	DEEw	Dee(Wales)
Wales	TAF	Taf	**Wales**	FFRA	Ffraw
Wales	WCLE	Western Cleddau	**Wales**	OGMO	Ogmore
Wales	NEVE	Nevern	**Wales**	NEAT	Neath
Wales	TEIF	Teifi	**Wales**	WYE	Wye

Database Content

The database is divided into several parts for ease of use by operators (Figure 2).

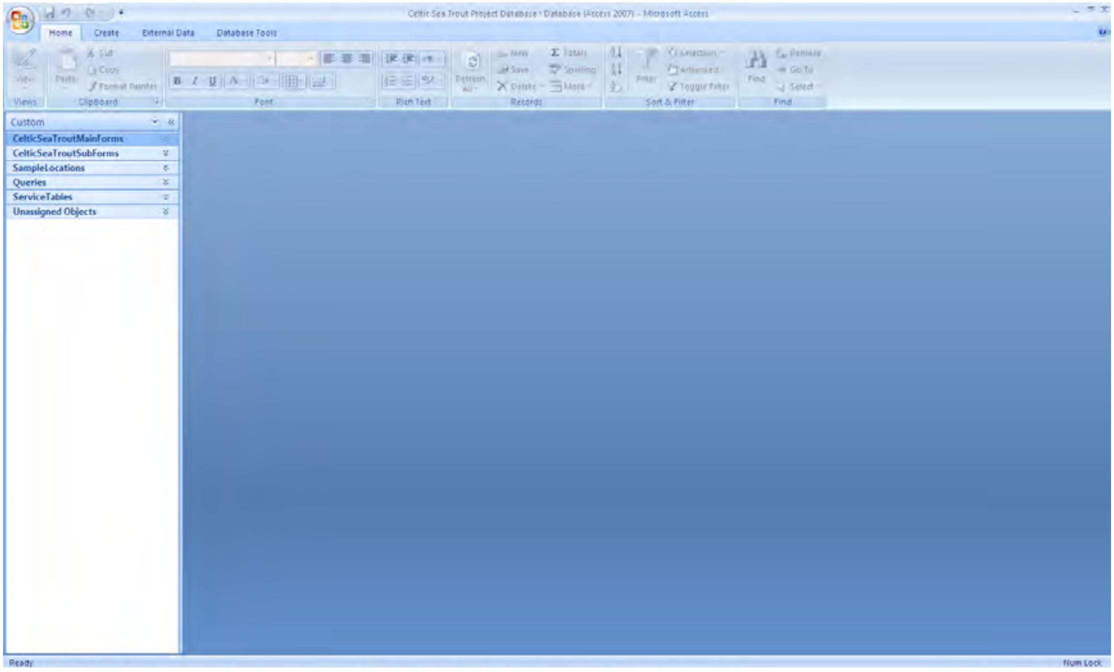


Figure 2 Navigation pane as viewed upon opening the database

Celtic Sea Trout Main Forms comprises of tables holding information relating to juvenile, smolt and adult sea trout samples. Additional laboratory obtained samples from adults are in this section. Freshwater survey site information for juvenile collections and marine survey sheets of dedicated sampling events are shown. The table containing country codes is the head table for the cascade system of the juvenile sampling information recording (See Figure 3). Further details are shown in Section 2.

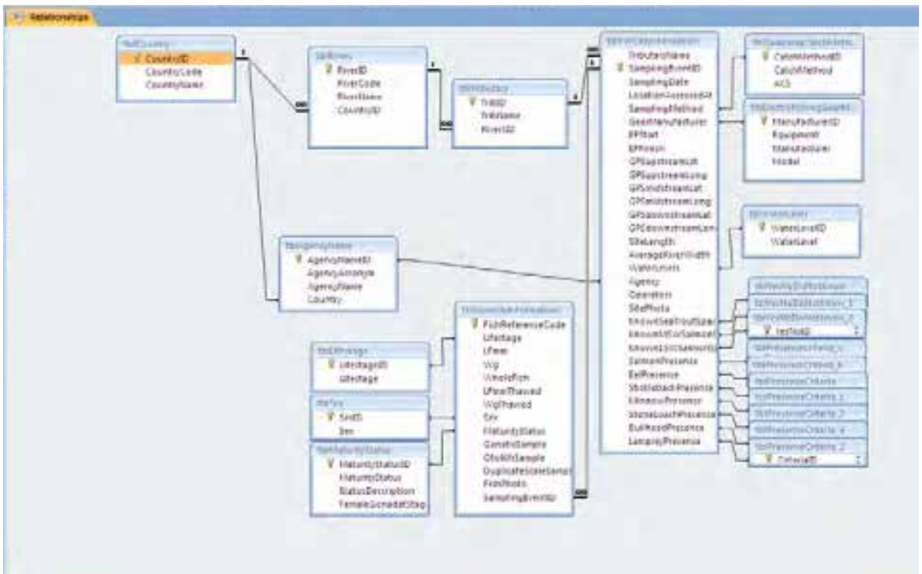


Figure 3 Relationship diagram for CSTP juvenile sample information tables

Celtic Sea Trout Sub Forms indicate the different tables of raw data recorded for each fish. This includes information on sea lice infestation, genetic assignments, gonad information, marine feeding, tissue for stable isotope analysis, tissue for condition factors, otolith information and ageing information. These data were recorded for fish which were received by the laboratory for processing. The sub forms relate to information cascading from the adult information and additional lab sample tables (See Figure 4). Further details are shown in section 3.

Sample Location tables were created to keep track of sample locations within the CSTP family of institutions. Further details can be seen in section 4.

Queries are created by users, selecting information required from fields in a range of tables. The tables must be linked in order for the information to be selected and appear in the output.

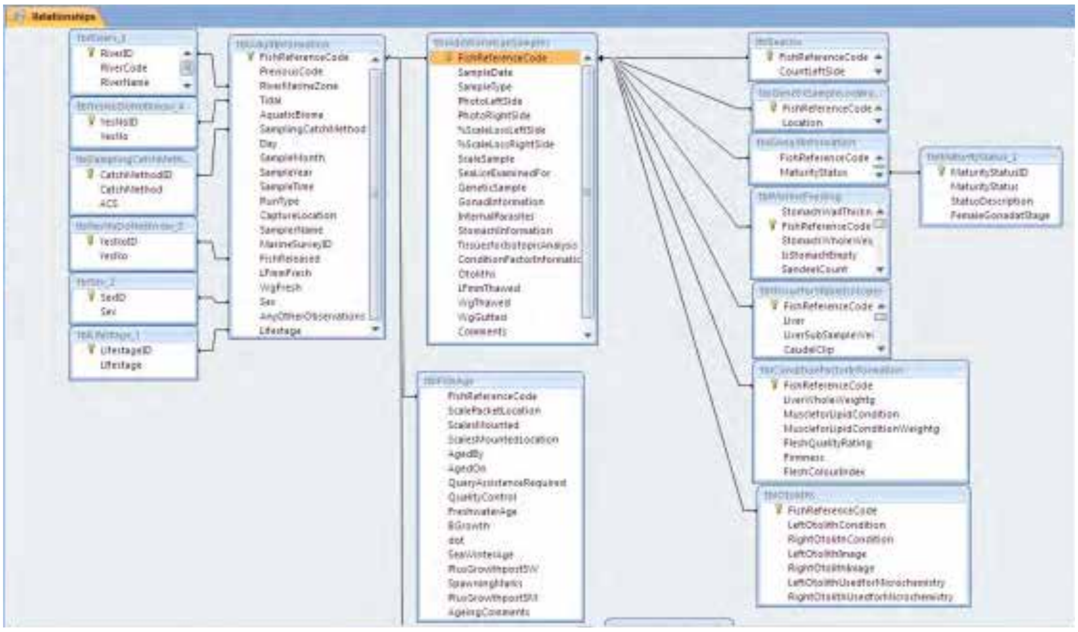


Figure 4 Relationship diagram for CSTP adult sample information tables

Service Tables were created for information management. The information in the service tables may be relevant to several higher order tables and may be used in several instances. For example where a yes or no check box does not allow for all information recorded a "yes, no, do not know or unknown" option is required. The service tables are all linked by numeric categories. For further information refer to section 5.

Data error mining

Errors in data are inevitable through human or recording error. The information within the database was screened for errors by plotting information such as length and weight to assess any outliers, any outliers were then checked against original recorded information and if errors were present these were amended. Information being uploaded from MS Excel templates were initially screened using filters in MS Excel; any erroneous information was checked and amended. As different versions of Microsoft were utilised by different project members, a few instances occurred where the information would not upload correctly (Error: Subscript out of range). To get around this error the information was either re-saved in a different version of MS Excel or typed into the database manually. In order to ensure that the correct data was recorded in all tables, queries were run within the database to find unmatched entries and duplicates. Unmatched data entries were filled in with correct matching data.

Database management

The database was managed primarily by CAD on the dropbox server with a back-up copy retained on the Bangor University server. When items are removed from a database, such as queries which are no longer required, it does not delete information completely but stores it; as a result it is very easy to allow the database to mushroom in size. As good practice the database was managed by the "compact and repair" function on a regular basis.

Section 2 – Celtic Sea Trout Main Forms

There are 7 tables in the category Celtic Sea Trout Main Forms. These contain information on Country, Freshwater Site Information, Juvenile Information, Smolt Information, Marine Survey Sheets, Adult Information and Additional Laboratory Samples. All information in these tables are based on direct observation information as recorded on the forms in Appendix 1.

tblCountry

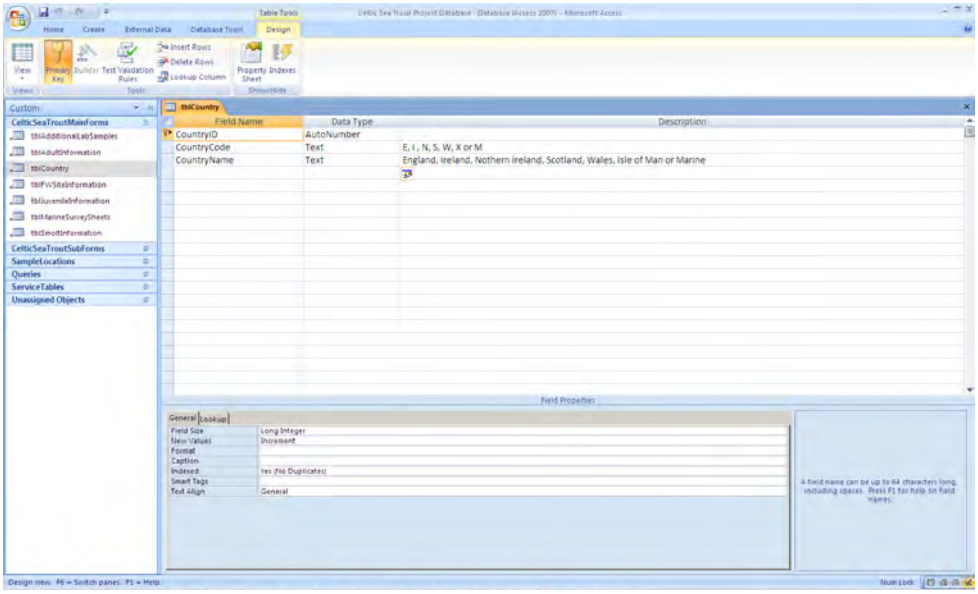


Figure 5 Screen grab of Country table design in database

The country code was based on the first letter of the country name with the exception of Isle of Man which conflicted with the code for Ireland, therefore and X was attributed to this country code. The country code was based on the coding system shown in Figure 1 adapted from codes utilised in the SALSEA-Merge project.

tblFWSiteInformation

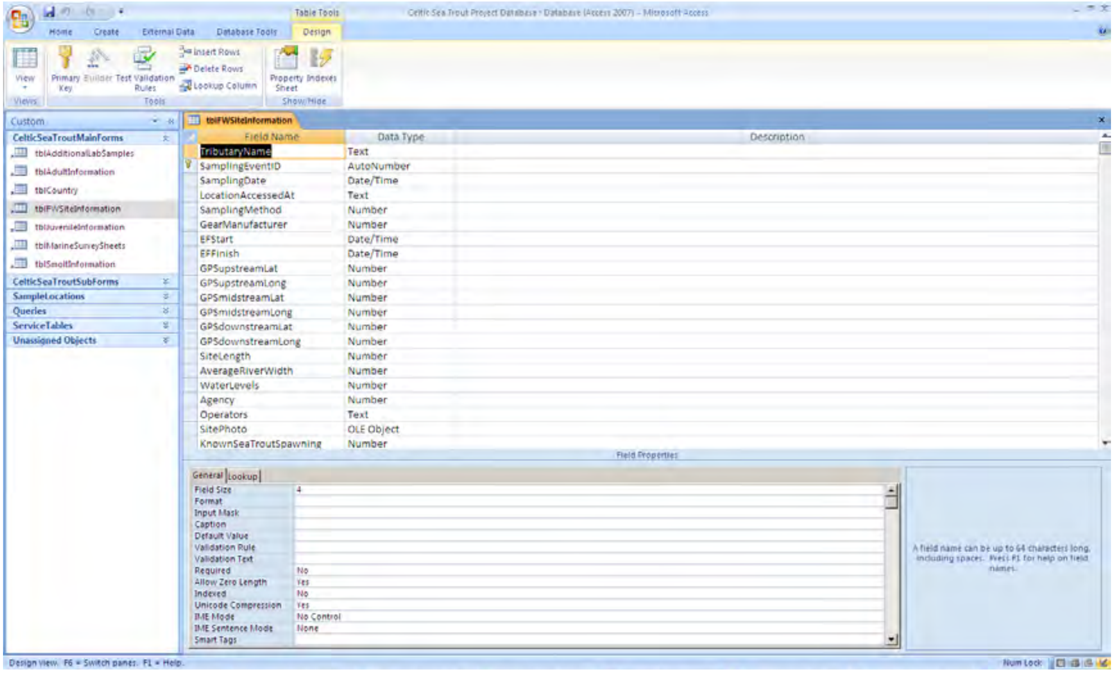


Figure 6 Screen grab of freshwater site information table design in database

Freshwater Site Information was recorded on the genetics/microchemistry juvenile sampling survey sheet (Appendix 1). The information recorded can be seen in Table 2. Tables for country, river and tributary name are part of the cascade which feeds into the freshwater site information and are linked by Tributary Name. Each sampling event depicted by different date, time or location on the river were issued a separate site recording form and ID code. Juveniles collected at each site are lined by the sampling event ID field in the juvenile information table.

Table 2 Description of information recorded in table FWSIteInformation

Field Name	Description
TributaryName	Name of River Tributary
SamplingEventID	Sequential number assigned to catalogue the sampling events
SamplingDate	Date in format of dd/mm/yyyy
LocationAccessedAt	Description of where the site was accessed from
SamplingMethod	Description of sampling method linked to service table Section 5 tblSamplingCatchMethod
GearManufacturer	Description of Gear Manufacturer linked to service table Section 5 tblElectrofishingGearManufactur
EFStart	Time in format of tt:tt
EFFinish	Time in format of tt:tt
GPSupstreamLat	Decimal Upstream Latitude (WGS 1984)
GPSupstreamLong	Decimal Upstream Longitude (WGS 1984)
GPSmidstreamLat	Decimal Midstream Latitude (WGS 1984)
GPSmidstreamLong	Decimal Midstream Longitude (WGS 1984)
GPSdownstreamLat	Decimal Downstream Latitude (WGS 1984)
GPSdownstreamLong	Decimal Downstream Longitude (WGS 1984)
SiteLength	length of site downstream to upstream along river
AverageRiverWidth	Average river width measured from Google Earth at u/s, m/ s & d/s
WaterLevels	Description of water level linked to service table Section 5 tblWaterLevel

Agency	Agency name linked to service table Section 5 tblAgencyName
Operators	Initials of operators present during survey
SitePhoto	Hyperlink to photo location
KnownSeaTroutSpawning	Answer to question whether this site is a known spawning area Linked to Section 5 tblYesNoDonotKnow
KnownMSWSalmonSpawning	ditto
Known1SWSalmonSpawning	ditto
SalmonPresence	Answer to question is this species present and in what abundance Linked to Section 5 tblPresenceCriteria
EelPresence	ditto
SticklebackPresence	ditto
MinnowPresence	ditto

tblJuvenileInformation

Juvenile samples were collected between 2009 and 2011 from specific rivers. The main information required related to which lifestage this information relates to, length and weight information and what samples are available for further analysis from these individuals. Most of these samples were collected for task 4 – Stock discrimination and structuring (Genetics) to form the basis of a genetic baseline for sea trout from rivers flowing into the Irish Sea. Parr samples were also collected for task 5 - Movements and distribution (Microchemistry). Information relating to length and weight were used in task 7 - Marine ecology and life history variation, fresh and thawed lengths and weights were recorded where possible, occasionally only thawed length and weight were recorded at a later date in the laboratory. A query could then be developed to correct for any changes in length and weight caused by the freezing and thawing process.

Table 3 Description of information recorded in table JuvenileInformation

Field Name	Description
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
Lifestage	Either Fry or Parr, see Section 5 tblLifestage
LFmm	Fork length of fresh fish
Wg	Whole weight of fresh fish
WholeFish	Was the whole fish retained, yes or no?
LFmmThawed	Fork length of thawed fish
WgThawed	Whole weight of thawed fish
Sex	Predominantly Unknown sex (See Section 5 tblSex)
MaturityStatus	Predominantly unknown (see Section 5 tblMaturityStatus)
GeneticSample	Was a genetic sample taken, yes or no?
OtolithSample	Was an otolith sample taken, yes or no?
DuplicateScaleSample	Is a duplicate scale sample available, yes or no?
FishPhoto	Hyperlink to photo location
SamplingEventID	linked to tblFWSiteInformation

tblSmoltInformation

A small number of smolt samples were collected for validation of genetic baseline information. Catch dates, locations and methods were recorded for these samples along with basic biological information.

Table 4 Description of information recorded in table SmoltInformation

Field Name	Description
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
River	See Table 1
CatchLocation	A description of catch location
CatchLat	Catch latitude in digital format (WGS 1984)
CatchLong	Catch longitude in digital format (WGS 1984)
SamplingCatchMethod	Which catch method was used to collect samples (see Section 5 tblSamplingCatchmethod)
SamplerName	Sampler name and contact details
Day	1 to 31, 0 = No data
SampleMonth	1 to 12, 13 = No data
SampleYear	Year in format XXXX
Lifestage	Smolt, see Section 5 tblLifestage
LFmm	Fork length of fish
Wg	Whole weight of fish
Sex	Predominantly Unknown sex (See Section 5 tblSex)
MaturityStatus	Predominantly unknown (see Section 5 tblMaturityStatus)
ScaleSample	Is a scale sample available, yes or no?
GeneticTissueSample	Was a genetic sample taken, yes or no?

tblMarineSurveySheets

Information relating to marine surveys were recorded on Marine sea trout sampling survey sheet (see Appendix 1). Data was recorded on geographic location, date and time, prevailing weather conditions, and how the site was selected. As part of licensing agreements, all bycatch had to be recorded. Fifty-two species were recorded as bycatch during the CSTP surveys.

Table 5 Description of information recorded in table Marine Survey Sheets

Field Name	Description
MarineSurveyID	Number assigned to catalogue sampling events
SurveyType	Which general area was the survey in (inshore, offshore, estuarine) linked to Section 5 tblMarineSurveyType
CSTPMarineZone	Marine Zones numbered 01 to 30, See Table 1
Country	Country code linked to tblCountry
County	name of county
Day	1 to 31, 0 = No data
SampleMonth	1 to 12, 13 = No data
SampleYear	Year in format XXXX
LocationName	Site name
LocationAccessedAt	Where the site was accessed from
NearestRiverMouth	See Table 1
StartLat	Recorded start of survey/netting Latitude (WGS 1984)
StartLong	Recorded start of survey/netting Longitude (WGS 1984)
FinishLat	Recorded End of survey/netting Latitude (WGS 1984)
FinishLong	Recorded End of survey/netting Longitude (WGS 1984)
SamplingCatchMethod	Which catch method was used (see Section 5 tblSamplingCatchmethod)
GearDetails	Further information relating to specific gear details
SiteSelectionCriteria	How was the site selected (see Section 5 tblSiteSelectionCriteria)
WeatherConditions	What were predominate weather conditions

WindSpeed	Approximate wind speed
WindDirection	Prevailing wind direction
SamplingStartTime	tt:tt
SamplingFinishTime	tt:tt
SamplingCourse	eg N to S
NetOrientationFromShore	How was the net orientated (see Section 5 tblNetOrientation)
TideState	What state was the tide in (see Section 5 tblTideState)
SubstrateType	Estimated substrate type, sand mud gravel etc
SamplingDepthm	Average fishing depth
Salinity	Salinity ppm
WaterTemperature°C	Water temperature in Celsius
AirTemperature°C	Air temperature in Celsius
KnownSeaTroutHabitat	Answer to question whether this site is a known sea trout area linked to Section 5 tblYesNoDonotKnow
Agency	Agency name linked to service table Section 5 tblAgencyName
LocalAssistance	Names or initials
VesselTypeLength	Description of vessel if one was used
Photographs	Hyperlink to photos
Additional comments	Any additional information or comments
FishRetainedforCSTP	Answer to question were samples retained linked to Section 5 tblYesNoDonotKnow
SamplesRetainedLocation	Where are the samples that were kept retained (see Section 5 tblLocation)
SeaTrout	Count
Salmon	Count
CuecumberSmelt	Count
Bass	Count
ThickLippedMullet	Count
ThinLippedMullet	Count
GoldenGreyMullet	Count
Plaice	Count
Flounder	Count
Topknot	Count
Sole	Count
DoverSole	Count
Dab	Count
Turbot	Count
Brill	Count
AlissShad	Count
ThwaiteShad	Count
Mackerel	Count
Whiting	Count
Herring	Count
Cod	Count
Coley	Count
Pollack	Count
Pilchard	Count
Haddock	Count
TubGurnard	Count
GreyGurnard	Count
Dragonet	Count
Garfish	Count

JohnDory	Count
SandGoby	Count
Weaverfish	Count
Pipefish	Count
Lamprey	Count
Tope	Count
Bullhuss	Count
LesserSpottedCatshark	Count
Smoothound	Count
ThornbackRay	Count
BlondeRay	Count
SandSmelt	Count
Sandeel	Count
Lumpfish	Count
LionManeJellyfish	Count
CommonJellyfish	Count
BrownJellyfish	Count
Sprat	Count
Anchovy	Count
EdibleCrab	Count
ShoreCrab	Count
SpiderCrab	Count
Scad	Count
Octopus	Count

tblAdultInformation

Information on adult fish were recorded on 3 different scale envelopes (depending on origin of fish, angler, commercial or scientific). In order to separate information for ease of use basic information on the fish (as recorded on the scale envelopes) were recorded in the Adult Information table. Any further measurements or samples taken from the fish were stored in a linked table on Additional Lab Samples. Studies have shown that length and weight of fish can be altered by freezing and thawing, therefore this information was stored in the additional information table as a secondary measurement.

Table 6 Description of information recorded in table Adult Information

Field Name	Description
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
PreviousCode	Any previous code applied by other samplers
RiverMarineZone	See Table 1
Tidal	Is the fish from a tidal area linked to Section 5 tblYesNoDoNotKnow
AquaticBiome	Is the body of water characterised as freshwater, estuarine or marine, linked to Section 5 tblAquaticBiome
SamplingCatchMethod	Which catch method was used to collect samples (see Section 5 tblSamplingCatchmethod)
Day	1 to 31, 0 = No data
SampleMonth	1 to 12, 13 = No data
SampleYear	Year in format XXXX
SampleTime	What time of day? see Section 5 tblSampleTime
RunType	Was the fish fresh or stale? see Section 5 tblRunType
CaptureLocation	Description of capture location
SamplerName	Name of sampler with contact details & agency

MarineSurveyID	link to tblMarineSurveySheets, if no survey sheet exists 0 was used
FishReleased	Was the fish released, yes or no? See Section 5l tblYesNoDoNotKnow
LFmmFresh	Fork length of fish taken when fresh
WgFresh	Whole weight of fish taken when fresh
Sex	Which sex was the fish? see Section 5 tblSex
AnyOtherObservations	Any other information recorded
Lifestage	Adult, see Section 5 tblLifestage

tblAdditionalLabSamples

Fish samples caught by CSTP project partners and samples of fish (whole or parts thereof) donated by anglers of commercial fishermen were processed at Bangor University or Inland Fisheries Ireland using a single protocol. Information was recorded onto the Celtic Sea Trout Project-Sampling Sheets (Appendix 1). Data recorded on these sheets which was not already accounted for on the tblMarineSamplingSheets or tblAdultInformation, were added to this table. It clearly shows when the samples were processed, whether it was a whole fish or part of the fish, samples are recorded as yes/no and linked to sub tables in Celtic Sea Trout Sub Forms. Thawed measurements and gutted weight are stored in this table. Any additional comments and initials of the sample processor/recorder are recorded (Figure 7).

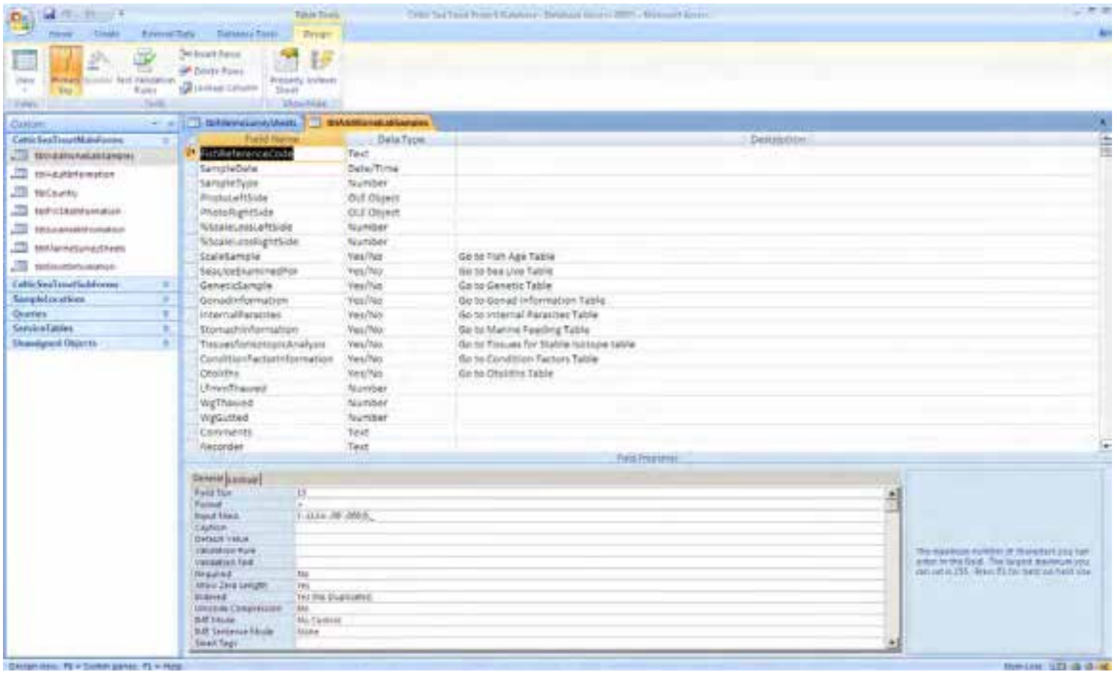


Figure 7 Screen grab of Additional Lab Samples table design in database

Section 3 – Celtic Sea Trout Sub Forms

tblFishAge

The age assessments of fish are recorded in this table. This is one of the few tables which does not contain the Fish Reference Code as the primary key. This is due to duplication of age assessments undertaken by several readers for assessments such as comparisons of precision in ageing. The locations of the original scale packets and mounted scales are held within this table (Table 7).

Table 7 Description of information recorded in table Fish Age

Field Name	Description

FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
ScalePacketLocation	Current location of original scale packet, see Section 5 tblLocation
ScalesMounted	Answer to question yes or no?
ScalesMountedLocation	Current location of mounted scales on slides, see Section 5 tblLocation
AgedBy	Initials of age reader
AgedOn	dd/mm/yyyy
QueryAssistenceRequired	Answer to question yes or no?
QualityControl	Answer to question yes or no?
FreshwaterAge	
BGrowth	
dot	
SeaWinterAge	
PlusGrowthpostSW	
SpawningMarks	
PlusGrowthpostSM	
AgeingComments	Any comments

tblSeaLice

The numbers of sea lice were recorded to assess background parasite levels on sea trout in the Irish Sea. Observations were recorded as counts (whole numbers) of the two main species *Lepeophtheirus salmonis* and *Caligus elongatus*. Records were made of the numbers of sex in the categories of adults, pre-adults and chalimus stages (Table 8).

Table 8 Description of information recorded in table Sea Lice

Field Name	Description
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
CountLeftSide	Count of numbers on left side of fish
CountRightSide	Count of numbers on right side of fish
CountInBag	Count of numbers in bag which have fallen off the fish
LsMale	Count of *Lepeohtheirus salmonis* – adult males
LsFemale	Count of *Lepeohtheirus salmonis* – adult females
LsPreAdultMale	Count of *Lepeohtheirus salmonis* – pre-adult males
LsPreAdultFemale	Count of *Lepeohtheirus salmonis* – pre-adult females
LsPreAdultIndeterminate	Count of *Lepeohtheirus salmonis* – pre-adult of indeterminate sex
LsChalimus	Count of *Lepeohtheirus salmonis* – any of the chalimus life stage
CeMale	Count of *Caligus elongatus*– adult males
CeFemale	Count of *Caligus elongatus*– adult females
CePreAdultMale	Count of *Caligus elongatus*– pre-adult males
CePreAdultFemale	Count of *Caligus elongatus*– pre-adult females
CePreAdultIndeterminate	Count of *Caligus elongatus*– pre-adult of indeterminate sex
CeChalimus	Count of *Caligus elongatus*– any of the chalimus life stage
Other	Identification of other external parasites
Comment	comments
SampleLocation	Current location of sea lice samples, see Section 5 tblLocation

tblT4GSIAssignment

Genetic assignment information was recorded as probability scores, with the highest probability as the primary regional assignment (Table 9).

Table 9 Description of information recorded in table T4 GSI Assignments

Field Name	Description
GSIAssignmentAvailable	Is a GSI Assignment available see Section 5 tblYesNoDoNotKnow
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
T4SampleIDCode	Code assigned by T4 for genetic assignment
CSTPMarineZone	See Table 2
RiverAssignment	Which area does the fish assign to? see Section 5 tblRegionalAssignments
RiverProbabilityScore	Probability score
ReportingRiverQC	Percentage score
RegionalAssigment	Primary region assignment
WestIreland	Region score
SouthIreland	Region score
SouthEastIreland	Region score
NorthEastIreland	Region score
NorthIreland	Region score
IOM	Region score
SolwayMorcambe	Region score
WestWales	Region score
SouthWales	Region score
VersionMark	Which version of the assignment this information relates to.

tblGonadInformation

Information was recorded on all gonads for whole weight and maturity status. For females measurements were taken for 10 individual eggs from each fish to assess egg size at different maturity. An estimation of egg numbers was made of the gonad whole weight from average egg weight (Table 10).

Table 10 Description of information recorded in table on gonad information

Field Name	Description
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
MaturityStatus	What is the maturity status of the fish? see Section 5 tblMaturityStatus
GonadRetained	Was the gonad retained, yes or no?
GonadWeightg	Total weight of whole gonad
Egg1Weightg	Individual weight of egg in g
Egg2Weightg	Individual weight of egg in g
Egg3Weightg	Individual weight of egg in g
Egg4Weightg	Individual weight of egg in g
Egg5Weightg	Individual weight of egg in g
Egg6Weightg	Individual weight of egg in g
Egg7Weightg	Individual weight of egg in g
Egg8Weightg	Individual weight of egg in g
Egg9Weightg	Individual weight of egg in g
Egg10Weightg	Individual weight of egg in g
Egg1Diameterµm	Individual diameter of egg in micron
Egg2Diameterµm	Individual diameter of egg in micron
Egg3Diameterµm	Individual diameter of egg in micron
Egg4Diameterµm	Individual diameter of egg in micron
Egg5Diameterµm	Individual diameter of egg in micron
Egg6Diameterµm	Individual diameter of egg in micron
Egg7Diameterµm	Individual diameter of egg in micron

Egg8Diameterµm	Individual diameter of egg in micron
Egg9Diameterµm	Individual diameter of egg in micron
Egg10Diameterµm	Individual diameter of egg in micron
GonadPhoto	Hyperlink to photo
EggPhoto	Hyperlink to photo
GonadSampleLocation	Current location of gonad samples, see Section 5 tblLocation

tblMarineFeeding

As part of the Marine Ecology and Life History task an analysis of stomach contents of sea trout was undertaken. Stomach was thickness was recorded as an indicator of whether the fish had fed recently. Stomach were recorded for total weight, whether they were empty or not, if they contained food items, these were counted and weighed into specific categories. Mush was recorded where the prey was unidentifiable but obviously not gastric juices (Table 11).

Table 11 Description of information recorded in marine feeding table

Field Name	Description
StomachWallThickness	Was the stomach wall thick, thin or not recorded?
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
StomachWholeWeightg	Weigh in g
IsStomachEmpty	Is the stomach empty, yes or no?
SandeelCount	Count
SandeelWeightg	Weigh in g
SpratCount	Count
SpratWeightg	Weigh in g
OtherFishCount	Count
OtherFishWeightg	Weigh in g
OtherFishIdentification	Identification of other fish prey species
CrabCount	Count
CrabWeightg	Weigh in g
PrawnShrimpCount	Count
PrawnShrimpWeightg	Weigh in g
AmphipodCount	Count
AmphipodWeightg	Weigh in g
PolychaeteCount	Count
PolychaeteWeightg	Weigh in g
OtherCount	Count
OtherWeightg	Weigh in g
OtherIdentification	Identification of other prey species
MushWeightg	Weigh in g

tblTissuesforStableIsotopes

Selections of tissues were taken from each fish for stable isotope analysis (see Appendix 1). Weights were taken and recorded of subsamples of liver and muscle tissue and the whole heart (Table 12).

Table 12 Description of information recorded in table on tissue for stable isotope analysis

Field Name	Description
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
Liver	Was a liver sample taken, yes or no?
LiverSubSampleWeightg	weight in g
CaudalClip	Was caudal clip taken, yes or no?
Heart	Was the heart kept, yes or no?
HeartWeightg	weight in g
AdiposeFin	Was the adipose fin taken, yes or no?
Muscle	Was a muscle sample taken, yes or no?
MuscleSubSampleWeightg	weight in g
LocationofLACHM	Current location of the above samples, see Section 5 tblLocation
DispatchDateLACHM	dd/mm/yyyy
ScaleSample	Was a scale sample collected for isotopic analysis, yes or no?
LocationofScaleSample	Current location of the scale samples, see Section 5 tblLocation
DispatchDateS	dd/mm/yyyy

tblConditionFactorInformation

A range of tissues and information were collected which relate to the condition of the fish including liver, tissue for lipid analysis and flesh quality indices. These were recorded for future use in the format shown in Table 13.

Table 13 Description of information recorded in table on condition factor information.

Field Name	Description
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
LiverWholeWeightg	Whole weight in g
MuscleforLipidCondition	Was tissue retained for lipid conditions, yes or no?
MuscleforLipidConditionWeightg	Weight of sample in g
FleshQualityRating	1 to 5 (1=low, 5 = high)
Firmness	1 to 5 (1 = spongy, 5= firm)
FleshColourIndex	based on SalmoFan colours

tblOtoliths

Otoliths were collected from all fish where heads were available. The condition was recorded to allow the user to assess whether they could be used for further ageing or microchemistry analysis. Images of all otoliths which were to be destructively analysed were taken and a record made of whether that particular otolith had been analysed using a destructive method (Table 14).

Table 14 Description of information recorded in table on otolith status.

Field Name	Description
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
LeftOtolithCondition	What was condition of otolith, whole, broken, missing, etc?
RightOtolithCondition	What was condition of otolith, whole, broken, missing, etc?
LeftOtolithImage	Hyperlink to photo
RightOtolithImage	Hyperlink to photo
LeftOtolithUsedforMicrochemistry	Was the otolith used for microchemistry, yes or no?
RightOtolithUsedforMicrochemistry	Was the otolith used for microchemistry, yes or no?

Section 4 - Sample Location

As a high number of samples were being generated to forward to project partners a tracking system was input into the database to track the last known position of each sample and when they were dispatched to that location.

tblGeneticSampleLocationAdult

Tissue for genetic analysis was sent to either BU or UCC as samples became available. Tissues were tracked using the information in Table 15.

Table 15 Description of information recorded in the table on the location of sea trout tissue for genetic analysis.

Field Name	Description
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
Location	Current location of adult tissue, see Section 5 tblLocation
DispatchDate	dd/mm/yyyy

tblGeneticSampleLocationSmolts

Similar to the adult tissue, smolt tissue was sent to the required destination when requested. The table for recording this information is the same format as Table 15.

tblInternalParasitesLocation

A collaborative exercise was initiated with researchers at Queen's University of Belfast to analyse the internal parasite samples. Samples were sent as and when the samples had been processed. It was essential to be able to ascertain when and in which box the samples had been dispatched (Table 16).

Table 16 Description of information recorded in the table on Internal Parasite Locations.

Field Name	Description
FishReferenceCode	CSTP fish code in format of A-AAAA-00-000; See Figure 1
Viscera	Were viscera collected, yes or no?
Hindgut	Were hindguts collected, yes or no?
LeftEye	Were the left eyes collected, yes or no?
RightEye	Were the right eyes collected, yes or no?
LeftGill	Were the left gills collected, yes or no?
RightGill	Were the right gills collected, yes or no?
VisceraLocation	Current location of viscera/hindgut, see Section 5 tblLocation
VisceraDispatchDate	dd/mm/yyyy
VisceraDispatchBoxNumber	The box number the sample was dispatched in.
LeftEyeLocation	Current location of left eye, see Section 5 tblLocation
LeftEyeDispatchDate	dd/mm/yyyy
LeftEyeDispatchBoxNumber	The box number the sample was dispatched in.
RightEyeLocation	Current location of right eye, see Section 5 tblLocation
RightEyeDispatchDate	dd/mm/yyyy
RightEyeDispatchBoxNumber	The box number the sample was dispatched in.

Section 5 – Service Tables

Service tables are created for look ups for the main and sub tables. The information is linked by numeric identifiers. Information and joins of a numeric type take up less byte space compared to text, allowing the database to be more streamlined and take up less processing memory when building queries and reports.

tblACS

Information was gathered from 3 main types, angler, commercial or scientific and a letter code assigned to differentiate between different sample origins (Table 17).

Table 17 Service table for ACS definition

ACSID	ACS	FullName
1	A	Angler
2	C	Commercial
3	S	Scientific

tblAgencyName

Different agencies from different countries were involved in the collection of samples. These are shown in Table 18.

Table 18 Service table of Agency definition

AgencyNameID	AgencyAcronym	AgencyName	Country (linked to tblCountry)
1	IFI	Inland Fisheries Ireland	Ireland
2	EA	Environment Agency	England
3	GFT	Galloway Fisheries Trust	Scotland
4	NDSFB	Nith District Salmon Fishery Board	Scotland
5	ADSFB	Annan District Salmon Fishery Board	Scotland
6	DARD	Department of Agriculture and Rural Development	Northern Ireland
7	AFBI	Agri-Food and Biosciences Institute	Northern Ireland
8	DEFA	Department of Environment, Food and Agriculture	Isle of Man
9	BU	Bangor University	Wales
10	EAW	Environment Agency Wales	Wales
11	LA	Loughs Agency	Northern Ireland
12	N/A	Not Appropriate	
13	DCAL	Department of Culture, Arts and Leisure	Northern Ireland

tblAquaticBiome

In order to differentiate between samples caught in different areas of river or sea, the category of aquatic biome was utilised (Table 19).

Table 19 Service table of aquatic biome

AquaticBiomeID	Biome
1	Fresh
2	Estuarine
3	Marine

tblElectrofishingGearManufacturer

Different agencies used different electrofishing gear for the juvenile collections. These were recorded in Table 20.

Table 20 Service table for electrofishing equipment type

ManufacturerID	Equipment	Manufacturer	Model
1	Safari Backpack	Safari	550E
2	Electracatch Generator6	Electracatch	WFC6
3	Electracatch Generator7	Electracatch	WFC7
4	Electracatch Backpack2	Electracatch	ELBP2
5	Intelysis Fish Magnet	Intelysis	HEAEFBP07
6	Intelysis Generator	Intelysis	HEAEFP038
7	E-fish Backpack	E-fish	

tblLifestage

As different life stages of trout were recorded a service table differentiated between them (Table 21).

Table 21 Service table of sea trout life stages

LifestageID	LIfestage
1	Fry
2	Parr
3	Smolt
4	Adult
5	Salmon

tblLocation

Locations of samples were recorded and contact information for each location was detailed in Table 22.

Table 22 Service table of sample locations with contacts

Location ID	Location Acronym	Location Name	Address1	Address2	City	Contact Name
1	BU-NFL	Bangor University	Nuffield Fish Lab	School of Ocean Science	Menai Bridge	Carys Ann Davies
2	BU-ECW	Bangor University	Environment Centre Wales	School of Biological Sciences	Bangor	Niklas Tysklind
3	BU-BRAMBEL	Bangor University	Brambell Building	School of Biological Sciences	Bangor	Nigel Milner
4	IFI-SWORDS	Inland Fisheries Ireland			Swords	John Coyne
5	UCC	University College Cork	Distillery Fields		Cork	
6	QUB	Queen's University	MBC, 97 Lisburn		Belfast	

		of Belfast	Road			
7	IMR	Institute of Marine Research	Postboks 1870, Nordnes	5817	Bergen	Egil Karlsbakk

tblMarineSurveyType

Marine surveys were categorised on the recording form (see Appendix 1) and differentiated in Table 23.

Table 23 Service table of marine survey types

MarineSurveyTypeID	MarineSurveyType
1	Estuarine
2	Inshore
3	Marine
4	Offshore

tblMaturityStatus

Maturity status was recorded ranging from I to VIII (Table 24). The recorders used the FAO (1974) on maturity and spawning in fish as a guide to maturity stages in sea trout.

Table 24 Service table for maturity status

MaturityStatusID	MaturityStatus	StatusDescription
1	Unknown	Status is not known
2	I	Immature
3	II	Developing
4	III	Maturing
5	IV	Maturing
6	V	Spawning
7	VI	Spawning
8	VII	Spent
9	VIII	Resting

tblNetOrientation

The net orientation using the shore as the horizontal was recorded (Table 25).

Table 25 Service table for net orientation

NetOrientationID	NetOrientation
1	Parallel
2	Perpendicular
3	Diagonal
4	Not Recorded

tblPresenceCriteria

The presence of other freshwater fish were recorded as part of the juvenile surveys, the criteria are shown in Table 26.

Table 26 Service table for presence criteria of freshwater fish

CriteriaID	Presence Criteria	Quantity
1	None	Zero
2	Present	1-10
3	Common	10-50
4	Abundant	50Plus

tblRegionalAssignments

Regional assignments were used to characterise genetic assignments. The categories in Table 27 were those developed by task 4.

Table 27 Service table for regional assignments of fish by genetics

Regional Assignment ID	Regional Assignment Code	Regional Assignment Name	Geographic Area Covered
1	WIre	WestIreland	Currane
2	SIre	SouthIreland	Old Head of Kinsale to Carnsore Point
3	SEIre	SouthEastIreland	Carnsore Point to Howth
4	NEIre	NorthEastIreland	Howth to Carlingford Lough
5	NIre	NorthIreland	Northern Ireland
6	IOM	IsleOfMan	Isle of Man
7	SolMcm	SolwayMorcambe	Solway Firth, Morecambe Bay
8	NWal	NorthWales	North Wales
9	WWal	WestWales	West Wales, Cardigan Bay
10	SWal	SouthWales	South Wales, Bristol Channel

tblRunType

The run type was characterised by the colouration of the fish and how long they had been in the river since entering to spawn (Table 28).

Table 28 Service table for run type of returning adults to river

RunID	RunType
1	Fresh
2	Stale
3	Do Not Know

tblSampleMonth

The month the samples were collected were stored as numeric information (Table 29), where no data was recorded, month 13 was allocated.

Table 29 Service table for month

MonthID	MonthName
1	January
2	February
3	March
4	April
5	May
6	June
7	July

8	August
9	September
10	October
11	November
12	December
13	No Data

tblSamplerName

The name of the sampler and contact details were recorded if written on the scale envelopes. For data protection this information is not included here.

tblSampleTime

The time of day was recorded as daytime or night time (Table 30).

Table 30 Service table for time of day

SampleTimeID	SampleTime
1	Day
2	Night
3	Unknown

tblSampleType

To account for the different samples which were sent by partner institutions or that were donated to the project, the sample type was recorded (Table 31).

Table 31 Service table for type of sample

SampleTypeID	SampleType
1	Whole Body
2	Head & Guts
3	Head Only
4	Scale Packet Only
5	Scale & Genetic Sample

tblSampleYear

The year the samples were collected were recorded under short numeric id's. Initially recorded in sequence however more samples were added from earlier years (Table 32).

Table 32 Service table of year samples were collected

YearID	SampleYear
1	1995
2	1996
3	1997
4	1998
5	1999
6	2000
7	2001
8	2002
9	2003
10	2004
11	2005

12	2006
13	2007
14	2008
15	2009
16	2010
17	2011
18	2012
19	1982
20	1984
21	1986

tblSamplingCatchMethod

Many different sampling and catch methods were utilised to obtain samples. The sampling type was recorded as the simplest version of equipment used and categorised by angler, commercial or scientific source (Table 33), with additional information relating to specific equipment dimensions recorded in tblMarineSurveySheets (Table 5).

Table 33 Service table of sampling catch methods categorised by A, C or S.

CatchMethodID	CatchMethod	ACS linked to Table 17
1	Fly	A
2	Spin	A
3	Bait	A
4	Not Recorded	A
5	Gill Net	C
6	Draft Net	C
7	Seine Net	C
8	Trawl Net	C
9	Haaf Net	C
10	Coracle	C
11	Compass Net	C
12	Stake Net	C
13	Coastal Net	C
14	Drift Net	C
15	Seine Net	S
16	Gill Net	S
17	Trawl Net	S
18	Electrofishing	S
19	Fish Trap	S
20	Fish Kill	S
21	Unknown	C
22	Fish Trap	A
23	Cobble Net	C
24	Fyke Net	S
25	Draft Net	S
26	Drift Net	S
29	Trammel Net	S

tblSex

The sex of the fish where determined was recorded as either female or male. Where sex was examined but could not be determined the category of indeterminate was utilised. If an animal was not examined then the final category was recorded (Table 34).

Table 34 Service table of sex

SexID	Sex
1	Female
2	Male
3	Indeterminate
5	Not Examined

tblSiteSelectionCriteria

The sites were selected according to the criteria recorded in Table 35.

Table 35 Service table of site selection criteria

SiteSelectionCriteriaID	SiteSelectionCriteria
1	Local Knowledge
2	Random
3	Strategic Survey

tblTideState

State of tide was recorded (Table 36).

Table 36 Service table of state of tide

TideStateID	TideState
1	Ebbing
2	Flooding
3	HW slack
4	LW slack
5	Not Recorded
6	Both

tblTributary

The names of the tributary of the main rivers were recorded (Table 37).

Table 37 Service table of tributary name

TribID	TribName	RiversID linked to Table 1
E01A	Twiston Beck	RIBB
E01B	Dunsop	RIBB
E03A	Ellergill Beck	LUNE
E03B	Austwick Beck	LUNE
E04A	Mint	KENT
E04B	Lambrigg Beck	KENT
E06A	Lickle	DUDD
E06B	Appletree Worth Beck	DUDD
E06C	Black Sike Beck	DUDD
E07A	Main River - Cumbrian Esk	ESKC
E07B	Whillan Beck	ESKC
E07C	Stanley Ghyll Beck	ESKC
E07D	Eel Beck	ESKC
E07E	Blea Beck	ESKC
E07F	Spothow Gill	ESKC
E08A	Main River - Irt	IRT
E08B	Mecklin Beck	IRT
E08C	Bleng	IRT

E08D	Kid Beck	IRT
E08E	Cinderdale Beck	IRT
E09A	Main River - Calder	CALD
E09B	Worm Gill	CALD
E10A	Kirk Beck	EHEN
E11A	Marron	DERW
E13A	Sunnygill Beck	EDEN
I01A	Main River - Monecarragh	MONN
I02A	Main River - Moygannon	MOYG
I03A	Main River - Ryland	RYLA
I04A	Main River -Cooley	COOL
I05A	Main River - Flurry	FLUR
I06A	Main River - Castletown	CAST
I06B	Creggan	CAST
I07A	Main River - Fane	FANE
I08A	Main River - Glyde	GLYD
I08B	Cormey	GLYD
I09A	Main River - Dee White River	DEWR
I11A	Trimblestown	BOYN
I11B	Mattock	BOYN
I12A	Main River - Nanny	NANN
I14A	Main River - Turvey	TURV
I15A	Main River - Broadmeadow	BROA
I16A	Rye	LIFF
I17A	Main River - Dodder	DODD
I18A	Main River- Dargle	DARG
I19A	Main River - Three Mile Water	TMWR
I20A	Main River - Vartry	VART
I21A	Main River - Potters	POTT
I22A	Main River - Redcross	REDC
I23A	Avonmore	AVOC
I23B	Derry	AVOC
I24A	Main River - Inch	INCH
I25A	Main River - Owenavarragh	OWVR
I27A	Main River - Sow	SOWi
I28A	Boro	SLAN
I28B	Urinn	SLAN
I28C	Boro - Aughnagappal	SLAN
I29A	Main River - Duncormick	DUNC
I30A	Main River - Owenduff	OWDF
I31A	Main River - Corock	CORO
I33A	Ballygallon Stream	NORE
I34A	Main River - Campile	CAMP
I35A	Blackwater	SUIR
I36A	Main River - Mahon	MAHO
I37A	Main River - Tay	TAYi
I38A	Main River - Colligan	COLL
I39A	Douglas	BRID
I39B	Glenaboy	BRID
I41A	Main River - Womanagh	WOMA
I42A	Main River - Owenacurra	OWCA
I43A	Cloughnagashen	GLSH
I44A	Aughnboy	OWBY
I45A	Brinney	BAND
I45B	Bridewell	BAND
I46A	Main River - Argideen	ARGI
I46B	Reanagar	ARGI
I47A	Renagh	ILEN

I48A	Commeragh	CURR
I48B	Finglas	CURR
I48C	Cloughvoola	CURR
I48D	Cappamore	CURR
I48E	Halliseys	CURR
I48F	Capall	CURR
I48G	Comavoher	CURR
I48H	Comavanniha	CURR
I49A	Owroe	INNY
I49B	Kealnenachrie	INNY
I49C	Toorcladine	INNY
N01A	Ballinrae	STBL
N02A	Main River Shimna	SHIM
N05A	Main River - Ghan	GHAN
S01A	White Lyne	ESKB
S01B	Kirk Beck	ESKB
S01C	Liddel Water	ESKB
S01D	Tinnis Burn	ESKB
S01E	Different Beck	ESKB
S01F	Roughley Burn	ESKB
S01G	Caddroun Burn	ESKB
S01H	Tarras Water	ESKB
S01I	Little Beck	ESKB
S01J	Wauchope Water	ESKB
S01K	Ewes Water	ESKB
S01L	Boyken Burn	ESKB
S01M	Meggat Water	ESKB
S01N	Stennies Water	ESKB
S02A	Dryfe Water	ANNA
S02B	Water of Ae	ANNA
S02C	Windyhill Burn	ANNA
S03A	Mennock Water	NITH
S03B	Wanlock Water	NITH
S06A	Barley Burn	FLEE
S07A	Palnure Burn	CREE
S07B	Penkiln Burn	CREE
S09A	Lady Burn	LUCE
S10O	Effgill Hope Burn	ESKB
S10P	Black Esk	ESKB
W01A	Main River - Tawe	TAWE
W02A	Aman	LOUG
W04A	Sawdde	TYWI
W05A	Main River - Taf	TAF
W06A	Anghof	WCLE
W07A	Brynberian	NEVE
W08A	Cych	TEIF
W08B	Nant Bargod	TEIF
W08C	Cerdin	TEIF
W09A	Mydr	AERO
W11A	Melindwr	RHEI
W12A	Cerist	DYFI
W14A	Nant Pwll-y-gele	MAWD
W16A	Teigl	DWYR
W17A	Nant Colwyn	GLAS
W18A	Dwyfach	DWYF
W19A	Nant Tal-y-mignedd	LLYF
W22A	Ffydlas	OGWE
W23A	Roe	CONW

W24A	Deunant	CLWY
W25A	Eglwyseg	DEEw
W25B	Ceiriog	DEEw
X01A	Main River- Glass	GLSS
X02A	Main River - Neb	NEB
X03A	Main River - Sulby	SULB
X03B	Glen Auldyn	SULB

tblWaterLevel

Water levels at freshwater sites were recorded (Table 38).

Table 38 Service table of river water level

WaterLevelID	WaterLevel
1	Low
2	Medium
3	High

Where a question was asked which required a yes or no response Table 39 was linked to it. The option of do not know was included where a response was not recorded.

Table 39 Service table of response to yes/no questions

YesNoID	YesNo
1	Yes
2	No
3	Do Not Know

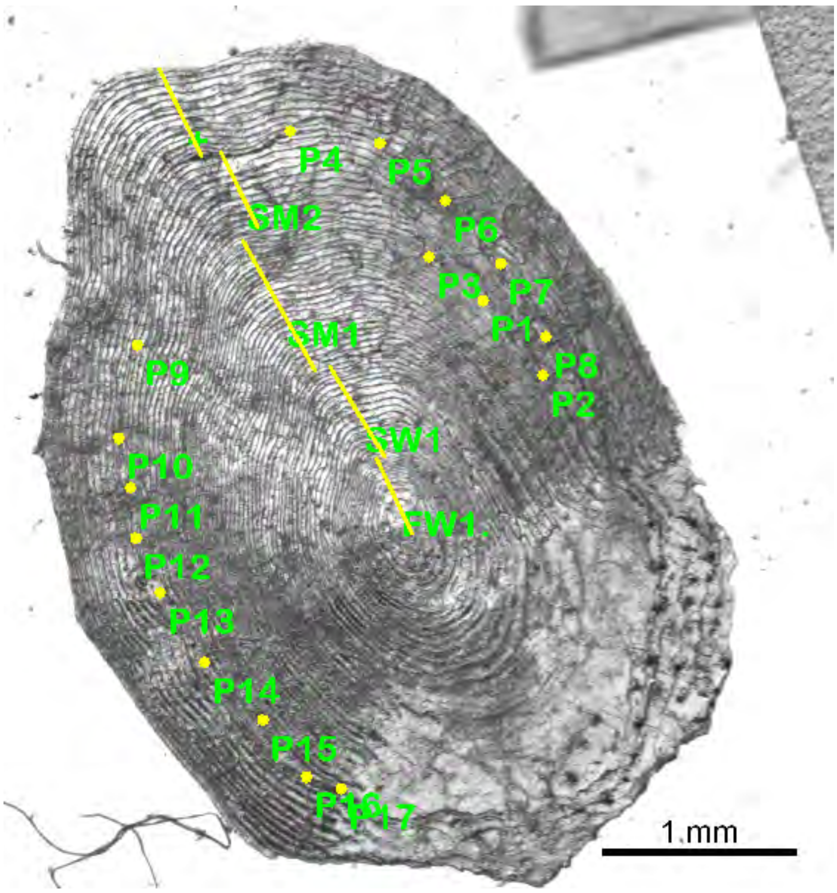
Section 3.20 CSTP procedure for scale image collection, ageing, and data recording:

Image Capture:

1. Set the microscope lens to 20x
2. Open *ImagePro 7*
3. Click on: Measure>Calibration>Spatial>Select "CSTP Leica 20x" and choose units "mm".
4. Click on: Measure>Calibration>Set System>Select Active Lens and System Calibration as "CSTP Leica 20x".
5. Click on: "videocamera icon" (Adquire>Video/digital picture)
6. Choose your settings.
7. Preview, focus image and click "snap"
8. Select image, then click on: Measure>Calibration>Select Spatial> Select "CSTP Leica 20x". Then click on "Marker". Select Colour: "Black" and "1 unit" and Ok.
9. To check that the calibration is correct (only needed for the first scale): Measure>Measurements> Select line and draw a line over the "Marker" and check the measurement is near 1mm. Then delete all features by clicking the red cross.
10. To save the image: click on the "camera icon" (Measure>Snap measurements), and then on the "Save" icon (File>Save or Ctrl+S)
11. Save file with the agreed name (Country-RiverCode-Year-Individual-ScaleAorB) in a blank image folder.

Scaled reading protocol for a labelled image:

12. Zoom into scale, then add lines for each phase the fish has gone through (first year in freshwater, second year, migration to sea, first spawning….). Click on: Measure>Measurements>Select straight line, and then draw lines between the starting and end points of each life phase. Draw the lines slightly off from one another so that the beginning of one is not confused with the end of another. If there are spawning marks (SM), indicate where in the scale you think you see evidence of scale erosion with “crossed circles” or a line. Change the names of the lines, by going in to Measurement/Measurements tab and clicking in each “feature”, change the name accordingly (FW1,FW2, SW1, SM1….). In the Options tab, you can choose whether to show the measurement value or not, and in “Edit settings”, change the line thickness to 3 and the Feature labels to “Arial Round” and size 36. Apply and Ok.
13. Once all the labelling is completed, save by clicking on the “camera” and “save” buttons. Save with the same name as the blank image but with scale reader initials at the end to indicate that the image has been analysed. Once finished with an imaging/reading session move all the analysed images to another folder.
14. Record the scale readings onto the Excel spreadsheet.



Scale reading input files:

Dynamic Excel files (CSTP-ScaleReadingForm.xlsm) for scale reading data were constructed to automate and accelerate the scale reading process. Individual CSTP fish codes (e.g. W-TAWE-12-045) are concatenated following filling of fields for country, river and year of sampling and lists of individual fish by row. Specific columns are used to add parr age (*FW*), migration to sea (.), plus growth (+), sea winters (*SW*), indeterminate winters (*IM*) and spawning marks (*SM*), in addition to tick boxes to indicate B growth and whether the reader deems any uncertainties in any of the particular phases (i.e. *FW.x, SW?* Table 8.4.1).

Table 8.4.1: List of tick boxes for common scale reading issues

fw.x	<=	Fresh water features unclear
replc	<=	replacement scale
B	<=	B growth between fresh and marine growth
sw.x?	<=	Extra sea winters? Number of SW unclear.
im.x?	<=	Extra indeterminate marks? Number of IM unclear
sm.x?	<=	Extra spawning marks? Number of SM unclear.
sw/sm?	<=	unclear adult winter marks

The input file automatically completes fields for *length*, *weight*, *capture month* and sex by querying the CSTP capture information database. Upon entry of ageing data, the scale reading file automatically constructs the fields including ID name, *total age*, *sea age*, and *formula* (with and without B growth).

Appendix 4

(No content)

Appendix 5

(No content)

Appendix 6

A number of organisations contributed data included in Appendix 6:

England:

Catchment-based environmental variables: digital elevation model (Nextmap DEM - a 50 metre resolution elevation model) and from the Land Cover Map 2000.

Geological data: British Geological Society 1:625000 maps adapted for development of Water Framework Directive river and lake typologies

Flow statistics for the river at head of tide were derived from the Low Flows Enterprise Model (Wallingford Hydrosolutions 2008).

Wales: Natural Resources Wales

Republic of Ireland: the Wetted Area model (McGinnity et al. 2012). Includes Ordnance Survey Ireland data reproduced under OSi Licence number MP 007508.

Land use data for Ireland were from the CORINE project (Environmental Protection Agency 2000).

Northern Ireland - AFBI - R.J Kennedy

Scotland: WFD river Basin plans published by SEPA, and from specific data requests to SEPA via the Boards and Trusts. See separate Data Notice from SEPA

Scottish Data also from the following Fisheries Boards and Trusts:

Nith District Salmon Fishery Board

River Annan District Fishery Board

Galloway Fisheries Trust

Catchment environmental and fishery variables (Please see Table 6.6.3 for explanations)

Principal CSTP rivers	NAME	UK NGR Location of outflow point	Latitude - Decimal	Logitude - decimal	Easting	Northing
	Nevern & Associated Tribs	SN 0627039536	52.020	-4.825	206270	239536
	Aeron	SN 4578562794	52.242	-4.260	245785	262794
	Dysynni	SH 5958603102	52.607	-4.075	259586	303102
	Tawe	SS 6610293240	51.622	-3.936	266102	193240
	Calder	NY 0249402701	54.410	-3.504	302494	502701
	Western Cleddau	SM 9554715556	51.801	-4.967	195547	215556
	Llyfni	SH 4321352997	53.051	-4.341	243213	352997
	Gwendraeth Fawr	SN 4111805542	51.726	-4.302	241118	205542
	Dwyfor	SH 4785537261	52.911	-4.264	247855	337261
	Loughor	SN 5831902839	51.706	-4.052	258319	202839
	Seiont	SH 4852661414	53.128	-4.265	248526	361414
	Glaslyn	SH 5925341339	52.951	-4.096	259253	341339
	Ogwen/Ddu	SH 6038371560	53.223	-4.093	260383	371560
	Ystwyth	SN 5814179964	52.399	-4.087	258141	279964
	Artro	SH 5806727530	52.827	-4.108	258067	327530
	Rheidol	SN 5945380325	52.403	-4.067	259453	280325
	Ehen and Keekle	NY0192203550	54.418	-3.513	301922	503550
	Ellen	NY 0388736339	54.713	-3.493	303887	536339
	Irt	SD 0716698855	54.377	-3.431	307166	498855
	Duddon	SD 2014987595	54.278	-3.228	320149	487595
	Tywi	SN 4502820576	51.862	-4.252	245028	220576
	Taf	SN2622015310	51.809	-4.522	226220	215310
	Teifi	SN 1932343513	52.060	-4.637	219323	243513
	Dyfi	SN 7188999372	52.577	-3.892	271889	299372
	Mawddach	SH 7182119313	52.756	-3.901	271821	319313
	Conwy	SH 7902263506	53.155	-3.811	279022	363506
	Clwyd	SJ 0325776680	53.278	-3.452	303257	376680
	Eden (NW)	NY 3556460041	54.931	-3.007	335564	560041
	Leven	SD 3405483508	54.243	-3.013	334054	483508
	Wyre (NW)	SD 4585541110	53.863	-2.825	345855	441110
	Derwent	NY 0040629131	54.647	-3.545	300406	529131
	Esk (Scottish Border)	NY 3555064921	54.975	-3.008	335550	564921
	Dee	SJ 4077165829	53.186	-2.888	340771	365829
	Ribble	SD 5645028407	53.750	-2.662	356450	428407
	Lune	SD 4816463282	54.063	-2.793	348164	463282
	Kent	SD 4839984341	54.252	-2.794	348399	484341
	Esk	SD 12168 97530	54.366	-3.353	312168	497530
	Dwyryd	SH 6647840746	52.947	-3.989	266478	340746
	Gwyrfai	SH 4576159247	53.108	-4.306	245761	359247
minor CSTP rivers	Wye	SO 5338005095	51.743	-2.677	353380	205095
	Usk	ST 3855794729	51.648	-2.889	338557	194729
	Severn	SO 8180721671	51.893	-2.266	381807	221671
	Neath	SS 7646498611	51.673	-3.788	276464	198611
	Annas	SD 0767788474	54.284	-3.420	307677	488474
	Bela	SD 4882381450	54.226	-2.787	348823	481450
	Black Beck	SD 1906784147	54.247	-3.244	319067	484147
	Keer	SD 4913371358	54.136	-2.780	349133	471358
	Aber	SH 6491273556	53.242	-4.026	264912	373556
	Afan	SS 7605489750	51.593	-3.791	276054	189750
	Arth	SN 4786564018	52.253	-4.230	247865	264018
	Cleddau (Eastern)	SN 0636814676	51.797	-4.810	206368	214676
	Erch	SH 3819035398	52.892	-4.407	238190	335398
	Ogmore	SS 8762276536	51.477	-3.620	287622	176536
	Gwaun	SM 9626937115	51.995	-4.969	196269	237115
	TAFF	ST 1706678079	51.496	-3.196	317066	178079
	Cegin (Menai Strait)	SH 5919872592	53.232	-4.111	259198	372592
	Ebbw	ST 3044985693	51.566	-3.005	330449	185693
	Leri	SN 6160089842	52.489	-4.040	261600	289842
	Dulas (Colwyn Bay)	SH 9114178715	53.294	-3.635	291141	378715
	Rhymney	ST 2086779883	51.512	-3.142	320867	179883
	Ely	ST 1491576633	51.482	-3.227	314915	176633
	Cefni	SH 4573772798	53.230	-4.313	245737	372798
	Ysgethin (Barmouth)	SH 5761721778	52.775	-4.112	257617	321778
	Wygyr (Anglesea)	SH 3724193467	53.413	-4.450	237241	393467
	Coron Lake (Anglesea)	SH 3575369233	53.195	-4.460	235753	369233
Solway rivers						
	Annan	NY 19009 68229	55.002	-3.268	319009	568229
	Nith	NX 96954 76030	55.068	-3.615	296954	576030
	Urr	NX 82139 60888	54.929	-3.841	282139	560888
	Dee	NX 69511 53540	54.860	-4.034	269511	553540
	Fleet	NX 59471 57007	54.888	-4.192	259471	557007
	Cree	NX 41655 64541	54.950	-4.474	241655	564541
	Bladnoch	NX 40829 54849	54.863	-4.482	240829	554849
	Luce	NX 19639 55797	54.864	-4.812	219639	555797
Irish Rivers	Shimna					
	Argideen		51.662	-8.777	146259.79	45778.22
	Bandon		51.765	-8.682	154013.43	57160.41
	Boyne		53.750	-6.428	303853	275731.55
	Castletown		54.187	-6.419	303690.19	309002.96
	Colligan		52.106	-7.457	224325.25	94906.3
	Currane/Waterville system		51.820	-10.176	50026	65228.63
	Dargle		53.209	-6.102	326802.72	219240.61
	Dee		53.872	-6.355	308240.13	292631.72
	Glyde		53.888	-6.363	307705.08	294388.91
	Slaney		52.454	-6.562	297808.02	134562

NAME	CATCHMENT _AREA KM2 - Land area upstream of head of tide	DISTSOURCE	SHREVE stream order at the head of tide	STRAHLER stream order at the head of tide	AVERAGE upstream elevation of catchment (land and water)	TRUE RIVER GRADIENT M/KM from modelled river network** E&W
Nevern & Associated Tribs	115.00	20289	79	5	155.86	54.19
Aeron	159.00	32781	86	4	184.74	54.00
Dysynni	106.50	20300	3	2	48.08	112.03
Tawe	260.00	47249	248	5	256.01	88.91
Calder	45.00	17297	55	4	271.23	67.81
Western Cleddau	313.00	38773	158	5	88.97	32.38
Llyfni	48.00	15348	31	3	247.67	82.56
Gwendraeth Fawr	75.00	23809	49	4	99.95	47.27
Dwyfor	109.00	21543	75	4	202.28	59.33
Loughor	241.00	33867	195	5	164.64	62.71
Seiont	81.00	24588	70	4	311.53	139.84
Glaslyn	137.00	28048	217	5	258.71	118.98
Ogwen/Ddu	85.00	21219	51	4	431.65	133.58
Ystwyth	191.00	43489	174	4	246.85	82.56
Artro	62.00	14532	38	4	260.18	76.02
Rheidol	187.00	45111	199	5	335.05	94.49
Ehen and Keekle	155.00	38629	148	5	202.65	88.20
Ellen	130.00	37578	78	4	143.24	44.22
Irt	115.00	29964	128	4	240.79	127.45
Duddon	115.00	25564	184	5	268.39	139.25
Tywi	1350.00	110824	1028	6	215.86	77.74
Taf	441.00	43918	230	5	122.81	53.63
Teifi	996.00	111920	507	5	198.55	50.36
Dyfi	534.00	49219	588	6	272.95	152.17
Mawddach	355.00	32690	375	6	307.10	51.18
Conwy	546.00	54116	606	6	310.50	96.01
Clwyd	806.00	53906	481	6	199.57	55.15
Eden (NW)	2339.00	134629	1605	6	241.96	65.06
Leven	305.00	44050	500	6	209.09	144.32
Wyre (NW)	433.00	56515	374	6	95.85	40.83
Derwent	679.00	71690	708	6	266.44	122.10
Esk (Scottish Border)	-	-	-	-	-	4.48
Dee	1985.00	158854	1506	6	223.45	60.96
Ribble	1861.00	119141	1891	6	165.34	45.48
Lune	1101.00	90805	1600	6	251.40	41.90
Kent	468.00	45360	407	6	159.73	26.62
Esk	109.00	26839	118	4	239.99	122.16
Dwyryd	165.00	28265	216	5	302.59	82.23
Gwyrfai	54.00	21250	46	3	258.74	96.31
Wye	4058.00	241829	2499	7	226.74	59.64
Usk	1118.00	109244	917	6	272.72	93.35
Severn	9961.00	284342	4877	7	144.60	37.30
Neath	253.00	37855	285	5	290.24	99.71
Annas	44.00	13920	42	4	190.00	72.28
Bela	131.00	28915	88	5	133.27	35.93
Black Beck	11.00	9396	12	3	215.11	63.37
Keer	59.00	13682	34	4	72.71	29.57
Aber	22.00	9007	6	2	467.54	207.16
Afan	91.00	24749	121	4	301.63	130.59
Arth	32.00	15171	19	3	193.53	44.11
Cleddau (Eastern)	207.00	27218	121	4	141.91	45.79
Erch	54.00	17763	29	4	124.04	30.03
Ogmore	273.00	28976	252	5	153.69	73.84
Gwaun	44.00	15423	22	3	194.36	75.16
TAFF	507.00	63510	500	6	297.39	49.56
Cegin (Menai Strait)	25.00	12426	11	3	134.53	40.78
Ebbw	225.00	46400	146	4	300.45	92.63
Leri	51.00	19689	38	4	248.00	81.75
Dulas (Colwyn Bay)	47.00	13542	38	4	174.35	43.59
Rhymney	202.00	53090	170	5	212.08	70.18
Ely	158.00	32174	161	5	100.69	44.62
Cefni	84.00	18108	46	4	56.04	14.03
Ysgethin (Barmouth)	14.00	10541	13	3	352.89	78.35
Wygyr (Anglesea)	28.00	10707	16	3	49.22	15.05
Coron Lake (Anglesea)	37.00	11371	19	4	39.94	10.56
Annan	960.00	67140				6.82
Nith	1230.00	86400			262.00	4.86
Urr	316.80	43200				
Dee	1020.00	75500				
Fleet	144.10	25200				
Cree	433.20	54600				
Bladnoch	384.00	48700				
Luce	202.20	29200				
Shimna		66000			400.00	29.20
Argideen	133.89	26030.1	62	4	123.30	0.45*
Bandon	512.52	55460.2	346	6	120.70	0.58*
Boyne	2532.11	98091.3	917	6	177.50	0.10*
Castletown	217.92	39349.7	84	4	50.30	0.74*
Colligan	106.85	24015.4	69	4	184.80	1.75*
Currane/Waterville system	116.68	24069.5	182	5	184.40	2.34*
Dargle	129.23	22638.5	111	5	10.70	2.37*
Dee	389.32	58836.2	155	5	82.60	0.23*
Glyde	359.44	53206.6	123	5	69.20	0.32*
Slaney	1319.18	97167.3	955	6	121.80	0.70*

* Irish Gradients are main stem only

** differs from that derived from DRN

NAME	USACIDG	USARABL	USBLWOO	USBOG12	USBRACK	USCALCG	USCONWO	USHEATH	USIMPGR	USNEUTG	USSALT2	USSETGR	USSUBUR	USURBAN
Nevern & Associated Tribs	16	13	8	0	2	3	2	1	44	7	0	0	3	1
Aeron	2	4	8	0	0	7	2	1	71	2	0	0	2	0
Dysynni	7	3	6	0	0	13	1	0	54	2	0	0	0	1
Tawe	12	2	8	0	8	5	4	9	19	20	0	0	10	1
Calder	13	7	3	10	12	0	3	6	16	28	0	0	0	2
Western Cleddau	5	13	3	0	1	5	2	1	65	1	0	0	3	0
Llyfni	38	0	4	0	0	7	1	9	23	7	0	0	2	0
Gwendraeth Fawr	1	2	12	0	0	6	1	2	58	5	0	0	8	0
Dwyfor	25	1	4	0	0	6	3	7	32	15	0	0	1	0
Loughor	9	2	6	0	1	5	2	8	47	12	0	0	6	0
Seiont	38	1	8	0	0	1	2	9	18	6	0	0	3	1
Glaslyn	39	1	14	0	1	2	7	12	16	3	0	0	0	0
Ogwen/Ddu	41	1	6	0	0	3	2	13	8	12	0	0	2	1
Ystwyth	24	2	4	0	0	2	13	3	47	2	0	0	2	0
Artro	36	0	11	1	0	1	0	25	15	8	0	0	0	0
Rheidol	43	1	3	5	0	1	14	4	22	1	0	0	2	0
Ehen and Keekle	12	11	6	0	10	8	5	7	28	8	0	0	2	0
Ellen	3	13	4	0	1	6	1	1	67	1	0	0	3	1
Irt	17	5	5	0	25	1	4	3	20	15	0	0	1	0
Duddon	9	3	6	8	24	0	5	3	11	28	1	0	0	0
Tywi	16	3	7	0	1	2	13	2	52	2	0	0	2	0
Taf	6	8	5	0	1	3	2	2	70	1	0	0	2	0
Teifi	7	6	7	0	0	4	5	1	63	3	0	0	2	0
Dyfi	34	1	10	0	1	2	20	5	21	4	0	0	0	0
Mawddach	37	0	10	1	1	1	18	12	8	10	0	0	0	0
Conwy	32	1	7	0	0	3	10	12	15	15	0	0	1	0
Clwyd	17	4	11	0	0	9	5	3	40	7	0	0	2	0
Eden (NW)	9	9	5	3	4	7	4	3	43	9	0	0	2	1
Leven	9	4	18	1	18	2	7	3	17	13	0	0	1	0
Wyre (NW)	3	15	5	2	0	6	0	8	42	6	0	0	7	3
Derwent	20	5	7	2	13	6	4	7	29	4	0	0	1	1
Esk (Scottish Border)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dee	17	10	6	0	0	9	6	8	29	6	0	0	4	2
Ribble	4	9	7	2	0	10	1	4	35	13	0	0	9	4
Lune	12	2	4	3	2	8	1	5	35	21	0	0	2	1
Kent	7	9	8	1	7	9	1	2	46	6	0	0	2	1
Esk	25	7	5	2	25	2	2	3	13	12	0	0	0	0
Dwyryd	46	0	9	0	1	1	11	10	9	4	0	0	1	0
Gwyrfai	37	1	6	0	0	2	7	7	24	7	0	0	2	0
Wye	10	17	8	0	2	9	5	4	32	6	0	1	1	1
Usk	6	5	9	0	4	11	4	12	34	11	0	0	1	0
Severn	4	30	9	0	0	8	3	1	29	4	0	2	5	3
Neath	11	3	8	0	4	4	17	11	13	19	0	0	4	1
Annas	19	11	2	13	12	3	0	1	27	11	0	0	0	0
Bela	2	6	6	0	2	8	0	0	65	5	0	0	3	2
Black Beck	14	15	1	19	1	0	1	3	23	21	0	0	0	1
Keer	0	7	10	0	0	9	2	0	60	1	0	0	5	4
Aber	50	0	9	0	1	0	8	19	5	2	0	0	0	0
Afan	16	1	4	2	3	0	43	6	11	3	0	0	4	1
Arth	2	3	5	0	2	8	7	1	62	6	0	0	3	0
Cleddau (Eastern)	12	11	3	0	1	8	5	1	51	5	0	0	2	1
Erch	6	1	4	0	1	19	4	2	41	18	0	0	1	0
Ogmore	9	8	12	0	2	2	6	2	39	6	0	0	10	2
Gwaun	18	6	6	0	1	0	4	1	57	3	0	0	3	0
TAFF	17	3	9	2	4	3	11	9	14	13	0	0	10	3
Cegin (Menai Strait)	8	4	11	0	0	3	11	2	41	17	0	0	4	0
Ebbw	22	4	8	0	2	1	9	20	12	4	0	0	13	3
Leri	41	2	3	2	1	1	7	1	40	0	0	0	1	0
Dulas (Colwyn Bay)	26	6	7	0	0	4	5	1	48	1	0	0	1	0
Rhymney	10	7	13	0	1	3	4	9	27	8	0	0	14	3
Ely	2	8	18	0	0	3	2	0	46	5	0	0	13	2
Cefni	0	6	5	0	0	13	3	0	69	1	0	0	2	0
Ysgethin (Barmouth)	68	0	3	0	1	0	0	6	8	9	0	0	1	0
Wygyr (Anglesea)	0	10	2	0	0	10	1	0	75	0	0	0	1	0
Coron Lake (Anglesea)	0	4	3	0	0	15	0	0	74	0	0	0	1	0
Annan	1		2				27		70	1				1
Nith	11		3	1		5	15		50	5	1		3	2
Urr														
Dee														
Fleet														
Cree														
Bladnoch														
Luce														
Shimna														
Argideen														
Bandon														
Boyne				Irish land cover estimated using Corine system - see separate entry										
Castletown														
Colligan														
Currane/Waterville system														
Dargle														
Dee														
Glyde														
Slaney														

NAME	GEO_CAL_%_	GEO_PEA	GEO_SAL	GEO_SIL	Alkalinity mean	Total Hardness mean as caco3	Total Catchment wetted area(from 1:250k)* differs from DRN-derived	Total catchment stream length (m) (from 1:250k)* differs from DRN-derived	% total stream length ≤ strahler order3 (from DRN)	Mean distance from head of tide of all reaches ≤ strahler order 3 (m) (from DRN)	total number of barriers	Number of significant and impassable barriers to migration
Nevern & Associated Tribs	6.36	0.00	0.00	93.57	21.75	50.72	714071	332293	83.05	9959.61	11	1
Aeron	0.00	0.00	0.00	100.00	21.97	80.24	1002528	407899	85.25	18204.67	14	1
Dysynni	6.26	0.00	0.00	93.28	6.34	13.64	1194480	461893	81.81	11181.03	57	3
Tawe	38.87	0.71	0.00	60.42	82.75	91.88	3019579	985665	82.05	23507.67	224	0[#]
Calder	37.72	23.95	0.00	38.33	27.89	84.01	364802	115960	84.78	11267.09	2	2
Western Cleddau	8.50	0.13	0.00	91.38	30.87	194.79	3156413	1396931	82.15	14846.77	6	2
Llyfni	0.00	0.08	0.00	99.92	13.98	48.68	351659	183261	79.26	9425.50	17	1
Gwendraeth Fawr	75.79	0.00	0.00	24.11	149.95	235.99	644062	283553	85.19	12279.06	1	0
Dwyfor	1.79	9.57	0.00	88.62	20.72	41.76	1150348	528357	79.93	12757.24	19	0
Loughor	41.20	0.49	0.00	58.31	99.65	282.19	2348446	908930	82.77	14724.46	63	3
Seiont	0.59	0.01	0.00	99.40	10.86	132.29	743261	291781	80.63	16305.31	49	1
Glaslyn	5.14	0.00	0.00	94.58	14.35	33.10	1901184	613370	85.46	16023.72	76	5
Ogwen/Ddu	2.49	3.14	0.00	94.37	10.97	98.45	750551	273441	79.02	12467.54	37	0
Ystwyth	0.00	0.00	0.00	99.99	10.80	44.00	1427149	463215	87.36	22245.00	41	4
Artro	0.00	2.65	0.00	97.18	7.08	16.84	517152	239853	77.96	6535.19	19	0
Rheidol	0.00	12.88	0.00	87.12	8.45	29.21	1471284	417672	83.47	25906.14	36	4
Ehen and Keekle	44.85	1.35	0.00	53.79	47.30	142.73	1286988	458296	85.03	22766.12	21	5
Ellen	78.20	0.07	0.00	21.70	126.21	202.75	721481	314835	84.67	22317.60	11	1
Irt	41.50	1.73	0.00	56.69	25.38	39.91	1033352	357362	83.49	18722.20	38	4
Duddon	21.87	14.48	0.00	63.47	15.84	13.49	1111698	430227	87.35	12424.44	22	0
Tywi	15.37	0.77	0.00	83.80	31.21	51.30	11197263	3668880	84.19	40005.46	90	8
Taf	8.65	0.00	0.00	91.29	32.13	93.93	2911867	1252570	80.40	16424.37	20	0
Teifi	0.00	1.54	0.00	98.43	18.30	50.87	6785866	2239214	82.31	52443.35	74	12
Dyfi	0.00	1.04	0.00	98.93	10.59	26.14	4509636	1688045	85.66	23311.95	94	17
Mawddach	3.87	1.62	0.00	93.40	9.00	13.92	3493841	1498547	84.71	10258.25	88	0
Conwy	6.69	1.87	0.00	91.04	12.80	41.27	5067976	2085291	84.58	16161.93	130	8
Clwyd	87.24	0.67	0.00	12.05	88.48	220.05	4660272	1838896	83.27	26759.16	41	4
Eden (NW)	59.21	10.31	0.00	30.47	110.91	200.85	18609661	5370952	82.97	74966.55	1006	27
Leven	8.41	2.35	0.00	89.24	23.51	22.69	2587036	1229857	88.80	25850.77	186	4
Wyre (NW)	60.14	12.29	0.31	26.22	114.91	183.94	3331144	1387669	84.99	15634.06	68	6
Derwent	21.47	6.08	0.00	72.45	43.27	70.00	5895129	2165470	86.23	41363.31	180	4
Esk (Scottish Border)	-	-	-	-	-	-	3932996	959705			40	3
Dee	54.04	1.20	1.31	43.42	106.05	153.23	14854130	4723424	82.84	84246.74	302	32
Ribble	66.01	6.03	0.00	27.80	109.75	218.22	16816286	5408367	84.25	31767.92	564	24
Lune	31.35	7.80	0.00	60.51	75.33	148.44	11178183	3801217	87.98	46805.21	535	45
Kent	35.07	1.82	0.00	62.26	85.86		3813607	1480393	85.45	25344.61	154	12
Esk	36.53	5.79	0.00	57.44	15.78	9.09	881122	360485	84.24	12245.41	40	3
Dwyryd	1.47	1.20	0.00	96.92	7.45	23.85	1406309	697319	84.55	8934.45	55	0
Gwyrfai	5.25	0.00	0.00	94.75	8.85	120.22	573608	276426	82.70	13180.17	16	2
Wye	70.33	0.34	0.00	29.33	125.87	160.36	33235461	8865729	82.34	########	411	6[#]
Usk	95.83	0.55	0.00	3.62	94.99	124.42	12033599	3882582	81.74	50895.82	219	?
Severn	70.78	0.61	0.54	28.07	164.10	217.10	69828690	21099734	81.62	########	1474	19[#]
Neath	52.75	2.73	0.00	44.52	164.10	138.62	3022997	1096370	85.20	18731.45	268	2
Annas	32.51	25.77	0.00	41.59	48.82	15.38	246160	113410	83.86	8292.72	12	0
Bela	40.69	0.00	0.00	59.31	197.04	143.40	819351	335588	78.09	18234.50	6	2
Black Beck	1.76	35.81	0.00	62.43	42.08	26.24	95943	35575	71.86	5960.17	8	0
Keer	60.91	0.00	0.00	39.09	171.94	201.78	204698	97294	86.30	8129.63	15	0
Aber	0.00	0.03	0.00	99.82	12.36	84.90	142194	53308	80.44	6503.88	6	0
Afan	5.90	23.10	0.00	70.99	38.12	187.18	900955	642170	81.96	14927.70	55	8
Arth	0.00	0.00	0.00	99.98	32.53	91.07	209192	94776	81.18	9693.79	1	1
Cleddau (Eastern)	9.76	0.61	0.00	89.63	24.81	68.86	1534997	1300937	82	13505	9	1
Erch	0.13	0.00	0.00	99.56	25.25	64.04	517460	259546	74.99	11060.33	3	0
Ogmore	52.39	0.26	0.00	47.35	95.04	154.26	2061008	847272	81.88	17364.52	63	1
Gwaun	12.66	0.00	0.00	87.33	17.80	51.21	283085	133237	93.94	8429.37	6	0
TAFF	36.21	7.23	0.00	56.56	92.42	118.49	5304692	1896211	83.46	41877.26	310	2
Cegin (Menai Strait)	0.04	0.00	0.00	99.96	29.22	285.11	180841	6604	76.79	8898.67	1	0
Ebbw	32.01	0.47	0.00	67.52	221.30	132.91	1580657	1175232	94.17	28054.75	83	5
Leri	0.00	5.49	0.00	94.51	12.46	25.5	315686	206252	84.58	11626.80	14	0
Dulas (Colwyn Bay)	100.00	0.00	0.00	0.00	117.84	155.86	231245	109671	86.80	9902.12	7	4
Rhymney	35.39	0.00	0.00	64.61	122.18	160.27	1725031	1399867	83.19	30163.72	130	1
Ely	57.40	0.53	0.00	42.07	132.86	242.35	1400747	1154783	83.00	29241.16	15	1
Cefni	30.74	0.00	0.00	69.26	131.39	326.58	413943	400346	82.46	9927.51	11	3
Ysgethin (Barmouth)	0.00	0.00	0.00	100.00	8.47	17.77	124685	93438	72.51	5013.38	2	0
Wygyr (Anglesea)	0.00	0.00	0.00	100.00	66.17	259.64	138935	146036	85.01	6037.86	19	0
Coron Lake (Anglesea)	0.56	0.00	0.00	99.44	119.77	134.24	178320	186523	80.16	7551.21	1	0
												# impassables c
Annan				100.00								10
Nith					estimated to be low		estimated moderate to high					29
Urr												0
Dee												4
Fleet					6.91	20.61						3
Cree												0
Bladnoch												1
Luce					7.77	21.54						0
Shimna	0.00	0.00	0.00	100.00				66000				0
Argideen	100.00	0.00	0.00	0.00	49.82	70.80	440154	134834				0
Bandon	100.00	0.00	0.00	0.00	44.33	53.50	2875254	584111				1
Boyne	100.00	0.00	0.00	0.00	307.41	335.10	26118400	2222393				0
Castletown	0.00	0.00	0.00	100.00	100.80	122.40	310434	220360				0
Colligan	0.00	0.00	0.00	100.00	24.60	54.10	326821	105180				0
Currane/Waterville system	0.00	0.00	0.00	100.00	6.65	13.00	16152491	213101				1
Dargle	0.00	0.00	0.00	100.00	65.02	136.90	870079	156773				2
Dee	0.00	0.00	0.00	100.00	191.65	170.10	2583259	428080				2
Glyde	0.00	0.00	0.00	100.00			3264292	314787				0
Slaney	0.00	0.00	0.00	100.00	81.30	93.20	5284566	1392960				0

NAME	Total accessible wetted area m^2	Mean daily flow naturalised (head of tide)	Mean daily flow actual	Q95 (at tidal limit)	Qn95 (at tidal limit)	Length of estuary tidal limit to headland (m)	Number of on-line lakes	Total wetted area of on-line lakes (m^2)	Mean annual air temperatures
Nevern & Associated Tribs		3.190	3.203	0.317	0.320		0	0.00	
Aeron		4.490	0.337	4.507	0.338		6	175961.50	
Dysynni		6.413	6.406	0.959	0.941		3	654872.0135	
Tawe		13.230	13.370	1.516	1.629		16	185780.5000	
Calder		2.044	2.032	0.474	0.458		0	0.00	
Western Cleddau		6.927	6.863	0.883	0.778		16	97601.0000	
Llyfni		2.494	2.322	0.248	0.254		13	655519.3799	
Gwendraeth Fawr		2.031	2.100	0.086	0.148		7	95034.5000	
Dwyfor		4.623	4.517	0.414	0.404		7	357073.0000	
Loughor		8.166	8.300	1.031	1.154		6	34151.5000	
Seiont		4.962	4.935	0.668	0.817		12	1581461.0000	
Glaslyn		7.687	7.709	0.826	0.828		24	1243208.3585	
Ogwen/Ddu		5.416	9.001	0.581	1.144		13	641629.0000	
Ystwyth		6.578	6.598	0.619	0.626		19	319291.4735	
Artro		2.549	2.526	0.234	0.240		11	327723.5000	
Rheidol		7.939	7.721	0.884	3.772		29	3070897.0810	
Ehen and Keekle		6.541	5.493	1.126	1.033		8	107916.0000	
Ellen		2.778	2.773	0.348	0.335		6	229486.5000	
Irt		5.632	5.998	0.851	0.882		8	2893264.0000	
Duddon		4.982	4.804	0.604	0.475		1	2119.5000	
Tywi		43.590	41.280	5.073	3.687		34	2665424.5000	
Taf		21.970	19.770	2.647	2.569		4	16627.0000	
Teifi		30.520	30.500	3.092	3.035		27	748826.0485	
Dyfi		21.360	21.390	1.911	1.925		21	615016.0480	
Mawddach		8.601	8.618	0.679	0.681		18	380197.0000	
Conwy		21.250	21.090	1.638	1.575		45	4187577.9286	
Clwyd		12.320	12.050	0.924	1.098		29	1292756.0000	
Eden (NW)		58.700	54.210	8.094	8.046		55	14466992.2315	
Leven		14.620	14.340	1.268	1.412		42	2769156.5000	
Wyre (NW)		6.688	6.173	0.724	0.111		40	1547810.5000	
Derwent		31.010	27.500	2.485	2.463		25	3673583.5000	
Esk (Scottish Border)		35.470	35.540	4.215	4.225				
Dee		39.130	4.230	35.550	5.335		94	15171648.0125	
Ribble		34.690	34.160	3.645	4.482		203	8558537.7880	
Lune		36.210	35.830	3.498	3.302		21	296656.56	
Kent		9.577	9.707	1.068	1.178		25	385072.5000	
Esk		4.531	4.532	0.427	0.424		9	677730.0000	
Dwyryd		4.591	5.707	0.357	0.599		48	6588681.5475	
Gwyrfai		2.784	3.000	0.256	0.347		9	1270496.5000	
Wye		78.480	74.240	7.703	7.868		232	10053078.3815	
Usk		29.930	26.760	4.165	2.856		66	5391558.0370	
Severn		109.500	105.200	20.370	20.280		942	23814424.0516	
Neath		12.080	12.160	1.253	0.995		19	515821.7780	
Annas		1.186	1.189	0.208	0.206		1	25381.5000	
Bela		3.516	3.559	0.321	0.294		12	1078325.0000	
Black Beck		0.492	0.493	0.042	0.041		0	0.00	
Keer		1.274	1.282	0.179	0.175		5	308851.5000	
Aber		1.185	1.182	0.125	0.13		1	43009.5000	
Afan		5.548	5.55	0.859	0.859		0	0.00	
Arth		0.701	0.704	0.03	0.029		0	0.00	
Cleddau (Eastern)		6.901	6.554	0.505	1.052		8	903119.5000	
Erch		1.418	1.422	0.198	0.196		2	66216.6855	
Ogmore		9.504	9.599	1.452	1.386		3	15675.0000	
Gwaun		1.592	1.594	0.212	0.212		0	0.00	
TAFF		21.97	21.44	3.893	2.647		48	3081973.5000	
Cegin (Menai Strait)		0.744	0.75	0.143	0.138		2	8535.5000	
Ebbw		7.817	7.102	0.354	1.327		29	618454.0000	
Leri		1.647	1.61	0.179	0.181		1	103784.5000	
Dulas (Colwyn Bay)		0.753	0.756	0.058	0.057		3	51633.0000	
Rhymney		6.258	6.195	0.742	0.835		27	534439.0503	
Ely		4.114	4.37	0.863	0.616		27	534439.0503	
Cefni		1.352	1.229	0.149	0.128		3	709724.5000	
Ysgethin (Barmouth)		0.671	0.479	0.058	0.079		3	279487.5000	
Wygyr (Anglesea)		0.407	0.41	0.031	0.03		2	50458.0000	
Coron Lake (Anglesea)		0.571	0.576	0.058	0.054		1	280183.5000	
Annan									
Nith						17200			13.1
Urr									
Dee									
Fleet			3.485	0.899					
Cree									
Bladnoch									
Luce			6.091	1.750					
Shimna						1000			*10*
Argideen	440154		2.690	0.180		10317.0		0	9.4
Bandon	2859465		15.039			20353.7		556405	9.4
Boyne	26118400		34.739			14607		13221896	8.8
Castletown	310434					5727.8		0	8.8
Colligan	326821					5461.4		0	10.2
Currane/Waterville system	15863992					0.0		15247805	10.4
Dargle	834847					250.8		0	9.3
Dee	2443766					2438.3		430364	8.8
Glyde	3264292		38.949	0.472		3068.2		1142900	8.8
Slaney	5284566		27.290	5.270		32015.8		13366	10.1

NAME	Mean 0+ trout density per m2	Mean >0+trout density per m2	Mean 0+ salmon parr density per m2	Mean >0+salmon parr density per m2	**Mean sea trout rod-catch per licence-day 2000-2010 inclusive**	mean annual total rod catch 2000-2010 inclusive
Nevern & Associated Tribs	0.886	0.805	0.731	0.361	0.4735	532.55
Aeron	1.201	0.286	0.393	0.107	0.4416	248.91
Dysynni	1.039	0.239	0.567	0.117	0.4206	370.82
Tawe	0.753	0.358	0.295	0.121	0.1373	233.20
Calder	0.390	0.113	0.664	0.179	0.0458	9.40
Western Cleddau	0.384	0.525	0.144	0.117	0.2500	501.16
Llyfni	1.100	0.258	0.147	0.147	0.4925	197.55
Gwendraeth Fawr	0.962	0.375	0.061	0.008	0.2026	48.94
Dwyfor	0.623	0.260	1.097	0.263	0.5595	573.79
Loughor	0.577	0.410	0.060	0.039	0.2118	277.94
Seiont	0.628	0.200	1.066	0.286	0.0702	50.64
Glaslyn	0.433	0.224	0.413	0.073	0.6044	456.09
Ogwen/Ddu	0.652	0.231	1.011	0.393	0.1530	123.64
Ystwyth	0.901	0.366	0.058	0.018	0.5201	174.91
Artro	0.607	0.376	0.642	0.220	0.2744	35.55
Rheidol	1.426	0.332	0.119	0.023	0.3849	469.27
Ehen and Keekle	0.355	0.106	0.749	0.125	0.1570	384.23
Ellen	0.282	0.166	0.809	0.167	0.2531	69.36
Irt					0.1563	113.55
Duddon	0.349	0.270	0.126	0.138	0.3264	123.27
Tywi	0.860	0.288	0.254	0.073	0.2187	2638.69
Taf	0.543	0.265	0.092	0.048	0.1867	285.73
Teifi	0.794	0.341	0.796	0.196	0.2557	2322.25
Dyfi	0.835	0.259	0.335	0.071	0.6961	1340.82
Mawddach	0.288	0.186	0.312	0.167	0.2915	790.30
Conwy	0.356	0.136	0.450	0.079	0.2147	422.45
Clwyd	0.870	0.224	0.331	0.074	0.3265	810.64
Eden (NW)	0.497	0.190	0.680	0.143	0.0431	394.33
Leven	0.712	0.167	0.485	0.129	0.1954	59.18
Wyre (NW)	0.013	0.017	0.036	0.009	0.1693	29.73
Derwent	0.459	0.150	1.938	0.255	0.0618	293.26
Esk (Scottish Border)	0.864	0.252	1.064	0.257	0.2630	1015.72
Dee	0.313	0.188	0.516	0.103	0.0345	240.86
Ribble	0.016	0.022	0.026	0.005	0.1200	0.95
Lune	0.030	0.011	0.104	0.035	0.1595	1379.95
Kent	0.653	0.243	1.205	0.358	0.1317	390.02
Esk	0.235	0.117	0.453	0.122	0.2341	106.36
Dwyryd	0.437	0.242	0.160	0.123	0.4457	117.09
Gwyrfai	0.779	0.163	3.196	0.141	0.1102	2.45
Wye	0.228	0.152	0.673	0.093	0.0077	35.30
Usk	0.329	0.303	0.464	0.202	0.0423	200.87
Severn					0.0053	24.26
Neath	0.565	0.216	0.070	0.021	0.2307	368.50
Annas	0.140	0.010	1.690	0.140	0.1500	3.82
Bela	0.346	0.226	0.262	0.053	0.1000	2.45
Black Beck					0.0300	0.09
Keer	0.038	0.114	0.003	0.010	0.1800	3.53
Aber	1.050	0.350	0.033	0.267	0.2000	3.64
Afan	0.582	0.538	0.045	0.086	0.2458	125.09
Arth	1.870	1.120	0.000	0.000	0.3200	1.63
Cleddau (Eastern)	0.296	0.322	0.167	0.137	0.3100	224.61
Erch	0.591	0.269	1.093	0.307	0.1600	202.88
Ogmore	0.587	0.581	0.114	0.057	0.2195	438.18
Gwaun	0.597	0.706	2.216	0.832	0.2400	9.40
TAFF	0.295	0.423	0.246	0.075	0.1600	59.09
Cegin (Menai Strait)					0.2900	5.54
Ebbw	0.313	0.441	0.100	0.059	0.1500	0.33
Leri	2.220	0.880	0.020	0.000	0.1500	2.89
Dulas (Colwyn Bay)					0.5000	13.45
Rhymney	0.198	0.374	0.120	0.077	0.3291	21.36
Ely	0.115	0.225	0.058	0.089	0.6200	5.24
Cefni	1.378	0.342	0.004	0.000	0.1900	2.02
Ysgethin (Barmouth)	0.613	0.575	0.038	0.200	0.0300	0.55
Wygyr (Anglesea)	0.392	0.125	0.000	0.000	0.3000	0.90
Coron Lake (Anglesea)					0.2600	0.80
Annan	0.145	0.464	0.240			
Nith	0.106	0.056				
Urr						
Dee						
Fleet	1.362	0.122				
Cree						
Bladnoch						
Luce						
Shimna	0.283	0.329				
					estimated total catch	
Argideen	0.283	0.053	0.710	juv salmon combined		434.00
Bandon	0.146	0.074	3.092	juv salmon combined		873.00
Boyne				juv salmon combined		1973.00
Castletown				juv salmon combined		1064.00
Colligan	0.326	0.144	0.046	juv salmon combined		1764.00
Currane/Waterville system	1.123	0.037	0.079	juv salmon combined		2826.00
Dargle				juv salmon combined		108.00
Dee	0.047	0.039	0.076	juv salmon combined		615.00
Glyde	?	?	?	juv salmon combined		201.00
Slaney	0.124	0.190	0.123	juv salmon combined		1000.00

abundance metric based on number caught on single run or first run

based on Zippin or efficiency estimate of first run

based on Zippin or Seber-LeCren multiple fishing

Irish catchment land use (from Corine 2000)

Catchment	Continuous urban fabric	Discontinuous urban fabric	Industrial or commercial units	Road and rail networks and associated land	Sea ports	Airports	Mineral extraction sites	Dump	Construction sites	Green urban areas	Sport and leisure facilities	Total Urban
Argideen	0	0	0	0	0	0	0	0	0	0	0	0
Bandon	0.054147978	0.618399674	0	0	0	0	0.071185776	0	0	0	0.077021818	0.148208
Boyne	0	0.846627418	0.03588345	0.0104445	0	0	0.252471238	0	0.092509336	0	0.251685603	0.596666
Castletown	0	0.438556461	0	0	0	0	0.143601258	0	0	0	0.310514623	0.454116
Colligan	0	0.733330081	0	0	0	0	0.015049459	0	0	0.005852734	0	0.020902
Currane / Waterville system	0	0.141491332	0	0	0	0	0	0	0	0	0	0
Dargle	0	4.756667383	0	0.36699012	0	0	0.215490031	0.228911	0	1.72473681	1.854962519	4.0241
Dee	0	0.823459721	0	0.33439976	0	0	0.064448739	0.032232	0.005592252	0.064740273	0.152219282	0.319233
Glyde	0	1.053678787	0	0.1723342	0	0	0.289036715	0.064386	0	0	0.297974981	0.651398
Slaney	0.004891105	0.723184281	0	0	0	0	0.089234201	0	0	0	0.113396978	0.202631

Catchment	Non-irrigated arable land	Pastures	Complex cultivation patterns	Land principally occupied by agriculture with significant areas of natural vegetation	Broad leafed forest	Coniferous forests	Mixed forest	Natural grassland	Moors and heathlands	Transitional woodland-scrub	Beaches, dunes, sand	Bare rocks	Sparsely vegetated areas	Burnt area
Argideen	16.95564626	67.9317732	6.244262773	3.48550555	0.5998779	1.11947	1.275701532	0	0	1.75071078	0	0	0	0
Bandon	10.11052048	66.1037331	1.803395768	4.4820147	0.6365486	4.07843	0.604521984	0.2278159	0	4.74599266	0	0	0	0
Boyne	13.09664253	72.5050346	0.988281164	2.16225598	0.1562398	1.1335	0.28232694	0.06470073	0	2.356740502	0	0	0	0
Castletown	0.934296688	78.9074026	3.285382415	4.19958427	0	2.07526	0	3.80459782	4.416696625	1.463598643	0	0	0	0
Colligan	4.140035654	53.0453044	2.98247E-05	4.79697186	0.4141265	8.14643	0.288655158	7.162354	0	9.961783694	0	0	0	0
Currane / Waterville system	0	12.4931316	0	3.8517225	1.2042349	1.5602	0	4.32729743	1.710855843	0.945531106	0	0	6.945714	0
Dargle	3.818562609	20.6322452	2.807587987	8.14707929	0.8551863	11.1375	1.73023816	1.09417543	0	9.972360315	0	0	0	0
Dee	21.9487876	71.1263065	2.541691863	1.35698305	0.3155653	0.22578	0.086608069	0	0	0.82569592	0	0	0	0
Glyde	19.10959894	67.6741457	4.543783998	4.35306953	0.5906836	0.10844	0.898703743	0	0	0.507658585	0	0	0	0
Slaney	26.20320698	49.3622528	3.987180937	3.14693396	0.2666443	5.16728	0.125288493	0.70659633	0	4.372009405	0	0	0	0

Catchment	Inland marshes	Peat bogs	Salt marshes	Intertidal flats	Stream courses	Water bodies	Coastal lagoons	Estuaries	Sea and ocean
Argideen	0.153787102	0.48325998	0	0	0	0	0	0	0
Bandon	0	6.32639278	0	0	0	0.05988	0	0	0
Boyne	0.090350532	4.96870642	0	0	0.0262813	0.67932	0	0	0
Castletown	0	0.02050429	0	0	0	0	0	0	0
Colligan	0	10.7692936	0	0	0	0	0	0	0.520783112
Currane / Waterville system	0	53.5264326	0	0	0	13.2837	0	0	0.009721784
Dargle	0	30.4417166	0	0	0	0.2156	0	0	0
Dee	0	0.00102612	0	0	0	0.09446	0	0	0
Glyde	0.081712555	0.03050001	0	0	0	0.22429	0	0	0
Slaney	0	5.73189676	0	0	0	0	0	0	0

Section 6.2 Data processing

This describes the steps in the statistical modelling of relationships between mean annual sea trout catch per licence-day and catchment characteristics.

Please refer to Table 6.4 in main text for explanation of variables and their abbreviations.

Data manipulation steps in Excel:

Remove empty column A and empty row 1.
Remove the following columns
Latitude – longitude
Number of "significant barriers to migration"
Total accessible wetted area - subtract area upstream of impassable barriers from column AW
LENGTH OF ESTUARY (HEAD OF TIDE TO HEADLAND (m)
Mean monthly temperatures. Jan-Dec.
Mean 1+ trout density +/- 95%cl
Mean 0+trout density +/- 95%cl
Mean > 1+ density +/- 95%cl
Mean salmon parr density +/- 95%cl
Remove 'location' column and replace with CPLD column
Rename column headers (shorter for use in R)
Rename river catchments in column A (shorter for use in R)

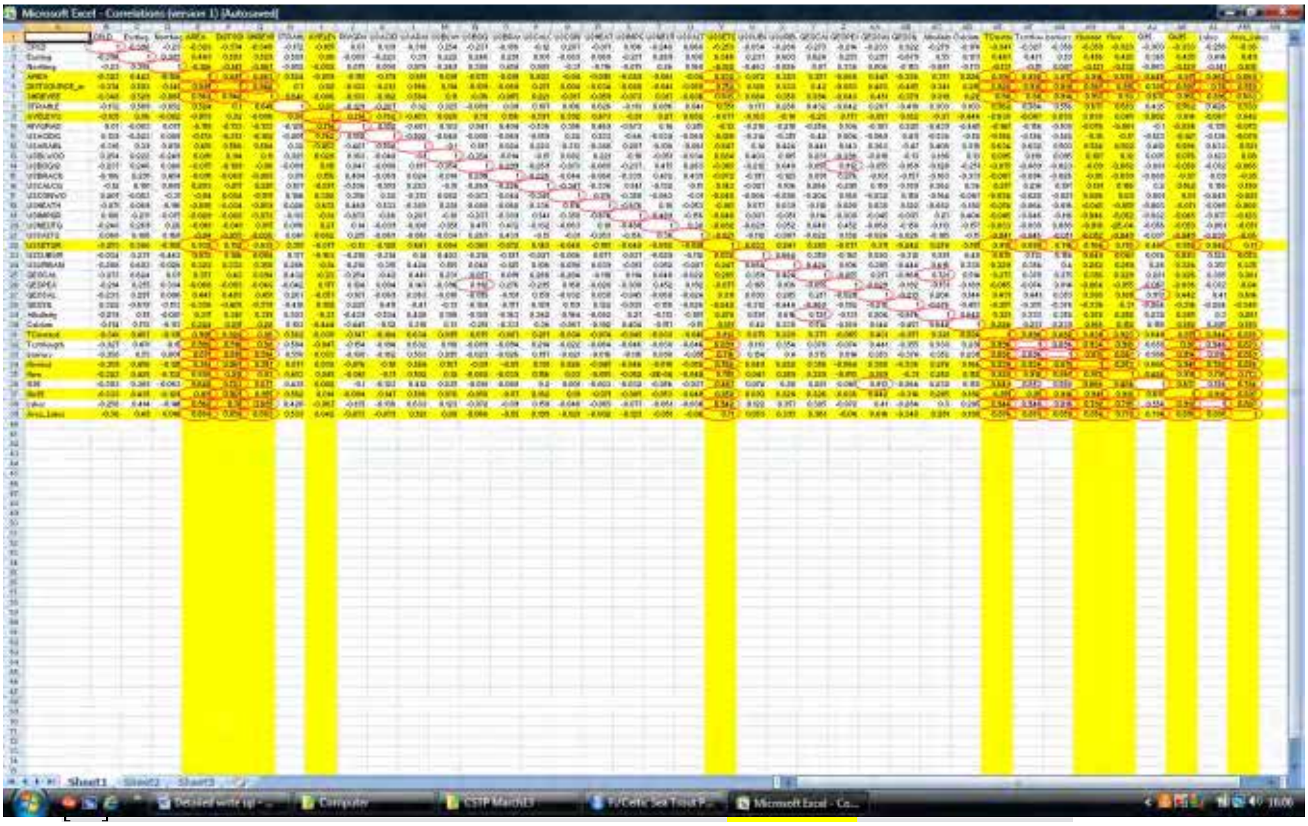
The above steps complete the worksheet 'Data1'.

In a new worksheet 'mean & sd' copy and paste dataset and calculate mean and sd for each column
In a new worksheet 'rescale' minus the column mean and divide by the column sd for each column except for 'Name' and 'CPLD'
Standardising the explanatory variables accounts for them being measured over wide ranging scales
In a new worksheet 'Data2' copy and paste the values from worksheet 'rescale'.
Save worksheet 'Data2' as a .txt file for importing into R

Data processing in R:

Import 'Data2.txt' into R. Should have 64 obs and 39 variables
Correlation matrix excluding 'Name'. Should have a 38x38 matrix

Export the correlation matrix into Excel and circle correlations of greater than 0.70 (Data - Data Validation – Circle Invalid Data(once criteria have been set))
Highlight those variables to be removed from model selection process

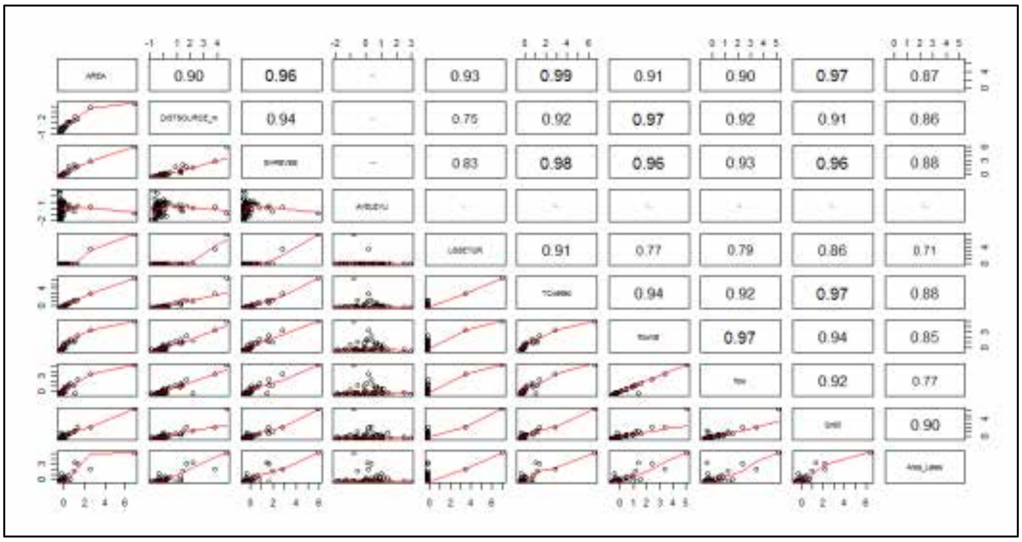


"USURBAN"

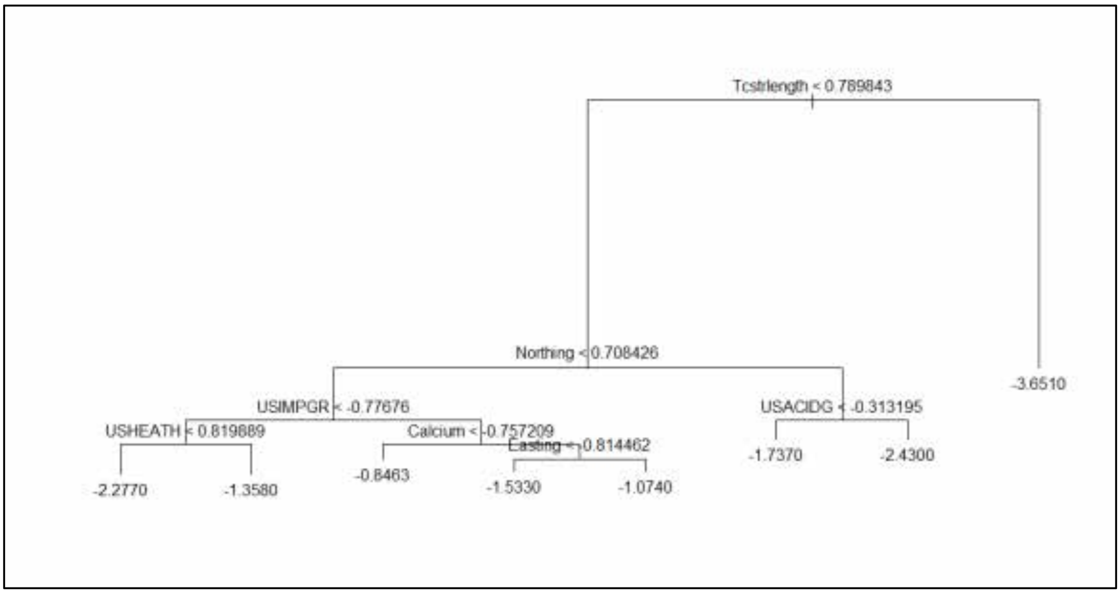
[25] "GEOCAL" "GEOPEA" "GEOSAL" "GEOSIL" "Alkalinity" "Calcium"

[31] "TCwetted" "Tcstrlength" "barriers" "flownat" "flow" "Q95"

[37] "Qn95" "Lakes" "Area_Lakes"



Tree model for CPLD on natural log scale shows that total catchment stream length appears to be the most important factor affecting log (CPLD).

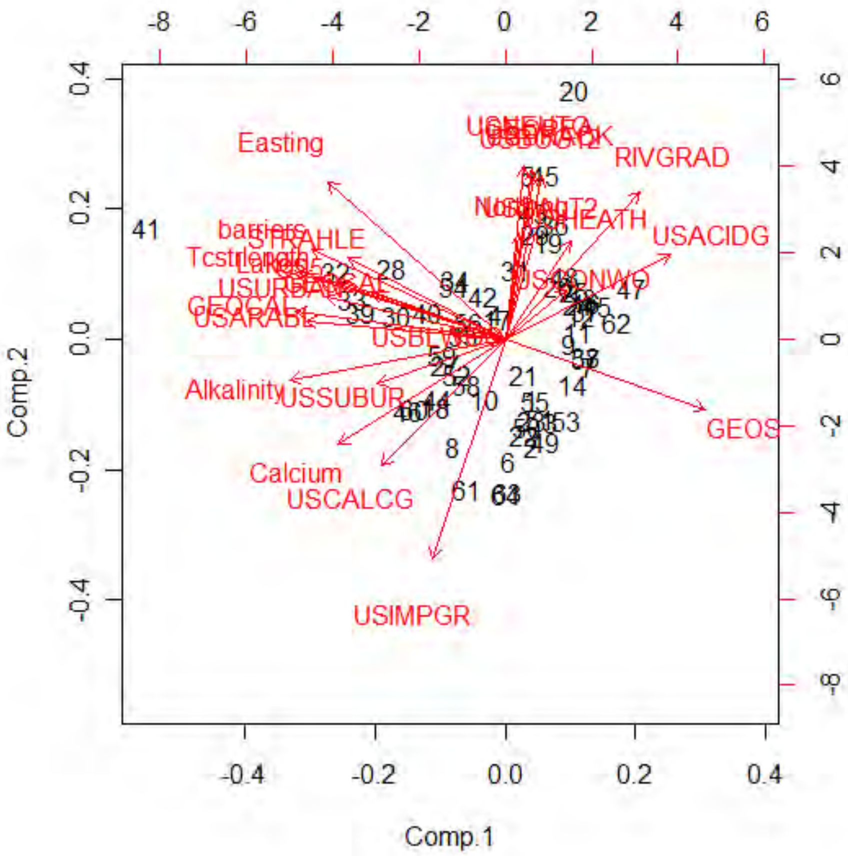


Principal components analysis

41 = Severn

20 = Duddon

- These are outliers
- No patterns or clusters of rivers appear to be present.



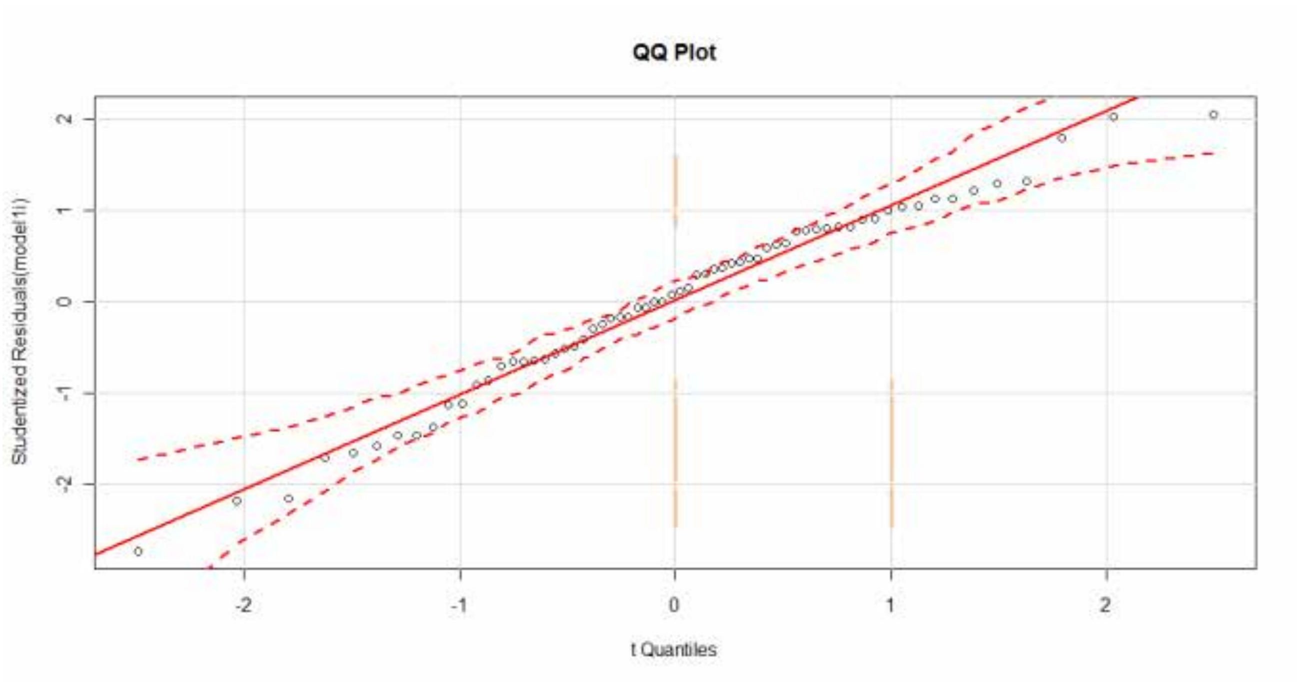
A general linear model is fitted to the data. The response variable is the natural log of catch per licence day (CPLD).

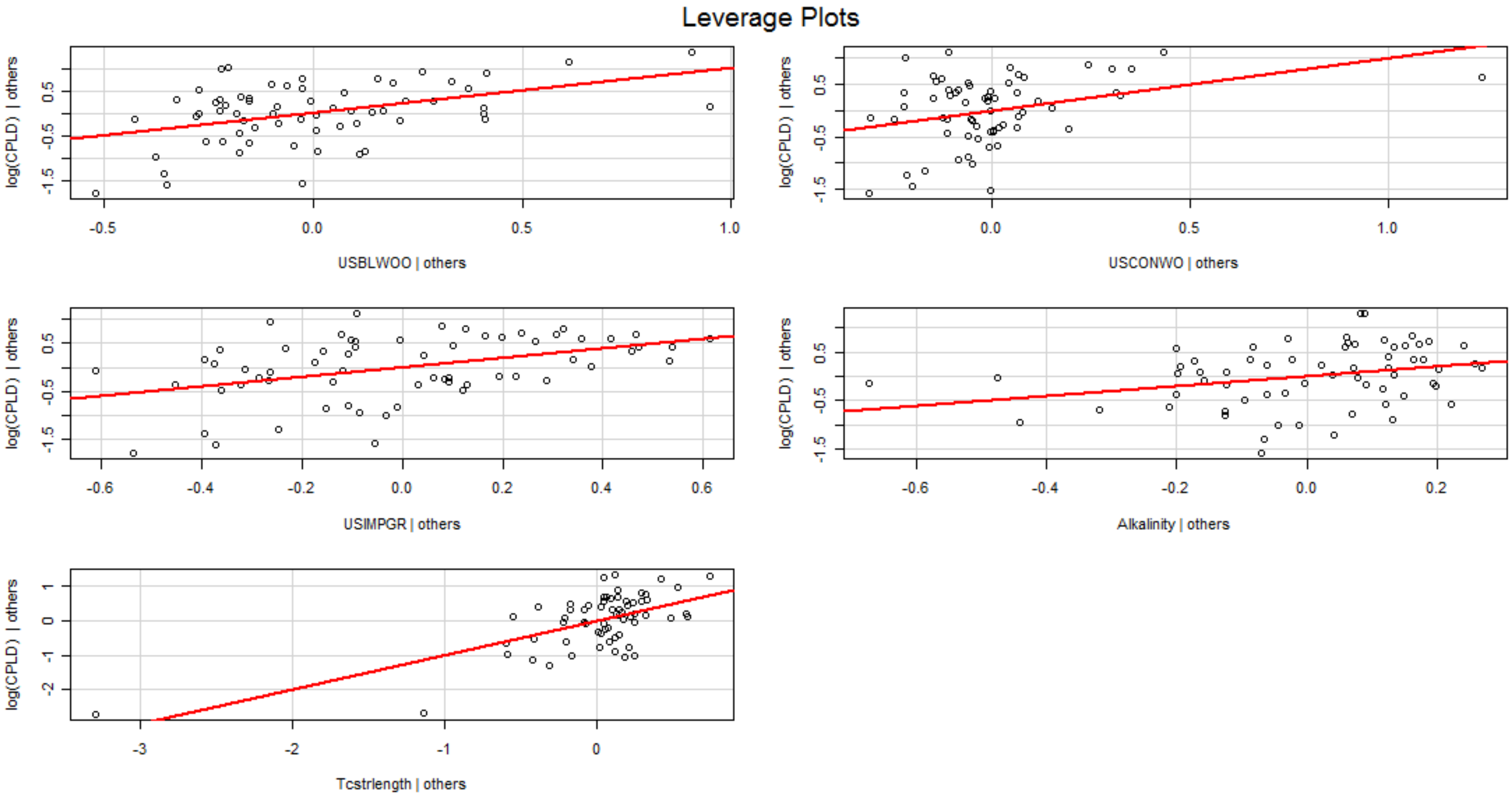
Model (1):

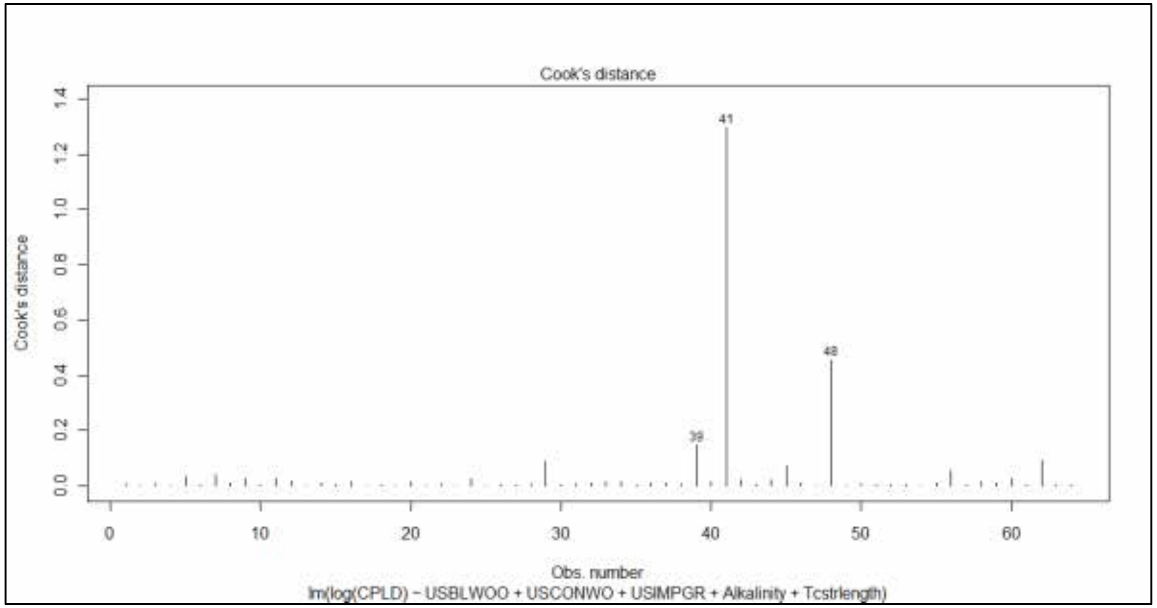
Tcstrlength (Total catchment stream length) was the most highly significant variable in the model, consistent with the results of the tree model presented previously.

```
lm(formula = log(CPLD) ~ USBLWOO + USCONWO + USIMPGR + Alkalinity +
    Tcstrlength, data = Data3)
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.72748    0.07845 -22.019  < 2e-16 ***
USBLWOO      0.30566    0.08335   3.667 0.000534 ***
USCONWO      0.23542    0.08501   2.769 0.007528 **
USIMPGR      0.33188    0.09012   3.682 0.000509 ***
Alkalinity  -0.21007    0.09083  -2.313 0.024305 *
Tcstrlength -0.55904    0.08484  -6.589 1.43e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6276 on 58 degrees of freedom
Adjusted R-squared: 0.5679
```

The diagnostic plots below *(Q-Q plot, Leverage Plots, Cook's Distance, residuals vs Leverage, Residuals vs Fitted)* do not show any cause for concern, other than highlighting the influential observation relating to the Severn catchment.




Leverage Plots
log(CPLD) | others
USBLWOO | others
USCONWO | others
USIMPGR | others
Alkalinity | others
Tcstrlength | others

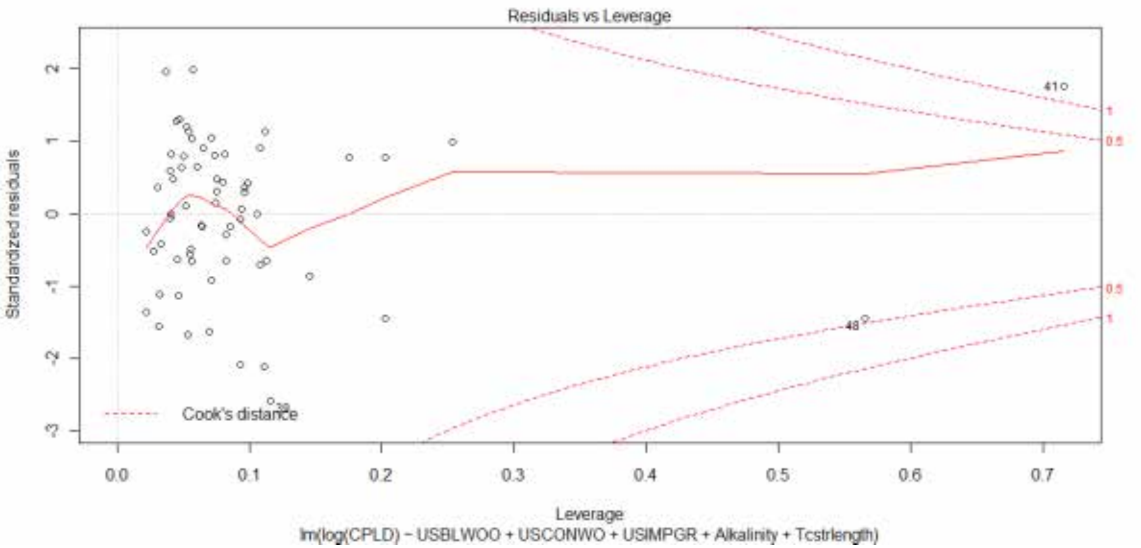


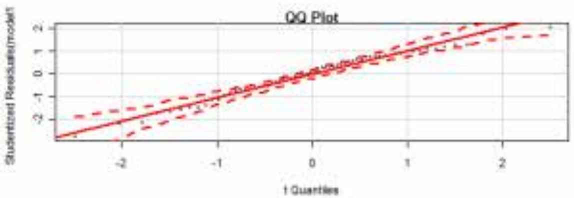
Outliers:

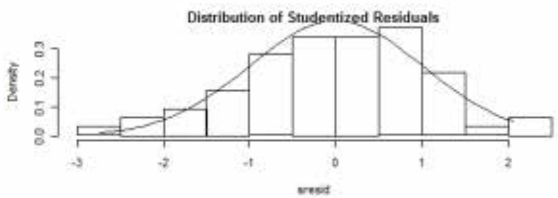
41 = Severn

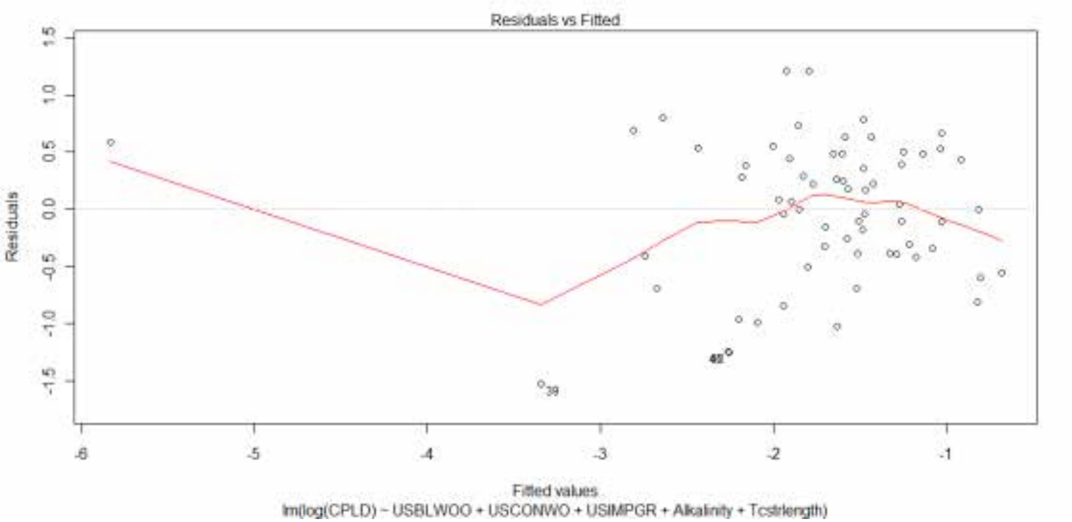
48 = Afan

39 = Wye


Residuals vs Leverage
Standardized residuals
Leverage
lm(log(CPLD) ~ USBLWOO + USCONWO + USIMPGR + Alkalinity + Tcstrlength)
Cook's distance
41
48
0.5
1


QQ Plot
t Quantiles


Distribution of Studentized Residuals
Density
sresid


Residuals vs Fitted
Residuals
Fitted values
lm(log(CPLD) ~ USBLWOO + USCONWO + USIMPGR + Alkalinity + Tcstrlength)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-6
-5
-4
-3
-2
-1
39

Model (2)

Removed Severn catchment from analysis dataset and repeat model selection process

```
lm(formula = log(CPLD) ~ USBLWOO + USCONWO + USIMPGR + Alkalinity +
    Tcstrlength, data = Data4)

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.75979    0.07909 -22.250  < 2e-16 ***
USBLWOO      0.30896    0.08183   3.776 0.000383 ***
USCONWO      0.24530    0.08362   2.934 0.004819 **
USIMPGR      0.33246    0.08846   3.758 0.000404 ***
Alkalinity  -0.19511    0.08954  -2.179 0.033479 *
Tcstrlength -0.78150    0.14958  -5.225 2.57e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.616 on 57 degrees of freedom
Adjusted R-squared: 0.4757
```

The same terms remain in the model as compared to the model including the Severn. By excluding the Severn the adjusted R-squared has reduced from 0.57 to 0.48.

Compare parameter estimates and standard errors of the 2 models:
Model (1) (including all catchments):

```
lm(formula = log(CPLD) ~ USBLWOO + USCONWO + USIMPGR + Alkalinity +
    Tcstrlength, data = Data3)

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.72748    0.07845 -22.019  < 2e-16 ***
USBLWOO      0.30566    0.08335   3.667 0.000534 ***
USCONWO      0.23542    0.08501   2.769 0.007528 **
USIMPGR      0.33188    0.09012   3.682 0.000509 ***
Alkalinity  -0.21007    0.09083  -2.313 0.024305 *
Tcstrlength -0.55904    0.08484  -6.589 1.43e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6276 on 58 degrees of freedom
Adjusted R-squared: 0.5679
```

Note that there is no flow variable in either final model (1) or (2).

The correlation coefficients for TCstrlength and TCWetted with Q95 are 0.653 and 0.649 respectively.

TCWetted already excluded. Also remove TCstrlength and repeat model selection process.

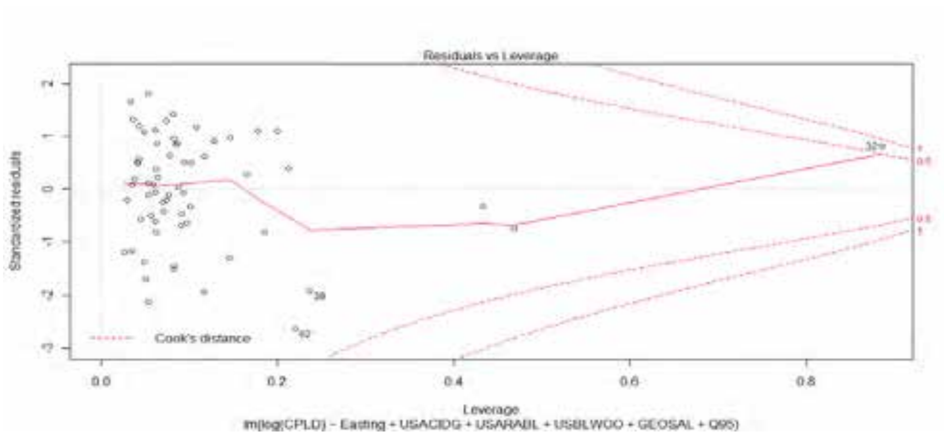
Having done this and refitted the model, Q95 remains in Model (3) shown below. The Severn catchment is not identified as being highly influential here. Interestingly this model brings in other catchment variables including saline geology (GEOSAL)

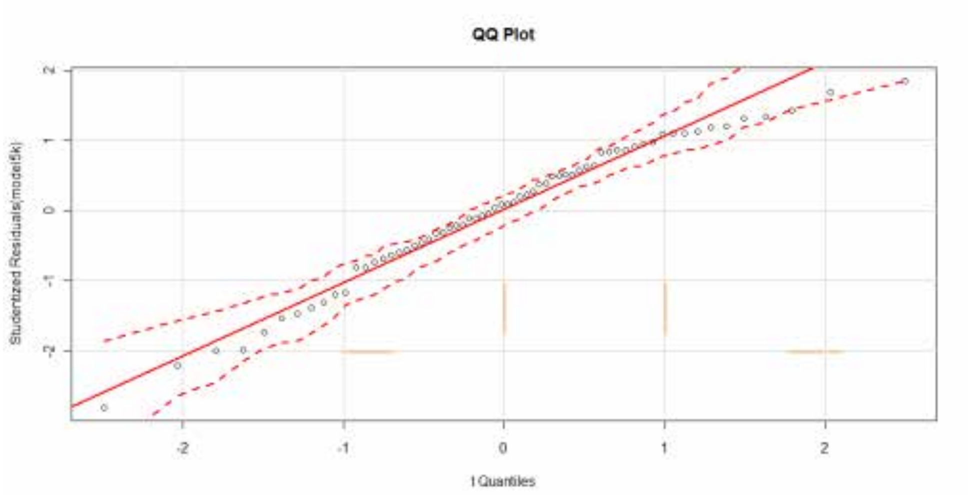
Final model (1) is statistically the preferred mode, and also has a slightly higher adjusted r-squared value associated with it compared to final model (3). However, from an ecological point of view it may be that a term representing flow being in the model is preferable i.e. if flow is expected to have an important influence on CPLD.

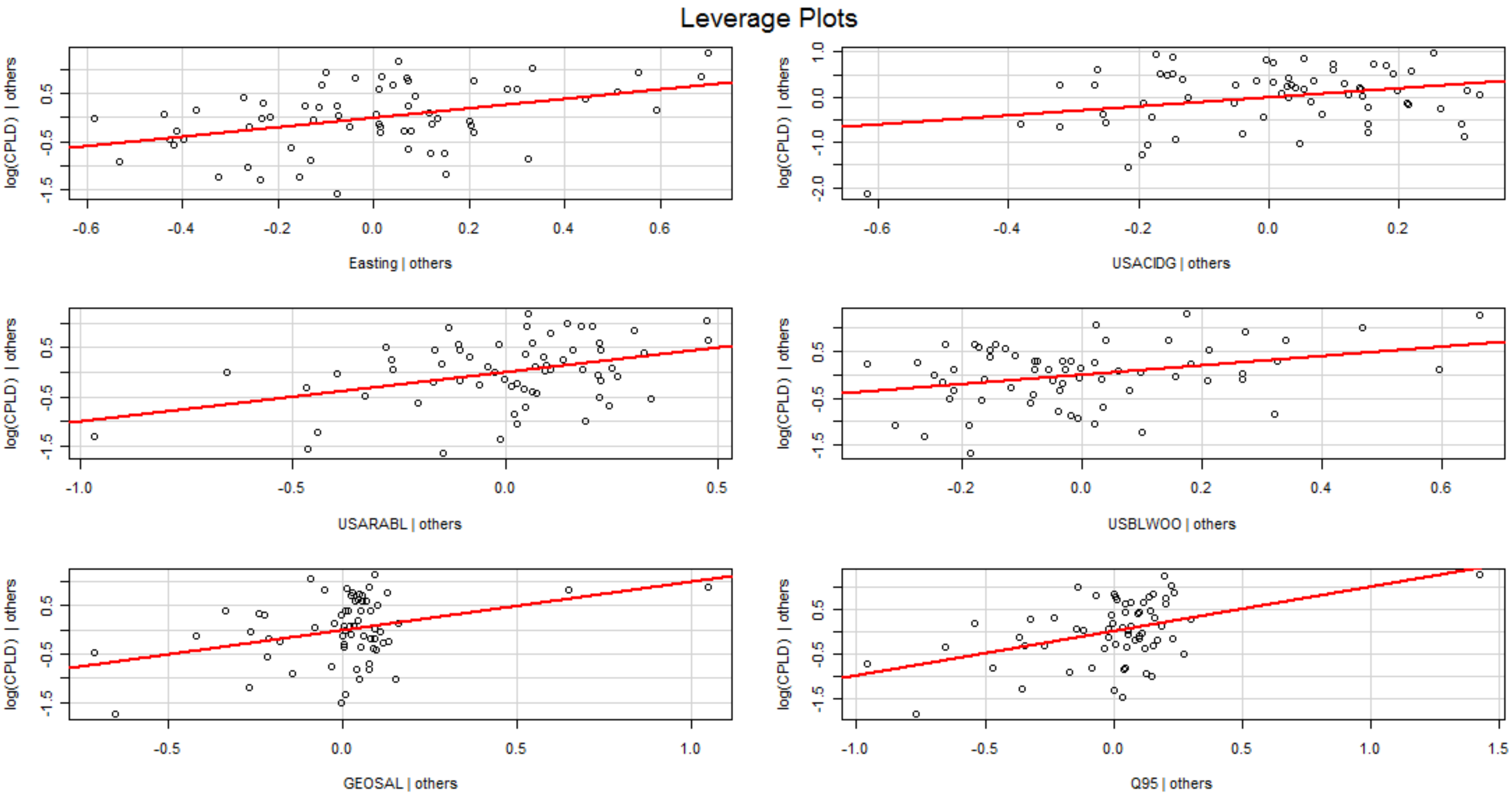
Model (3)

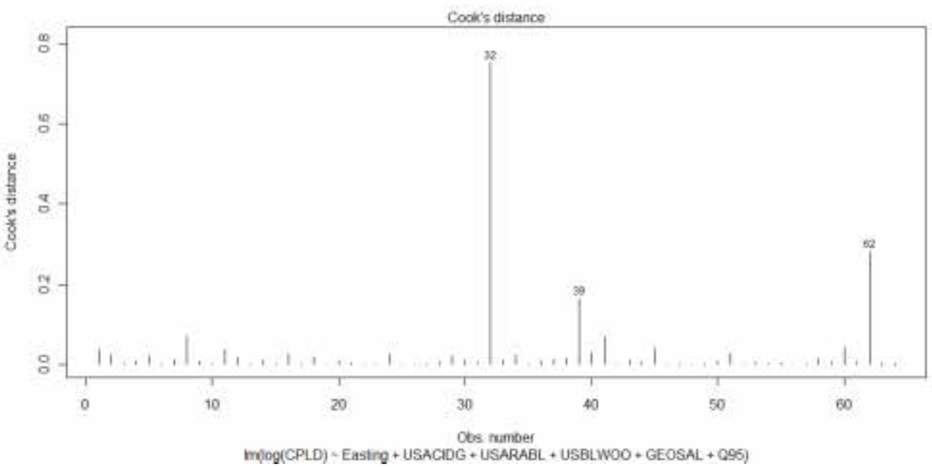
```
lm(formula = log(CPLD) ~ Easting + USACIDG + USARABL + USBLWOO +
    GEOSAL + Q95, data = Data5)

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.72748    0.08051 -21.456  < 2e-16 ***
Easting     -0.33211    0.09465  -3.509 0.000886 ***
USACIDG     -0.22852    0.09550  -2.393 0.020034 *
USARABL     -0.34397    0.10824  -3.178 0.002398 **
USBLWOO      0.22372    0.08603   2.600 0.011836 *
GEOSAL       0.57553    0.20173   2.853 0.006025 **
Q95         -0.79136    0.20837  -3.798 0.000356 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6441 on 57 degrees of freedom
Adjusted R-squared: 0.5449
```

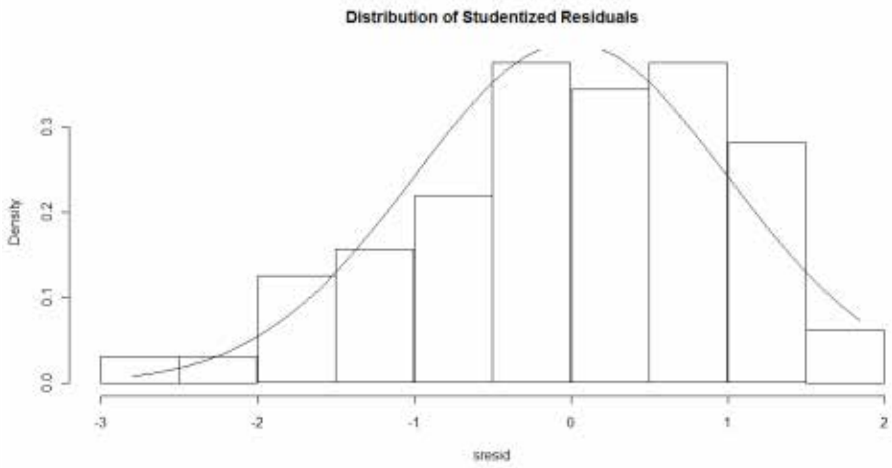
Diagnostic plots for Model 3:






Leverage Plots
log(CPLD) | others
Easting | others
USACIDG | others
USARABL | others
USBLWOO | others
GEOSAL | others
Q95 | others


Cook's distance
Cook's distance
Obs. number
lm(log(CPLD) ~ Easting + USACIDG + USARABL + USBLWOO + GEOSAL + Q95)


Distribution of Studentized Residuals
Density
sresid

Prediction Intervals

R can produce the fitted value and prediction intervals for a set of values for the explanatory variables in the model (see the code and output below). Such an interval provides an estimation of the limits within which a future observation will fall. The observations relating to the Nevern have been used as an example here. To calculate the prediction interval the variance reflecting the errors in estimating the fitted regression plus sigma^2 (variability in an individual response (Y)) are required.

The example below is based on Model (3) shown above which includes Q95.

The results in the R output below require anti-logging to get back to the original scale.

Therefore, as an example, using the data from the Nevern, but assuming it is new data and we want to predict the CPLD:

Observed CPLD= 0.473526797 (from original dataset)

Predicted CPLD=0.2490

Lower prediction interval (95%) CPLD=0.0614

Upper prediction interval (95%) CPLD=1.0093

Once a model has been decided upon this process can be repeated if required for a number of ‘new’ catchments. The model used here is the model including Q95 (Final Model (3). Fitted or predicted values can be calculated for all catchments and compared to the CPLD observed.

```
#Prediction Intervals

> newData <- data.frame(Easting=-1.69889996,
+                   USACIDG=-0.08011976,
+                   USARABL=1.39330950,
+                   USBLWOO=0.30239820,
+                   GEOSAL=-0.1878588,
+                   Q95=-0.34652247)
> predict(model5k, newdata=newData,interval="prediction")
       fit       lwr      upr
1 -1.390453 -2.790205 0.009299
```

The R code used for the analysis described above is as follows:

Lines prefixed by # are for guidance and not part of the R-code typed by the user

```
#Read in Data2.txt

Data2 <- read.delim("F:/Celtic Sea Trout Project/CSTP March13/Data2.txt", quote="")
View(Data2)
attach(Data2)
names(Data2)
head(Data2)
summary(Data2)
str(Data2)
#Install packages
```

```
library("tree")
library("car")
library(MASS)
#####Analysis on Data2.txt - rescaled data#####
#correlation matrix excluding character variable 'name'
cor_Data2 <- cor(Data2[,-c(1)], use="pairwise.complete.obs")
View(cor_Data2)
#pair plots and correlations
names(Data2)
#function for producing plot with scatter and correlations
panel.cor <- function(x, y, digits=2, prefix="", cex.cor, ...)
{
 usr <- par("usr"); on.exit(par(usr))
 par(usr = c(0, 1, 0, 1))
 r <- abs(cor(x, y))
 txt <- format(c(r, 0.123456789), digits=digits)[1]
 txt <- paste(prefix, txt, sep="")
 if(missing(cex.cor)) cex.cor <- 0.8/strwidth(txt)
 text(0.5, 0.5, txt, cex = cex.cor * r)
}
#Produce plot containing those variables identified as being highly correlated
#with each other. These variables will not be included iin the modelling to
#avoid issues associated with multicolinearity#
pairs(Data2[,c(5,6,7,9,22,31,34,35,37,39)], lower.panel=panel.smooth, upper.panel=panel.cor)
#create dataset for modelling
Data3 <- (Data2[,-c(1,5,6,7,9,22,31,34,35,37,39)])
View(Data3)

#Tree Model CPLD
model_tree_Data3b <-tree (CPLD ~ .,data=Data3,method="anova")
plot(model_tree_Data3b)
text(model_tree_Data3b)
print(model_tree_Data3b)

#Tree Model log(CPLD)
model_tree_Data3 <-tree(log(CPLD) ~ .,data=Data3,method="anova")
plot(model_tree_Data3)
text(model_tree_Data3)
print(model_tree_Data3)

#Principal Components Analysis
pc_Data3 <- princomp(Data3[,-c(1)], cor=T)
summary(pc_Data3)
loadings(pc_Data3)
plot(pc_Data3,type="lines")
pc_Data3$scores
biplot(pc_Data3)
#Linear Modelling using stepwise regression
names(Data3)
model1a <- lm(log(CPLD) ~ ., data=Data3)
vif(lm(log(CPLD) ~ ., data = Data3))
sqrt(vif(lm(log(CPLD) ~ ., data = Data3)) > 2) #ok if not >2
model1b <- step(model1a)
summary(model1b)
#Complete remaining steps manually
```

```
model1c <- update(model1b, ~. - USSUBUR)
summary(model1c)
model1d <- update(model1c, ~. - Calcium)
summary(model1d)
model1e <- update(model1d, ~. - barriers)
summary(model1e)
model1f <- update(model1e, ~. - GEOSAL)
summary(model1f)
model1g <- update(model1f, ~. - Q95)
summary(model1g)
model1h <- update(model1g, ~. - USSALT2)
summary(model1h)
model1i <- update(model1h, ~. - USBOG12)
summary(model1i)
vif(lm(log(CPLD) ~ USBLWOO+USCONWO+USIMPGR+Alkalinity+Tcstrlength, data = Data3))
sqrt(vif(lm(log(CPLD) ~ USBLWOO+USCONWO+USIMPGR+Alkalinity+Tcstrlength, data =
Data3)) > 2) #ok if not >2
layout(matrix(1))
plot(model1i)
# Assessing Outliers
outlierTest(model1i) # Bonferonni p-value for most extreme obs
qqPlot(model1i, main="QQ Plot") #qq plot for studentized resid
leveragePlots(model1i) # leverage plots

# Influential Observations
# Cook's D plot
# identify D values > 4/(n-k-1)
cutoff <- 4/((nrow(Data3)-length(model1i$coefficients)-2))
plot(model1i, which=4, cook.levels=cutoff)
# Influence Plot
influencePlot(model1i, id.method="identify", main="Influence Plot", sub="Circle size is proportial
to Cook's Distance" )
# Normality of Residuals
# qq plot for studentized resid
qqPlot(model1i, main="QQ Plot")

# distribution of studentized residuals
sresid <- studres(model1i)
hist(sresid, freq=FALSE,
    main="Distribution of Studentized Residuals")
xfit<-seq(min(sresid),max(sresid),length=40)
yfit<-dnorm(xfit)
lines(xfit, yfit)
#Repeat analysis excluding Severn
#create dataset for modelling
Data4 <- (Data2[-c(41),-c(1,5,6,7,9,22,31,34,35,37,39)])
View(Data4)

#Linear Modelling using stepwise regression
names(Data4)
model2a <- lm(log(CPLD) ~ ., data=Data4)
vif(lm(log(CPLD) ~ ., data = Data4))
sqrt(vif(lm(log(CPLD) ~ ., data = Data4)) > 2) #ok if not >2
model2b <- step(model2a)
summary(model2b)
```

```
#Complete remaining steps manually
model2c <- update(model2b, ~. - barriers)
summary(model2c)
model2d <- update(model2c, ~. - USBRACK)
summary(model2d)
model2e <- update(model2d, ~. - USSALT2)
summary(model2e)
model2f <- update(model2e, ~. - STRAHLE)
summary(model2f)
model2g <- update(model2f, ~. - USBOG12)
summary(model2g)
#Analysis on original scale for completeness.  It was established in
#earlier analyses that the data was log-normal.
#Modelling data on original scale including Severn
#Linear Modelling using stepwise regression
names(Data3)
model3a <- lm((CPLD) ~ ., data=Data3)
vif(lm((CPLD) ~ ., data = Data3))
sqrt(vif(lm((CPLD) ~ ., data = Data3)) > 2) #ok if not >2
model3b <- step(model3a)
summary(model3b)
#Complete remaining steps manually
model3c <- update(model3b, ~. - USURBAN)
summary(model3c)
model3d <- update(model3c, ~. - USSUBUR)
summary(model3d)
model3e <- update(model3d, ~. - USARABL)
summary(model3e)
model3f <- update(model3e, ~. - USNEUTG)
summary(model3f)
model3g <- update(model3f, ~. - USCALCG)
summary(model3g)
model3h <- update(model3g, ~. - GEOPEA)
summary(model3h)
model3i <- update(model3h, ~. - USBOG12)
summary(model3i)
model3j <- update(model3i, ~. - USSALT2)
summary(model3j)
model3k <- update(model3j, ~. - USACIDG)
summary(model3k)
model3l <- update(model3k, ~. - Lakes)
summary(model3l)
layout(matrix(1))
plot(model3l)
#Repeat analysis excluding TCstrlength.  There is no flow variable
#in the final model.  Investigate impact of removing TCstrlength as
#it's quite highly correlated with Q95.
names(Data2)
Data5 <- (Data2[,-c(1,5,6,7,9,22,31,32,34,35,37,39)])
View(Data5)
names(Data5)
#Linear Modelling using stepwise regression
names(Data5)
model5a <- lm(log(CPLD) ~ ., data=Data5)
vif(lm(log(CPLD) ~ ., data = Data5))
```

```
sqrt(vif(lm(log(CPLD) ~ ., data = Data5)) > 2) #ok if not >2
model5b <- step(model5a)
summary(model5b)
#Complete remaining steps manually
model5c <- update(model5b, ~. - GEOCAL)
summary(model5c)
model5d <- update(model5c, ~. - Alkalinity)
summary(model5d)
model5e <- update(model5d, ~. - RIVGRAD)
summary(model5e)
model5f <- update(model5e, ~. - USSALT2)
summary(model5f)
model5g <- update(model5f, ~. - USSUBUR)
summary(model5g)
model5h <- update(model5g, ~. - Northing)
summary(model5h)
model5i <- update(model5h, ~. - USCONWO)
summary(model5i)
model5j <- update(model5i, ~. - Calcium)
summary(model5j)
model5k <- update(model5j, ~. - USNEUTG)
summary(model5k)
layout(matrix(1))
plot(model5k)
# Assessing Outliers
# Bonferonni p-value for most extreme observations,
outlierTest(model5k)
 #qq plot for studentized residual
qqPlot(model5k, main="QQ Plot")
# leverage plots
leverage Plots(model5k)
# Influential Observations
# Cook's D plot
# identify D values > 4/(n-k-1)
cutoff <- 4/((nrow(Data5)-length(model5k$coefficients)-2))
plot(model5k, which=4, cook.levels=cutoff)
# Influence Plot
influencePlot(model5k, id.method="identify", main="Influence Plot", sub="Circle size is proportial
to Cook's Distance" )
# Normality of Residuals
# qq plot for studentized resid
qqPlot(model5k, main="QQ Plot")
# distribution of studentized residuals
sresid <- studres(model5k)
hist(sresid, freq=FALSE,
    main="Distribution of Studentized Residuals")
xfit<-seq(min(sresid),max(sresid),length=40)
yfit<-dnorm(xfit)
lines(xfit, yfit)
#Prediction Intervals
newData <- data.frame(Easting=-1.69889996,
                USACIDG=-0.08011976,
                USARABL=1.39330950,
                USBLWOO=0.30239820,
                GEOSAL=-0.1878588,
```

```
                 Q95=-0.34652247)
predict(model5k, newdata=newData,interval="prediction")
################################
```

Section 6.3 Sea-trout distribution, barriers to migration and spawning locations – England and Wales.

Note: The fisheries information displayed on these maps was correct as of 2012 / 2013, consequently contemporary accuracy cannot be guaranteed.

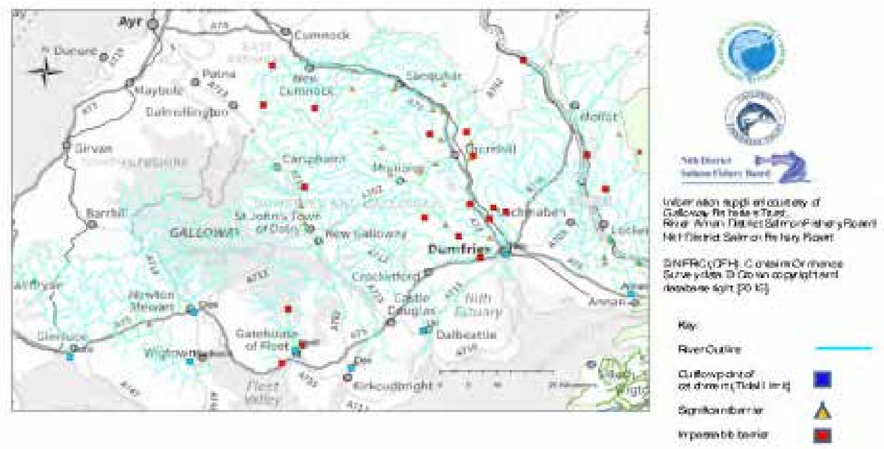


Figure A6.3. 1 Locations of barriers to migration, Solway rivers.

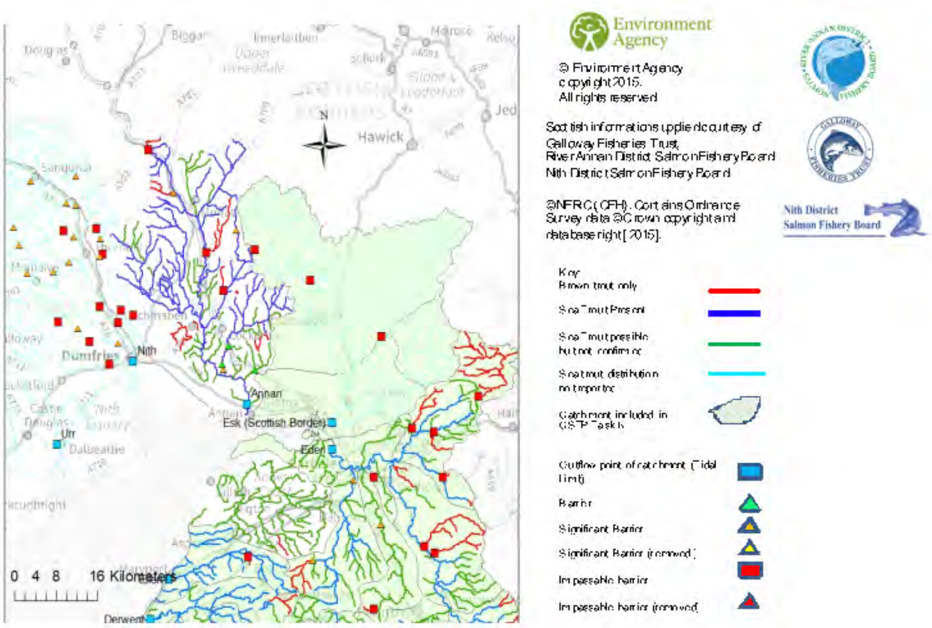


Figure A6.3. 2 Sea Trout distribution and locations of migration barriers, Border Esk, Annan and North Cumbria.

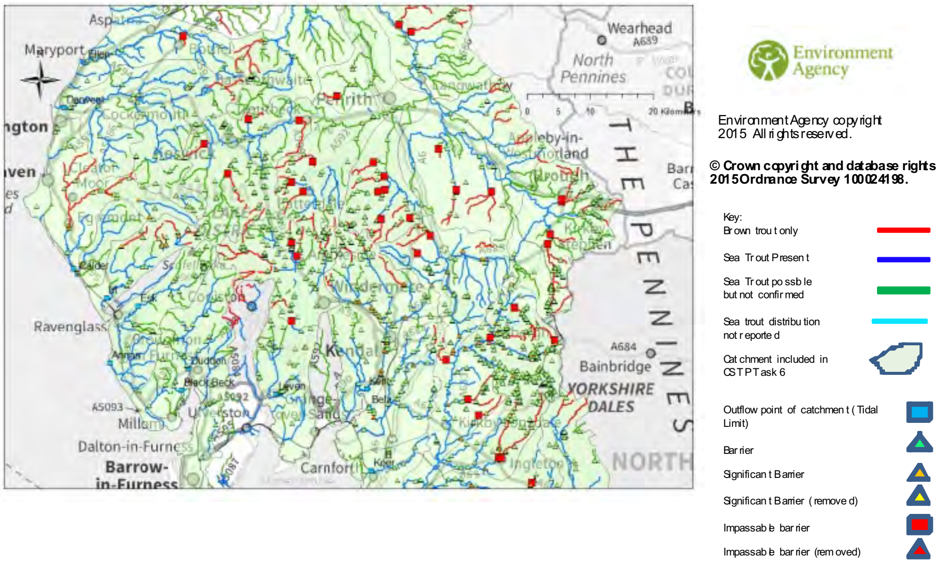


Figure A6.3. 3 Sea Trout distribution and location of migration barriers, Cumbria **.**

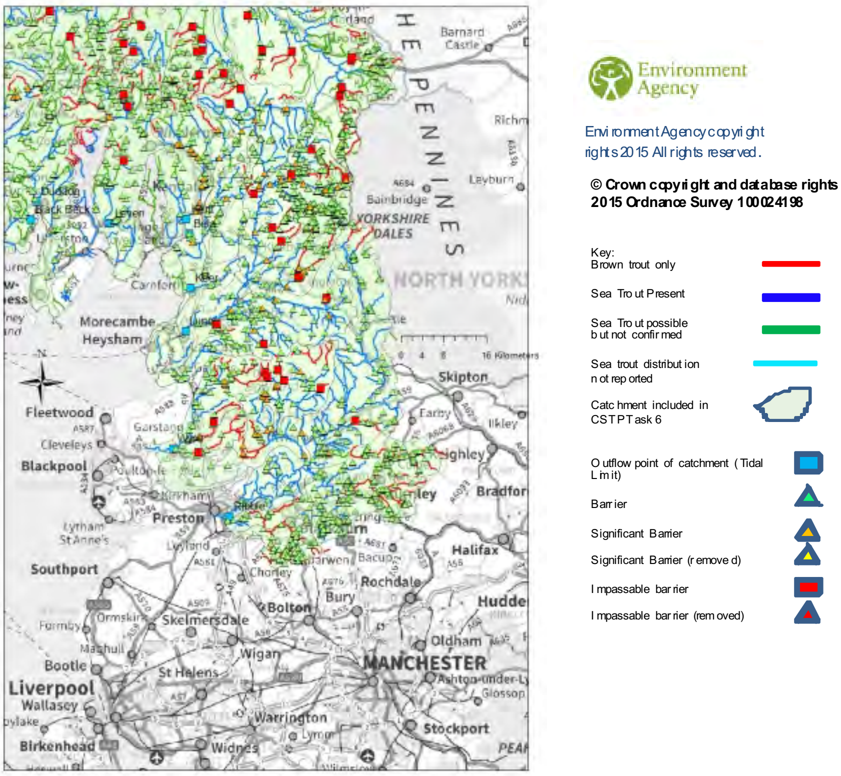


Figure A6.3. 4 Sea Trout Distribution and locations of migration barriers, Lancashire/South Cumbria.

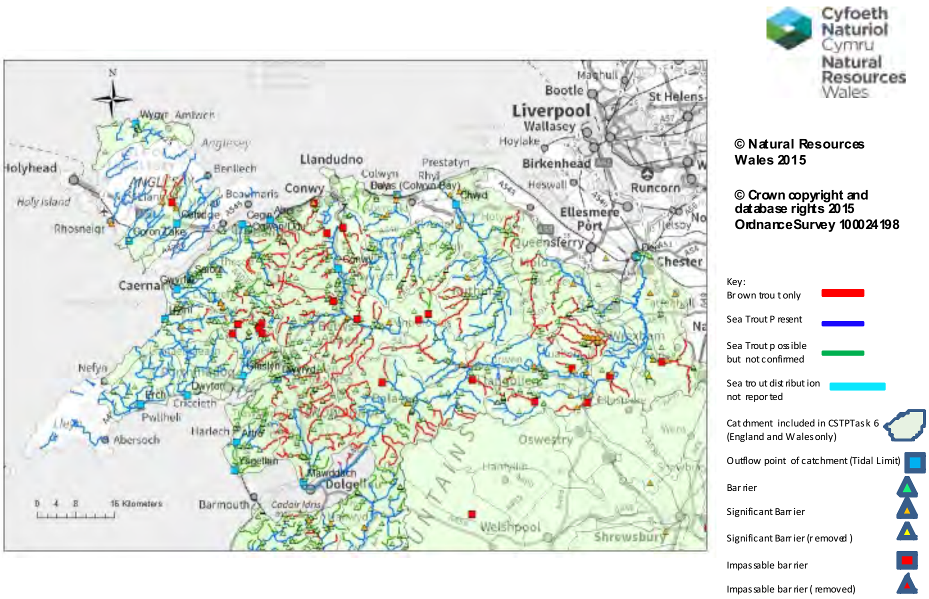


Figure A6.3. 5 Sea Trout distribution and locations of migration barriers, North Wales.

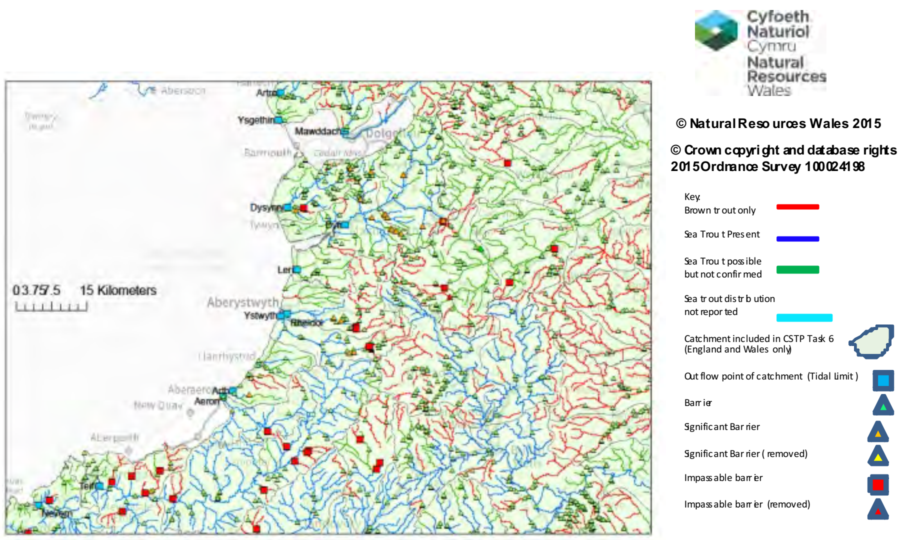


Figure A6.3. 6 Sea Trout distribution and locations of migration barriers, Mid-Wales.

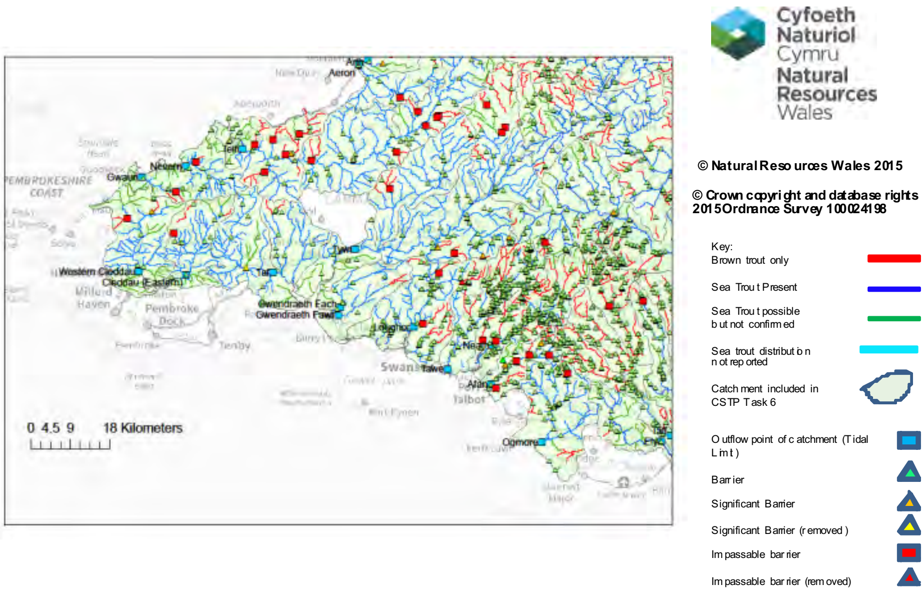


Figure A6.3. 7 Sea Trout distribution and locations of barriers, South Wales.

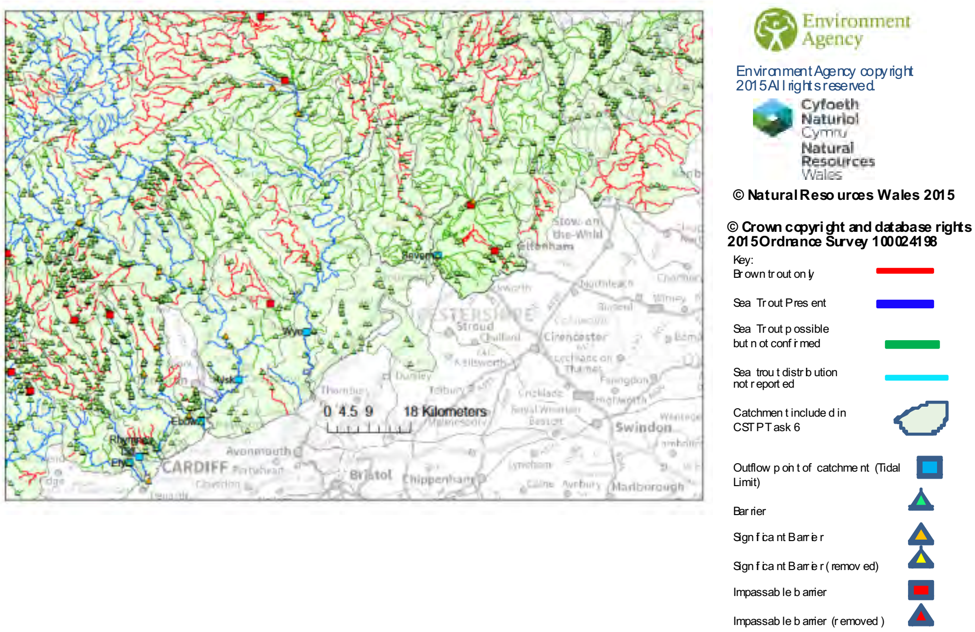


Figure A6.3. 8 Sea Trout distribution and locations of migration barriers, South-East Wales, south Midlands**.**

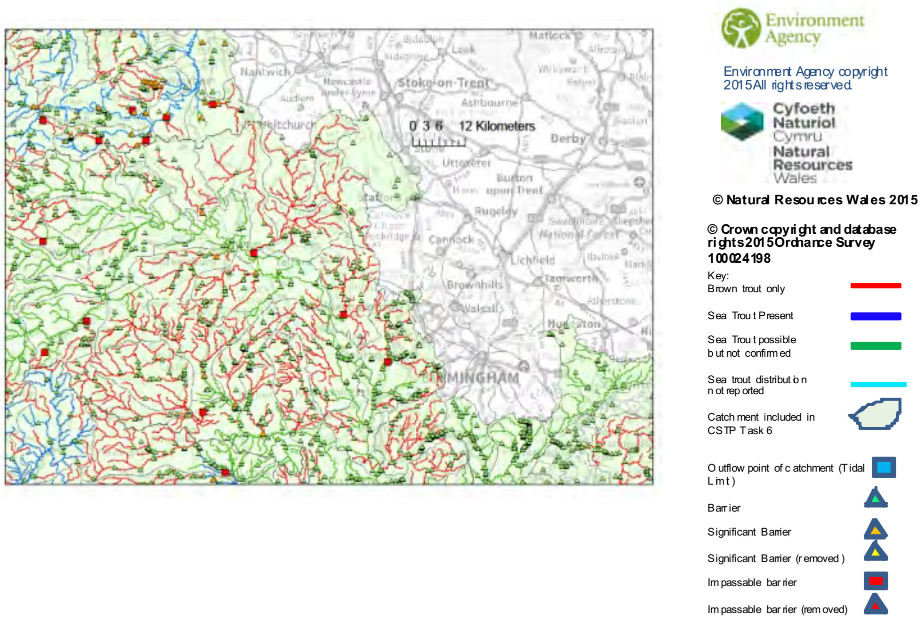


Figure A6.3. 9 Sea Trout distribution and locations of migration barriers, Midlands.

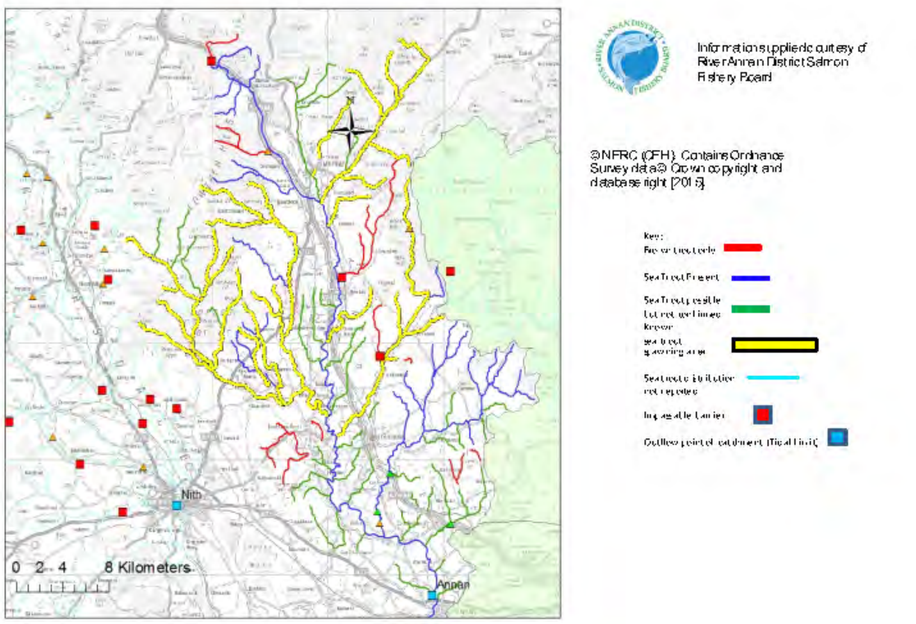


Figure A6.3. 10 Known sea trout spawning areas, Annan catchment.

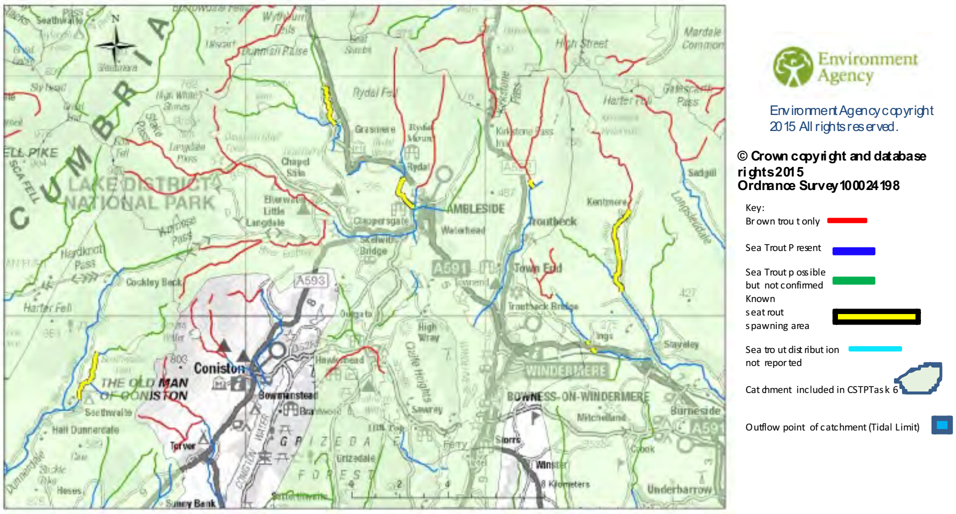


Figure A6.3. 11 Known sea trout spawning locations, Cumbria.

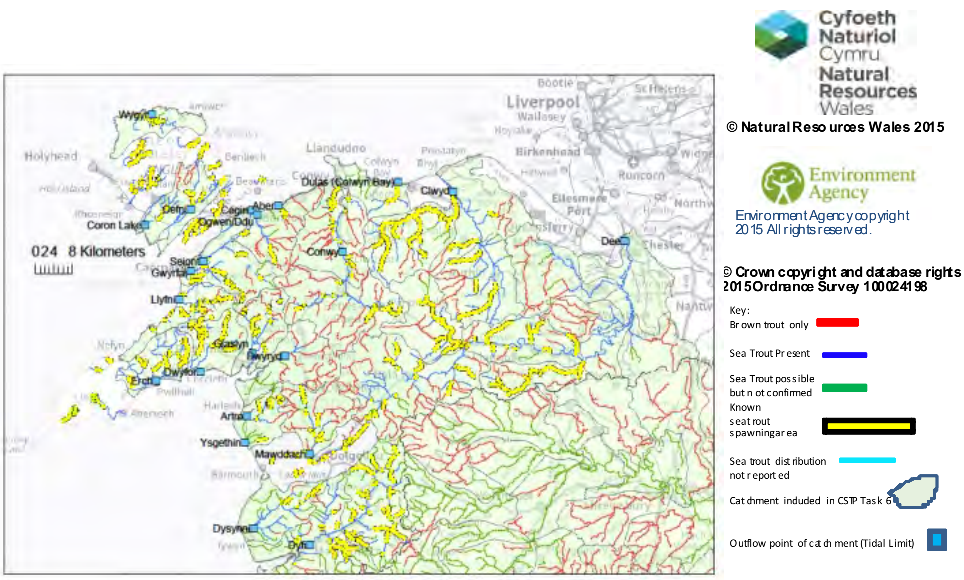


Figure A6.3. 12 Known sea-trout spawning areas in North Wales.

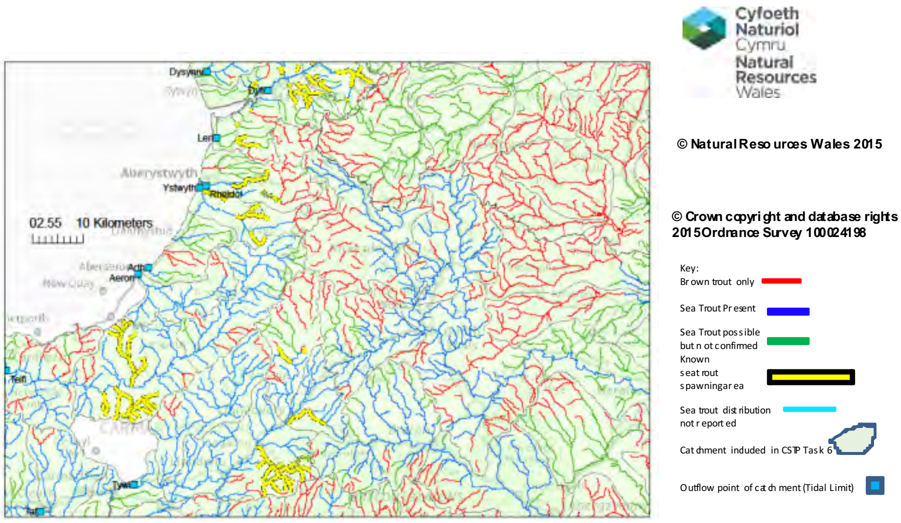
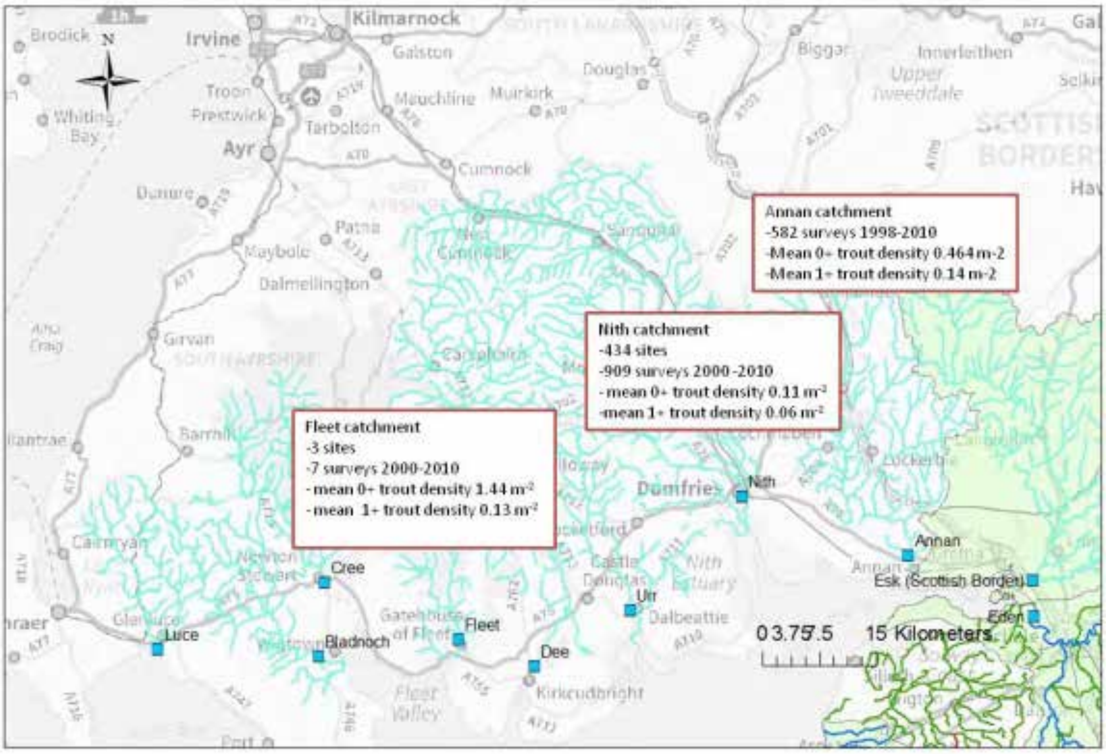


Figure A6.3. 13 Known sea-trout spawning areas in mid and south west Wales.

Sectio 6.4 Maps of mean densities of juvenile salmonids, 2000 -2010 inclusive



Information supplied courtesy of
Galloway Fisheries Trust,
River Annan District Salmon Fishery Board
Nith District Salmon Fishery Board

Figure A6.4. 1 Juvenile trout densities, Scottish rivers

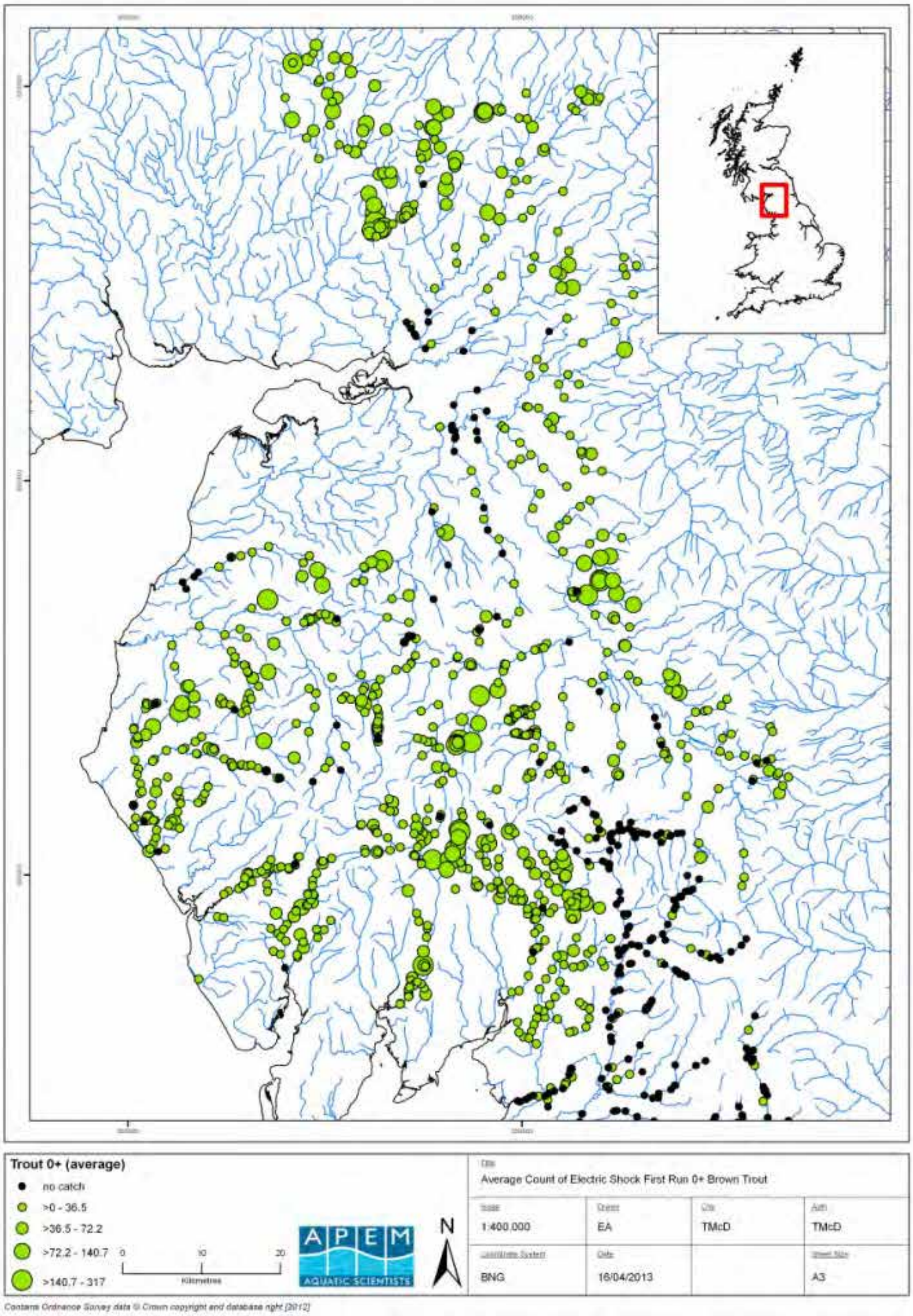


Figure A6.4. 2 Density of 0+ trout in CSTP rivers, Border Esk and Cumbria.

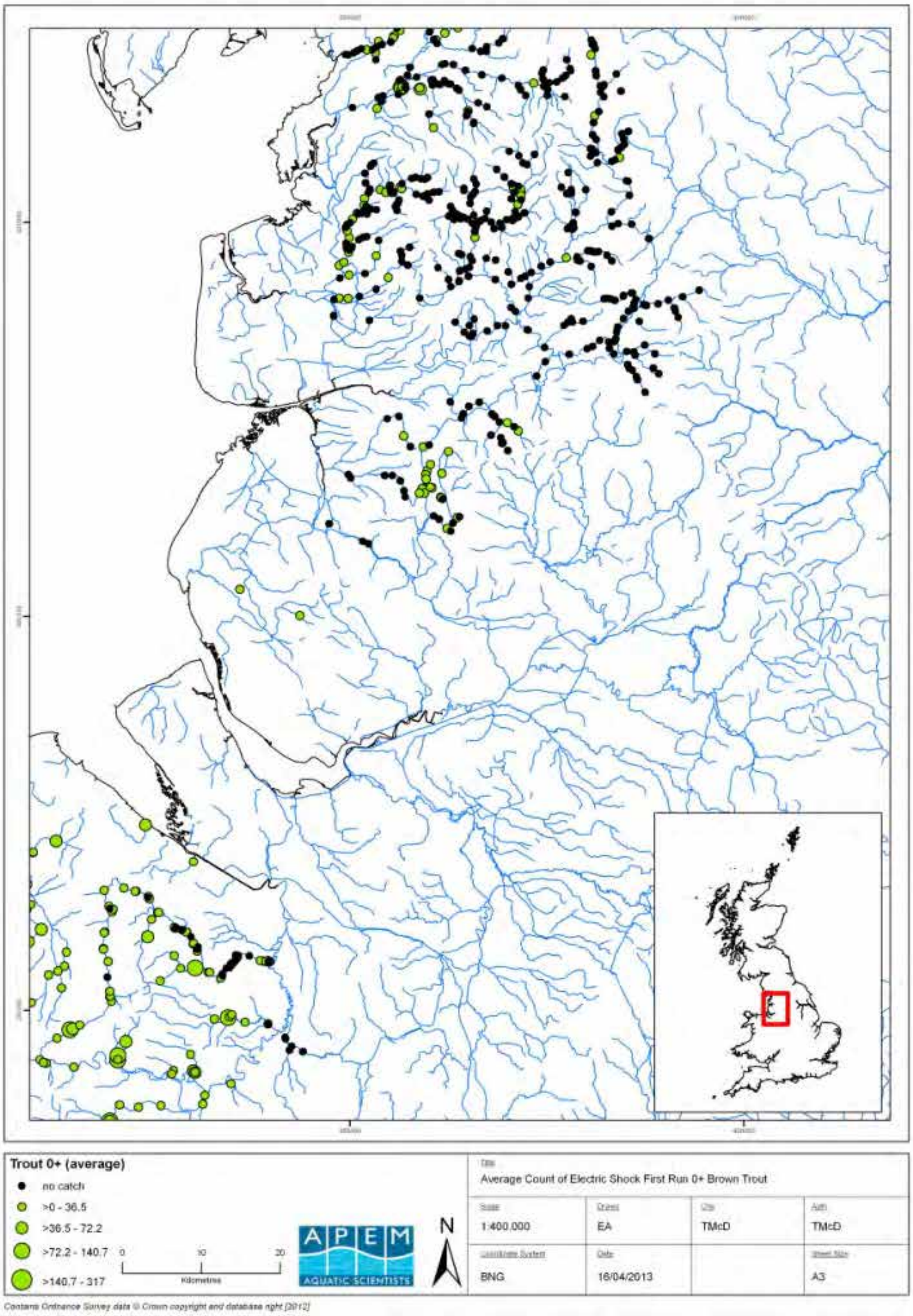


Figure A6.4. 3 Density of 0+ trout in CSTP rivers, Lancashire & north-east Wales.

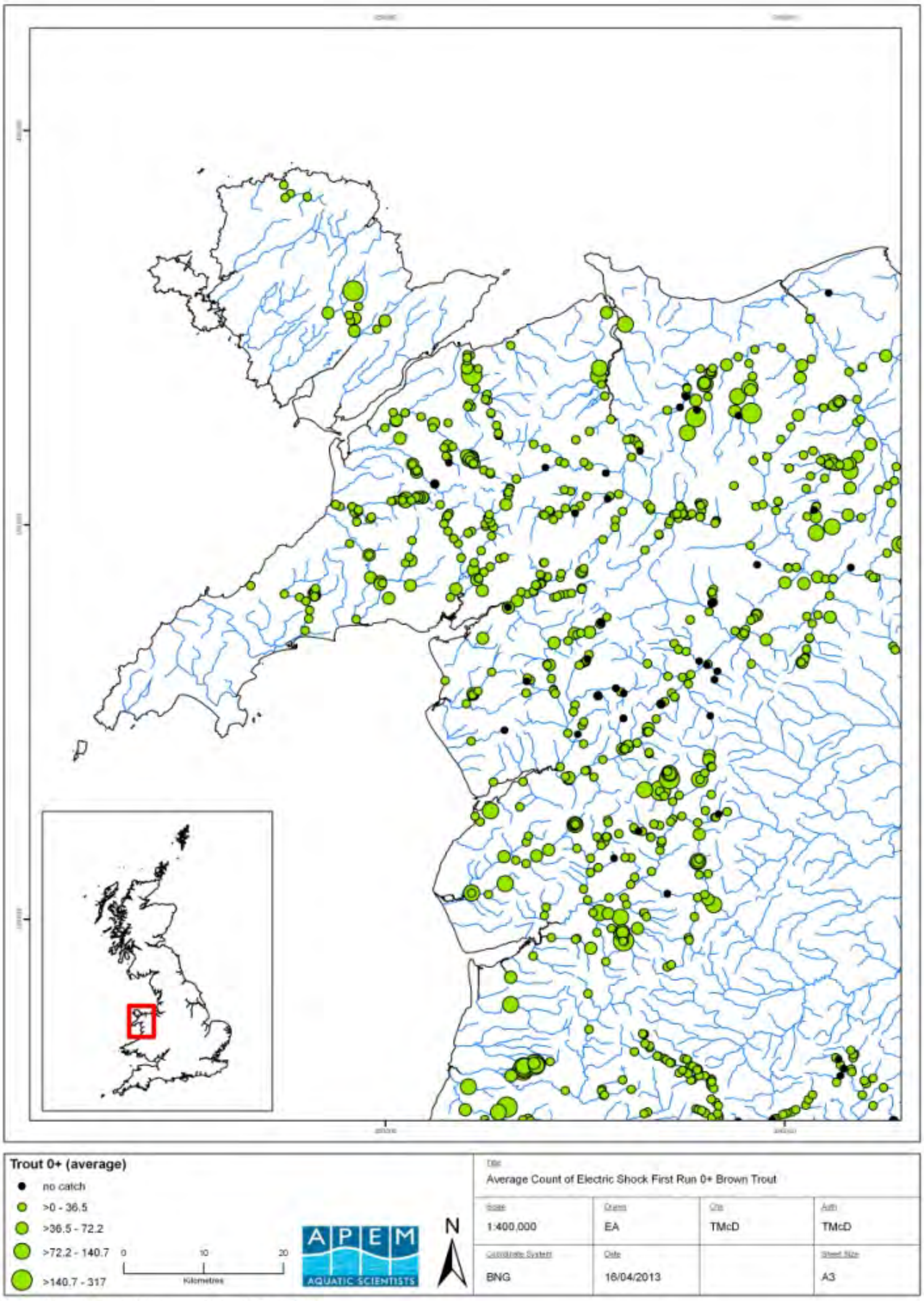


Figure A6.4. 4 Density of 0+ trout in CSTP rivers, NW Wales & Mid-Wales.

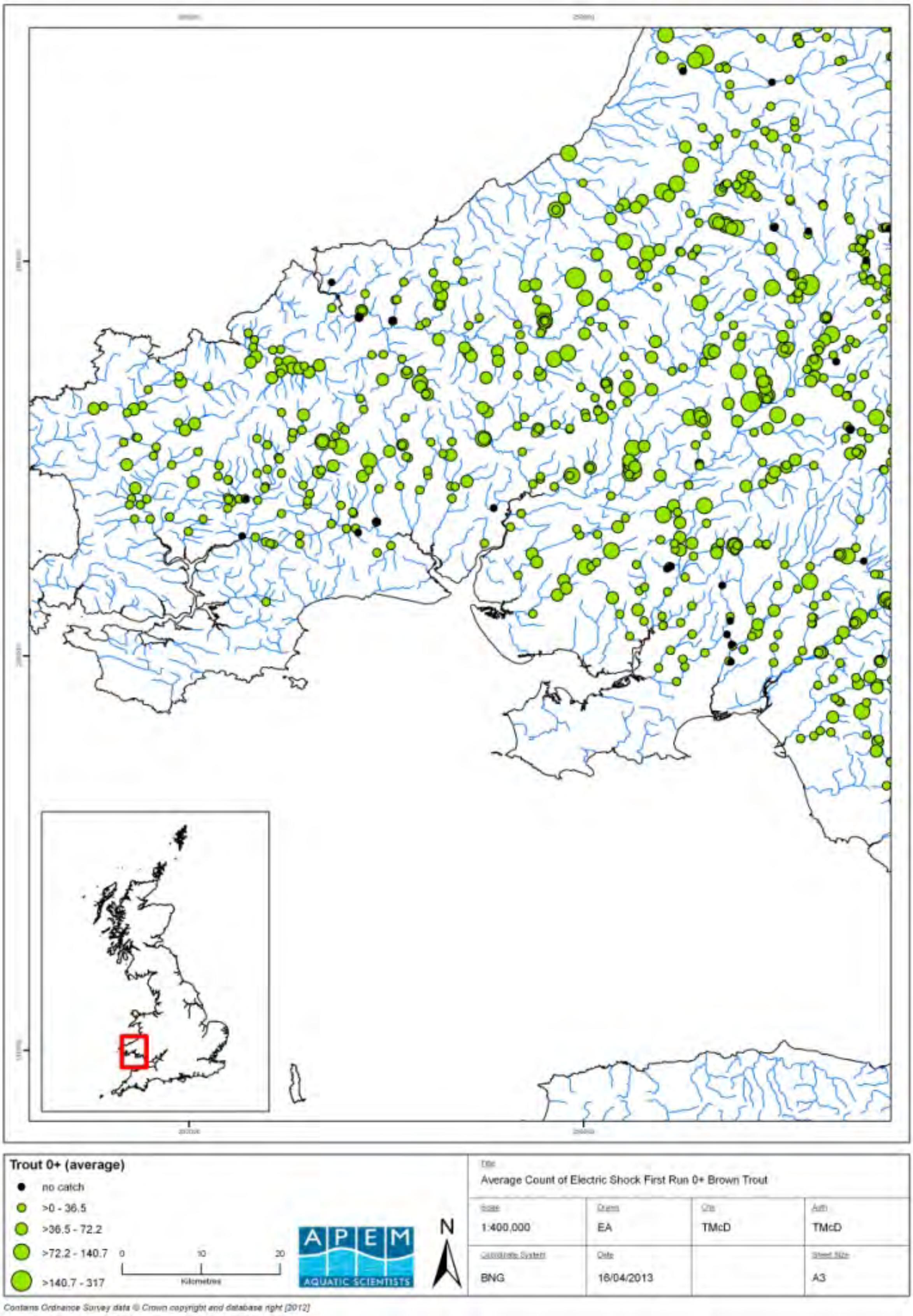


Figure A6.4. 5 Density of 0+ trout in CSTP rivers in the SW Wales area.

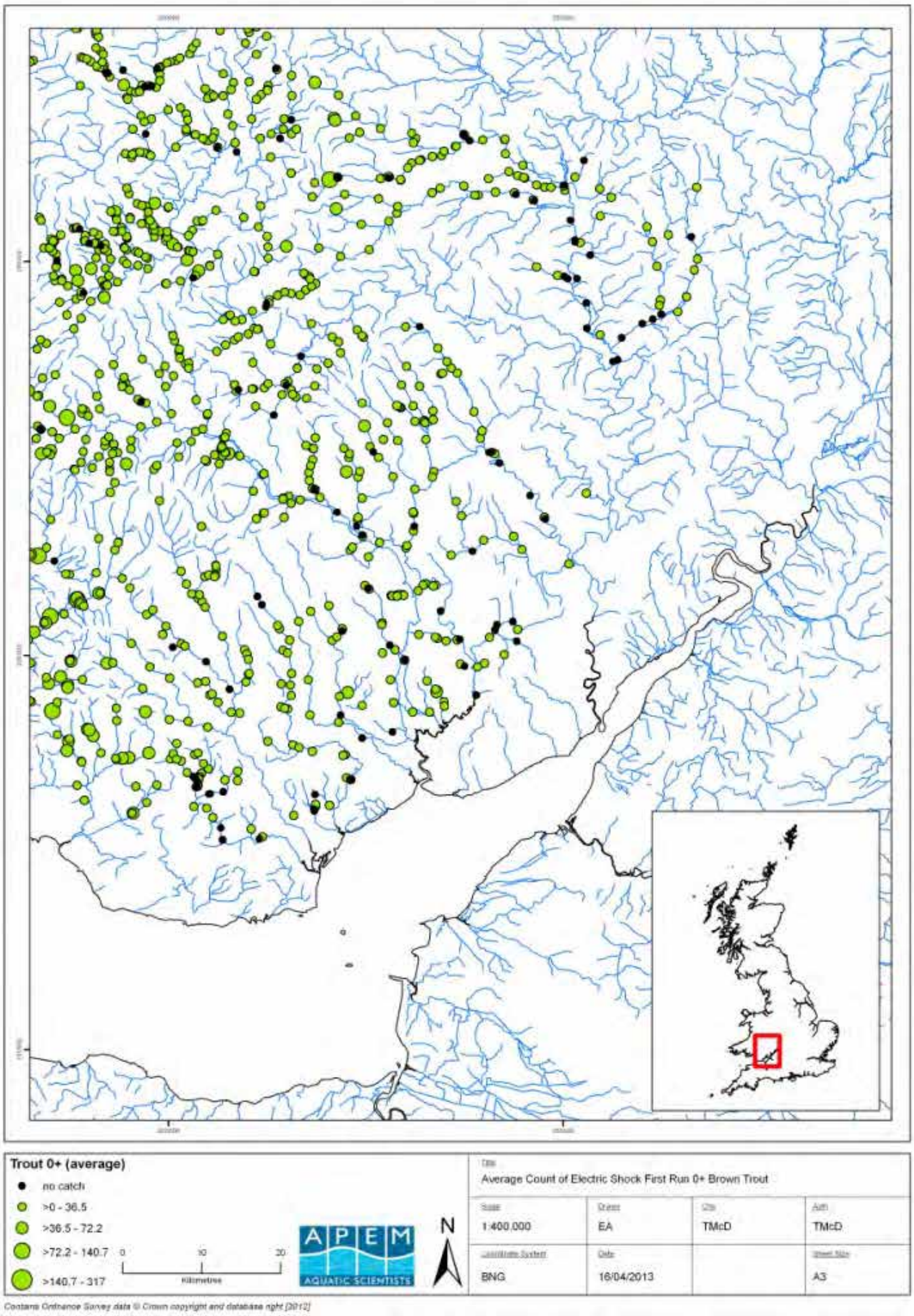


Figure A6.4. 6 Density of 0+ trout in CSTP rivers in the SE Wales area.

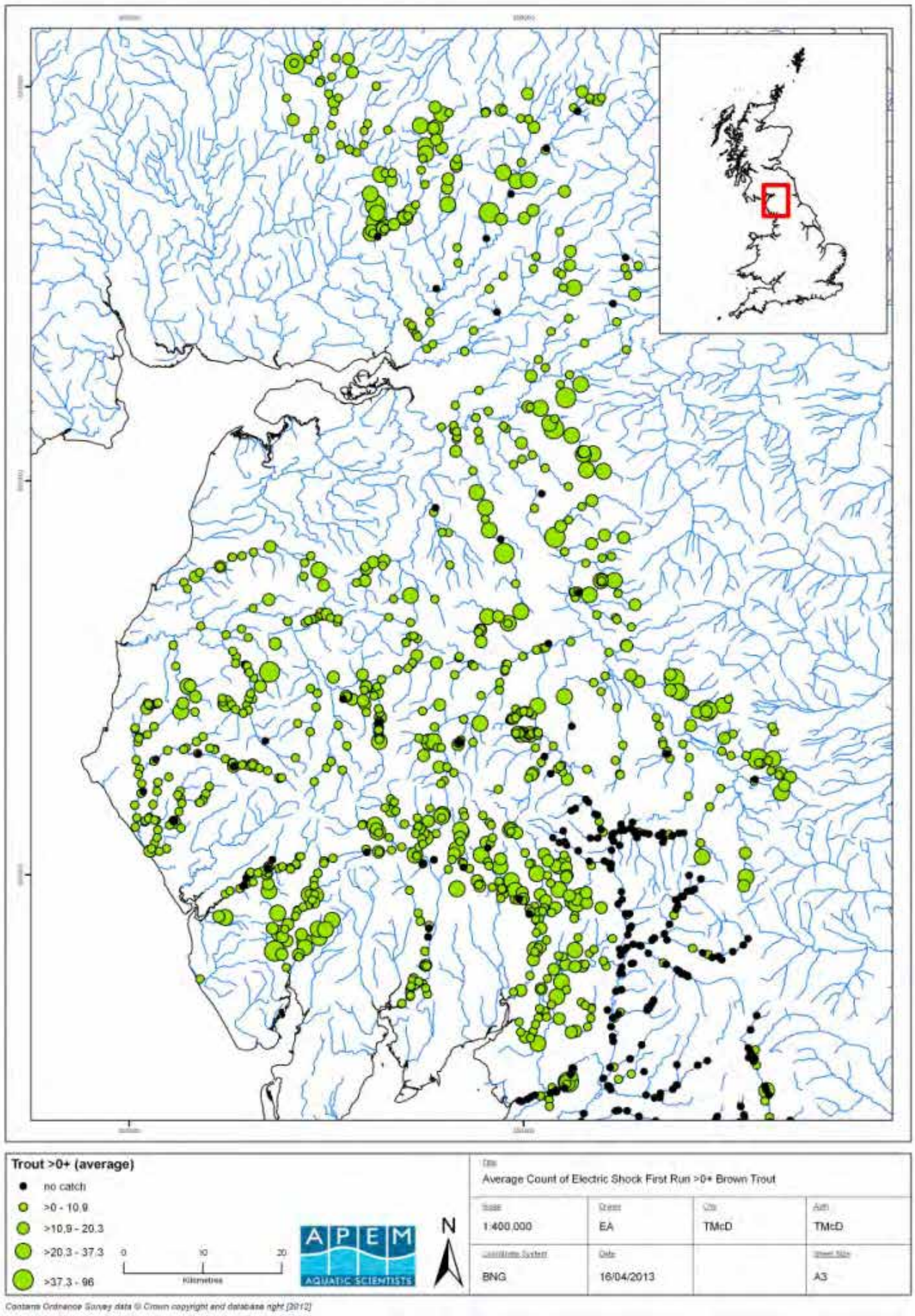


Figure A6.4. 7 Density of >0+ trout in CSTP rivers Cumbria incl Border Esk

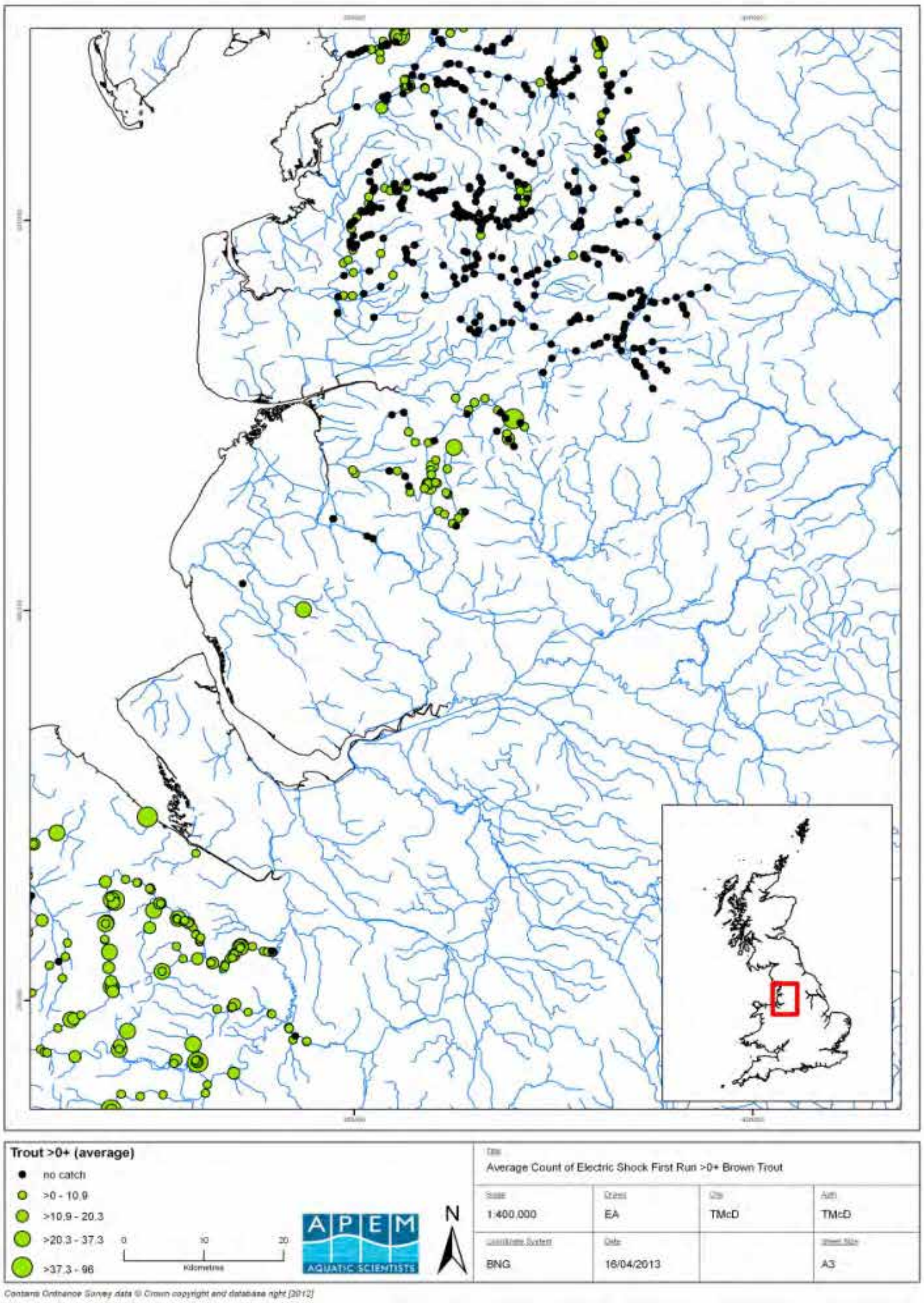


Figure A6.4. 8 Density of >0+ trout in CSTP rivers in the NW England and N Wales areas.

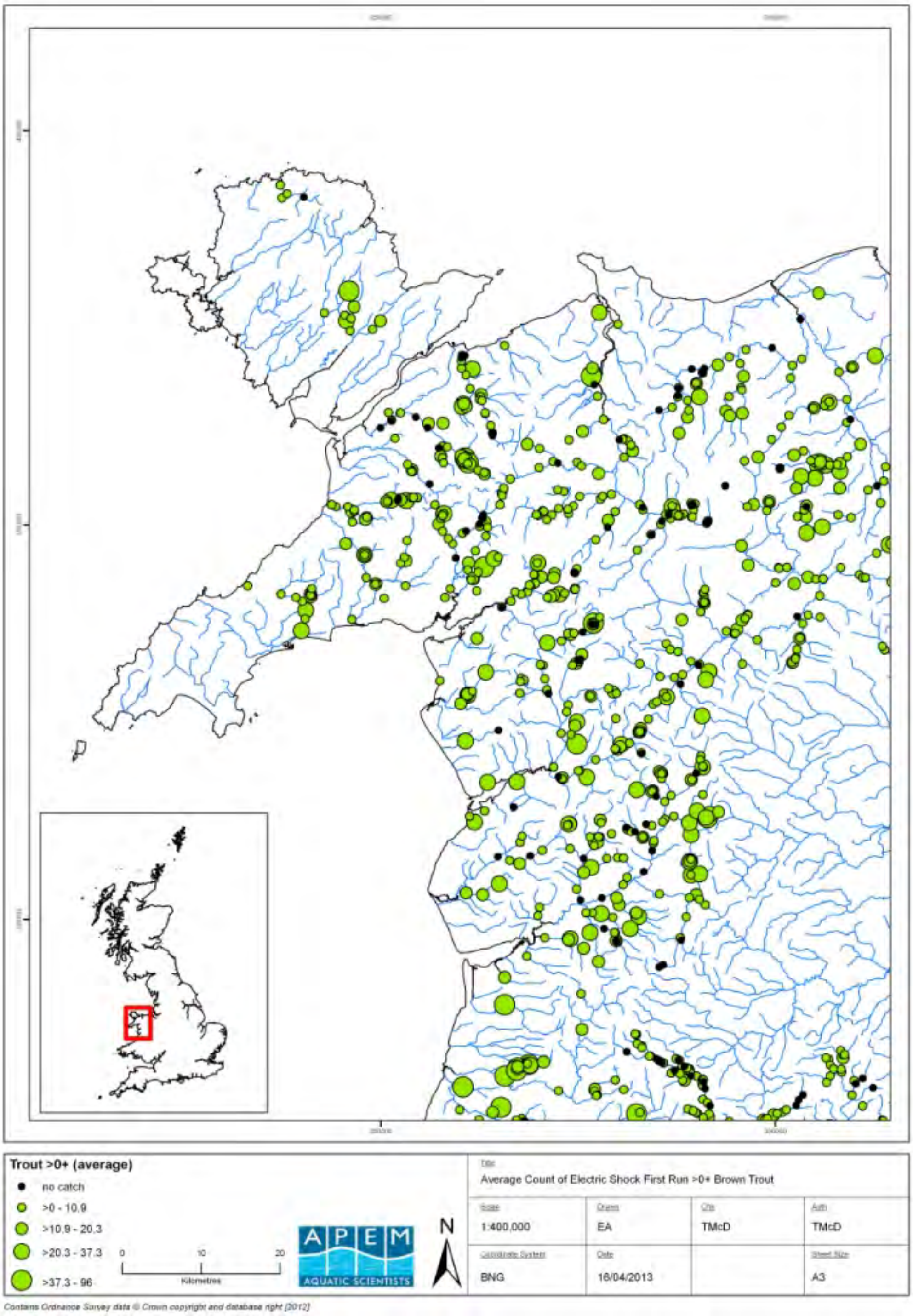


Figure A64. 9 Density of >0+ trout in CSTP rivers in the NW Wales area.

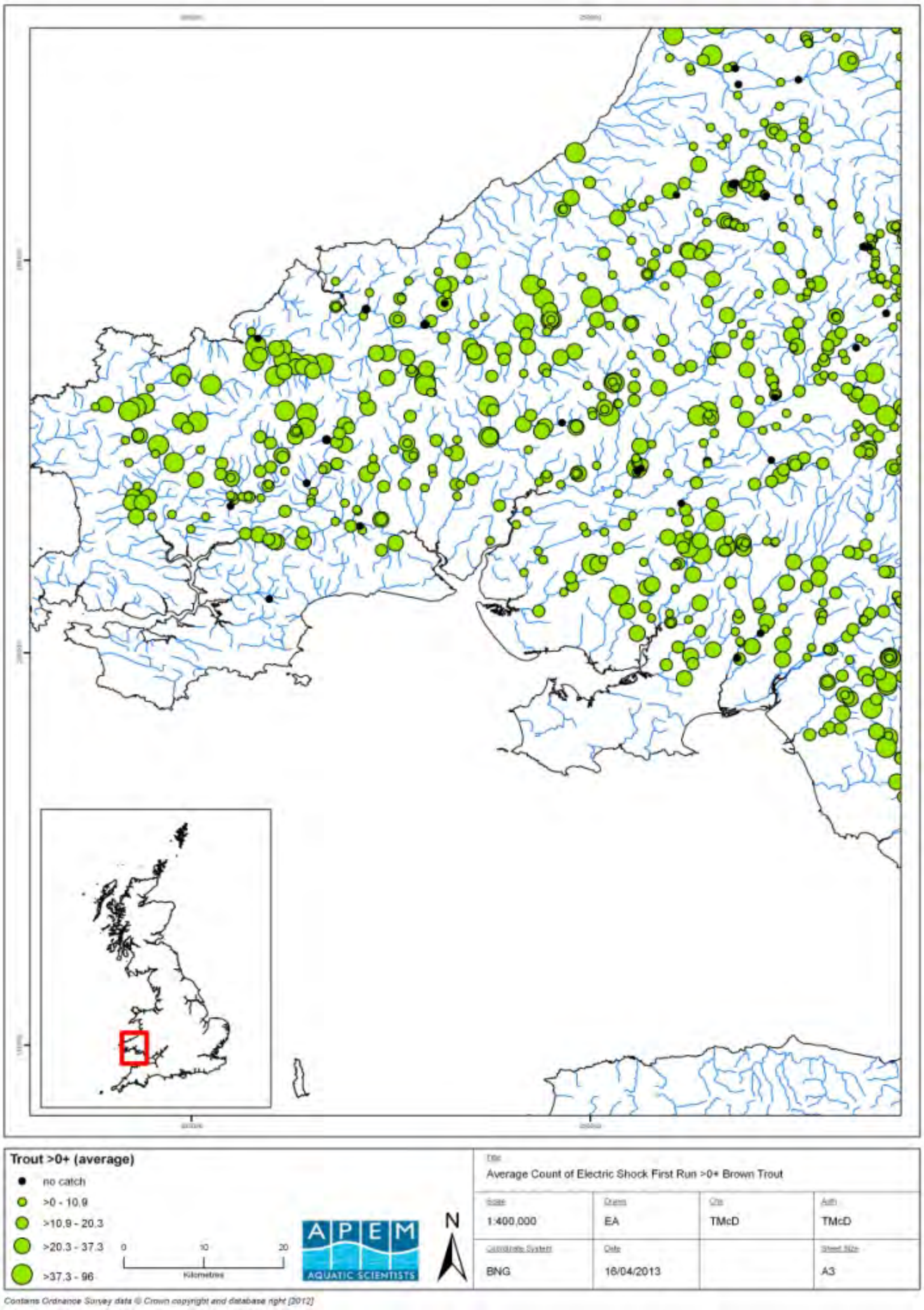


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Figure A6.4. 10 Density of >0+ trout in CSTP rivers in the SW Wales area.

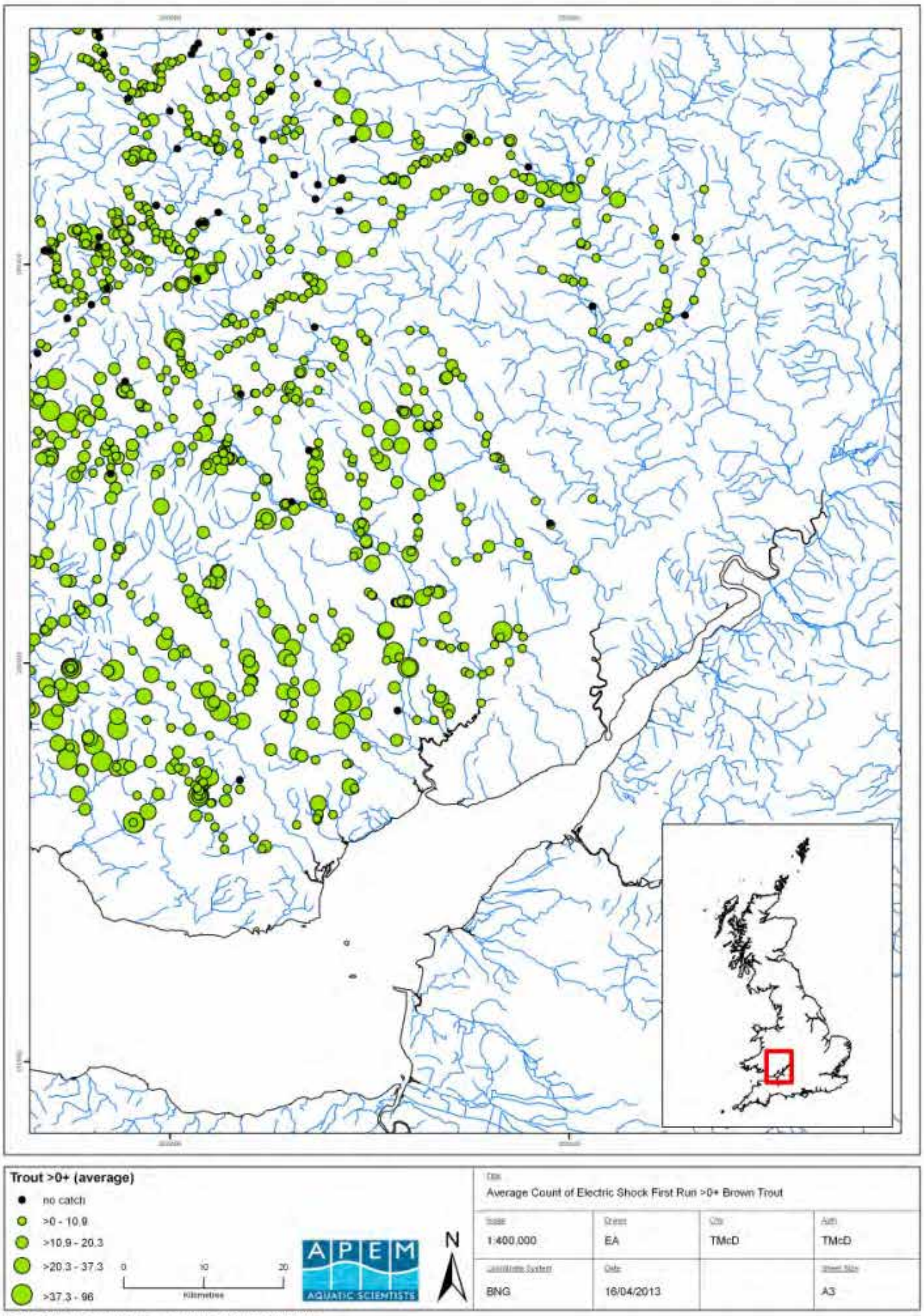

Figure A6.4. 11 Density of >0+ trout in CSTP rivers in the SE Wales area.

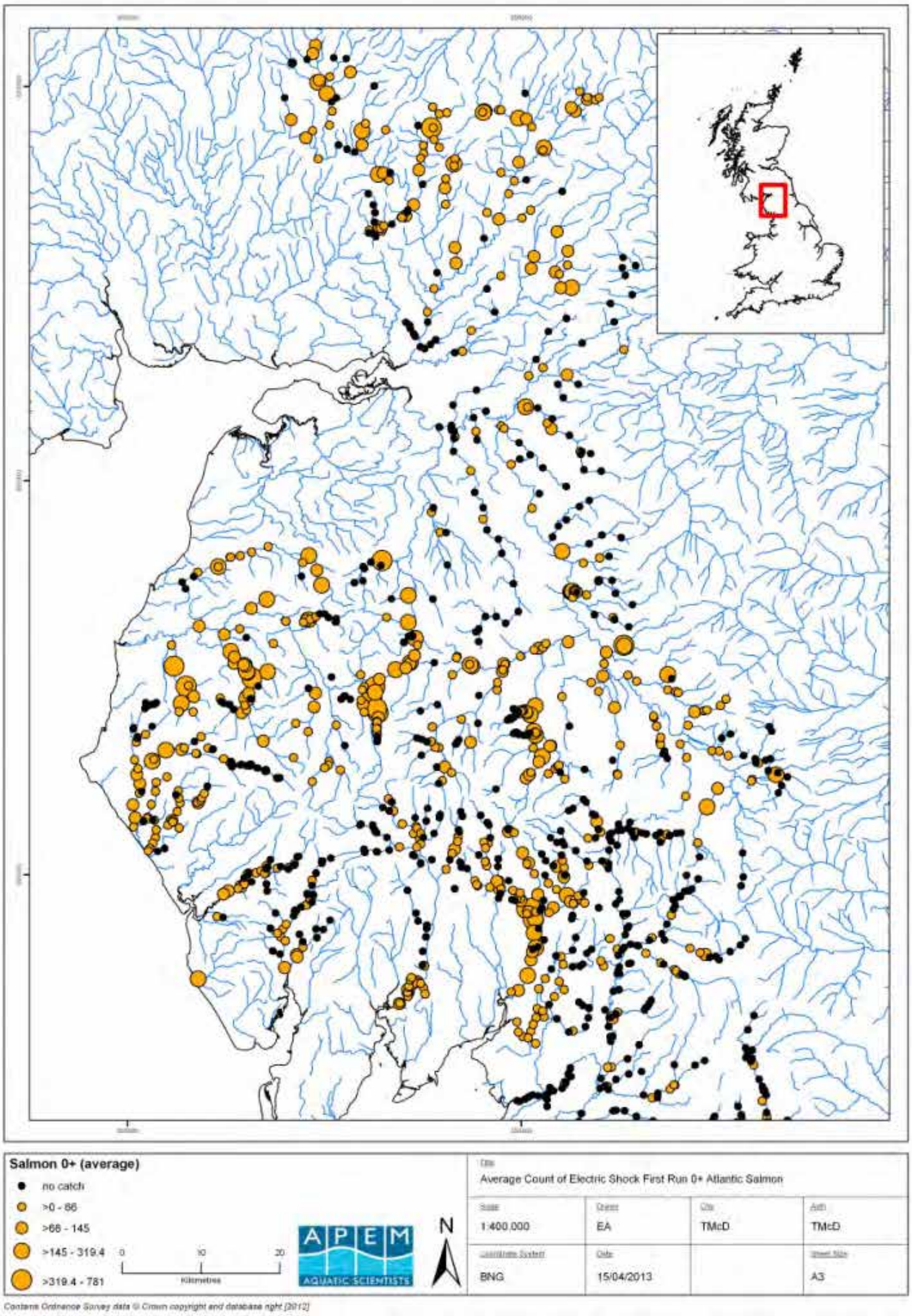

Figure A6.4. 12 Density of 0+ salmon in CSTP rivers in Cumbria incl Border Esk

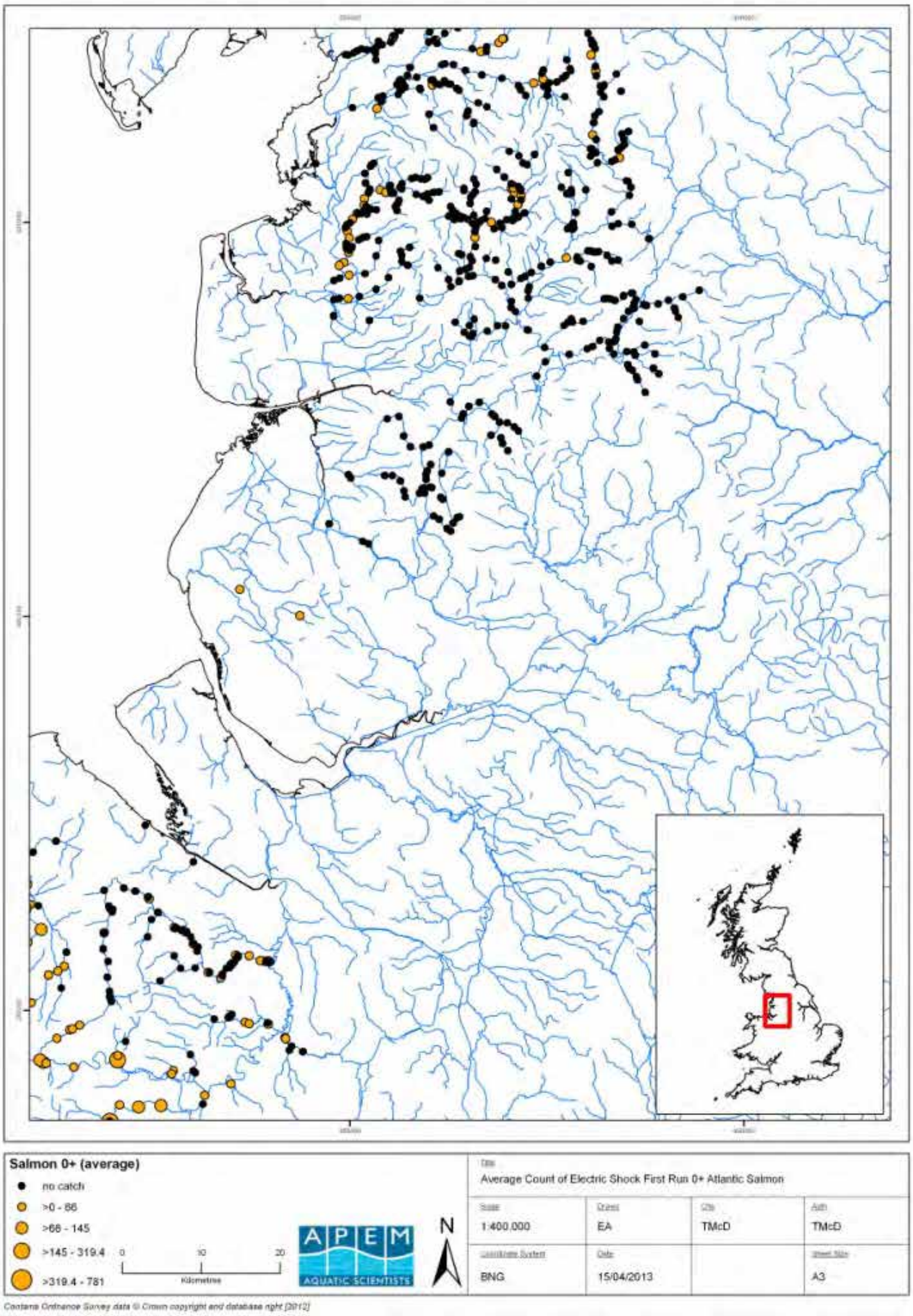

Figure A6.4. 13 Density of 0+ salmon in CSTP rivers in the NW England and N Wales areas.

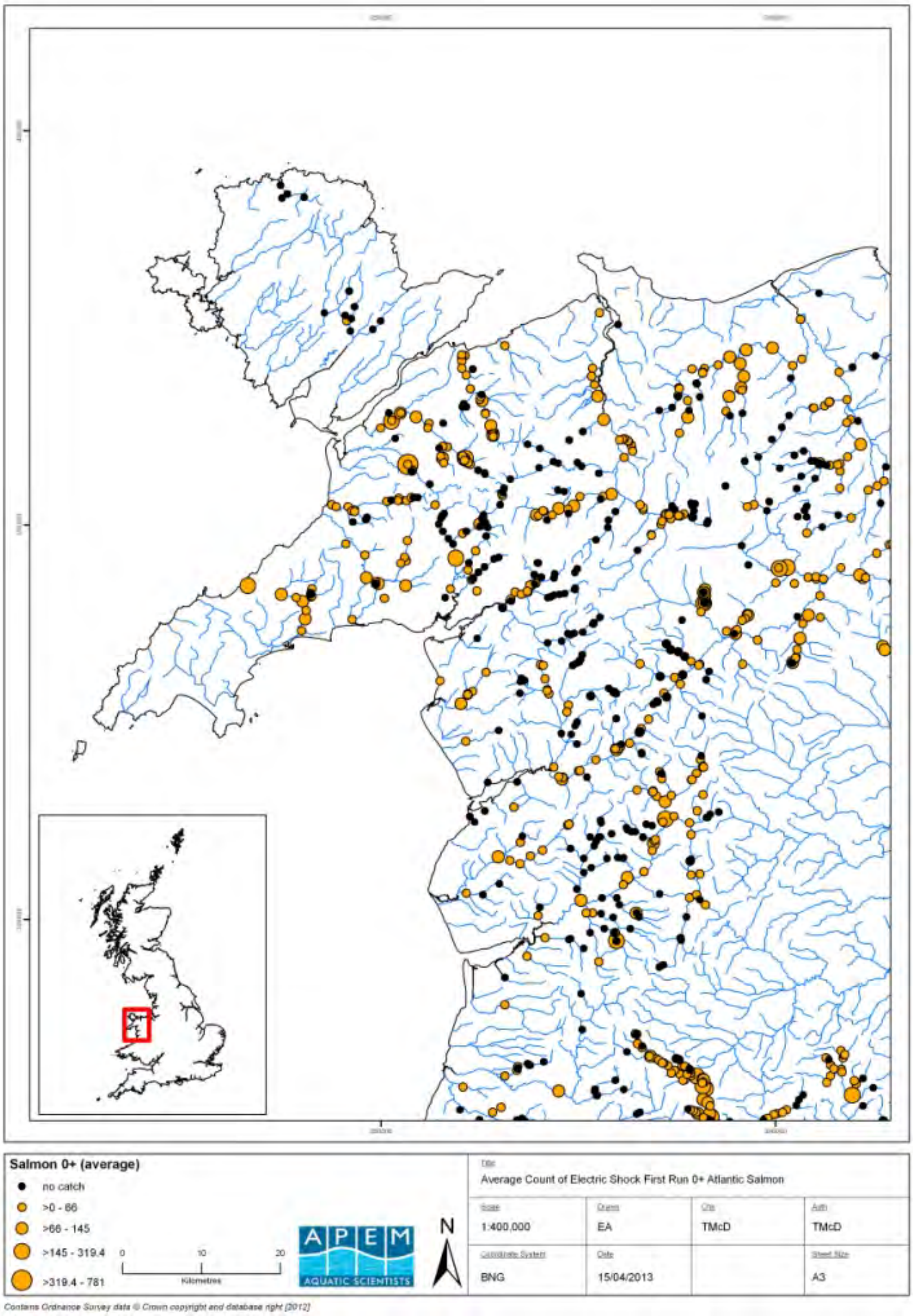

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Figure A6.4. 14 Density of 0+ salmon in CSTP rivers in the NW Wales area.

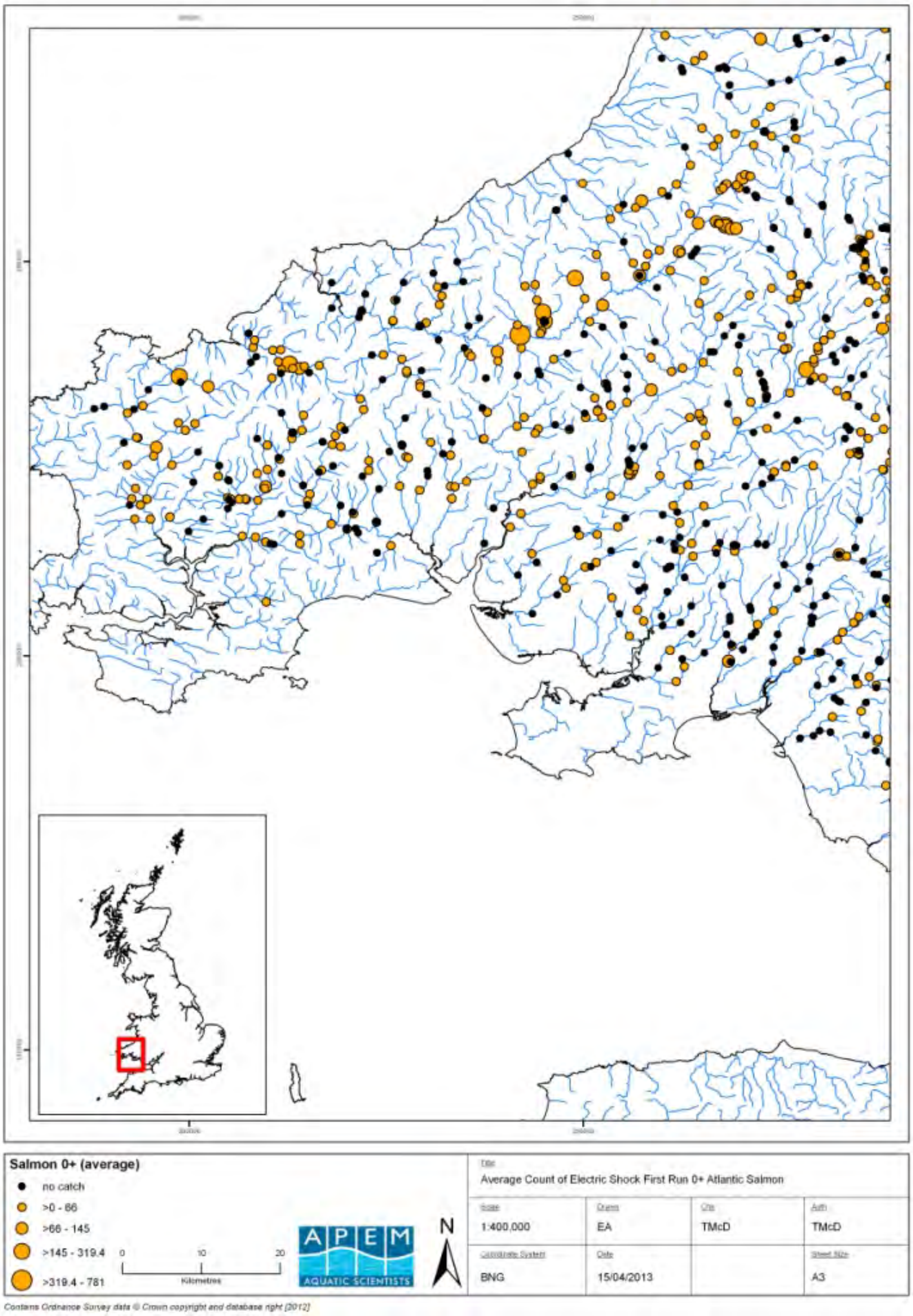

Figure A6.4. 15 Density of 0+ salmon in CSTP rivers in the SW Wales area.

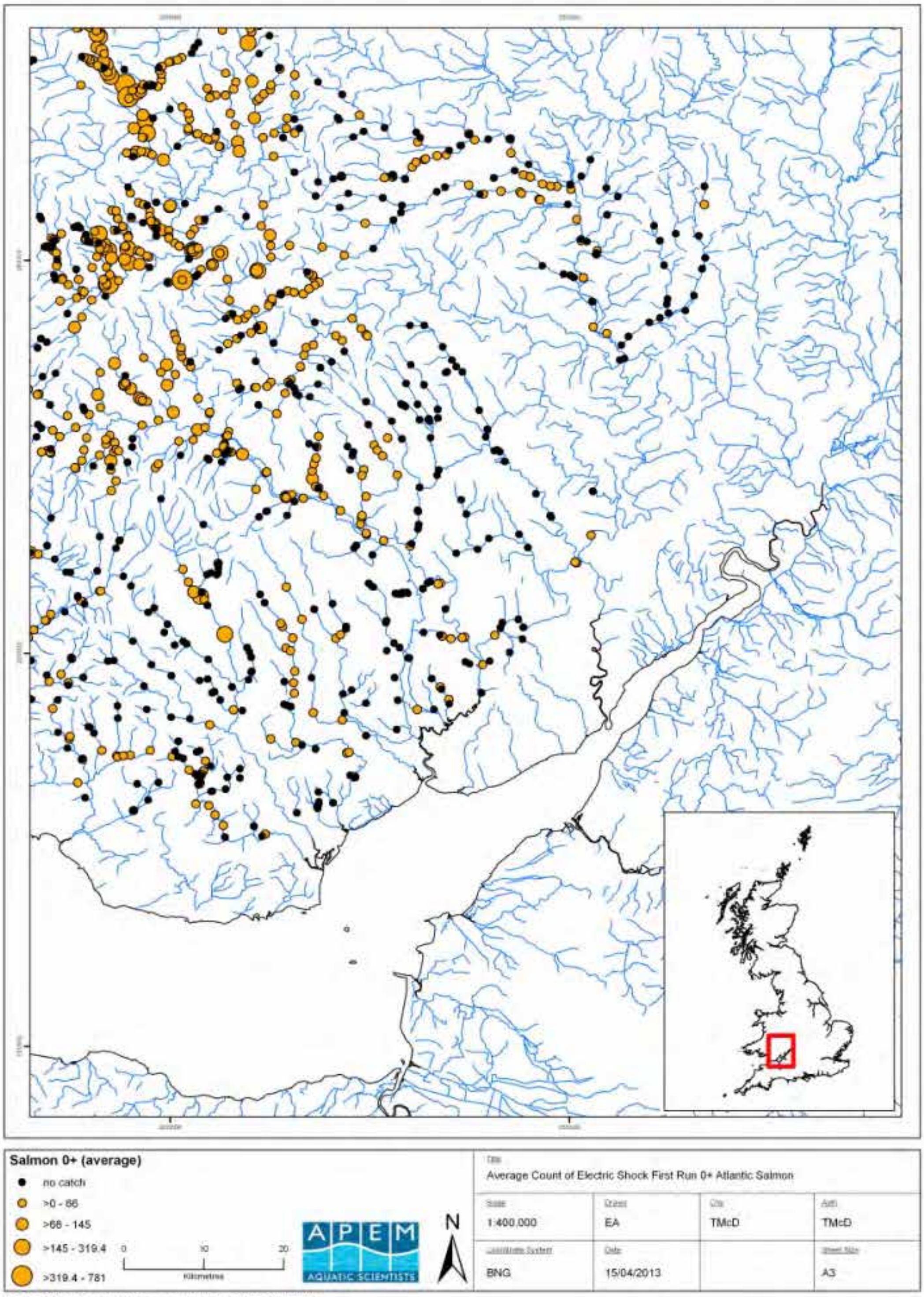

Figure A6.4. 16 Density of 0+ salmon in CSTP rivers in the SE Wales area.

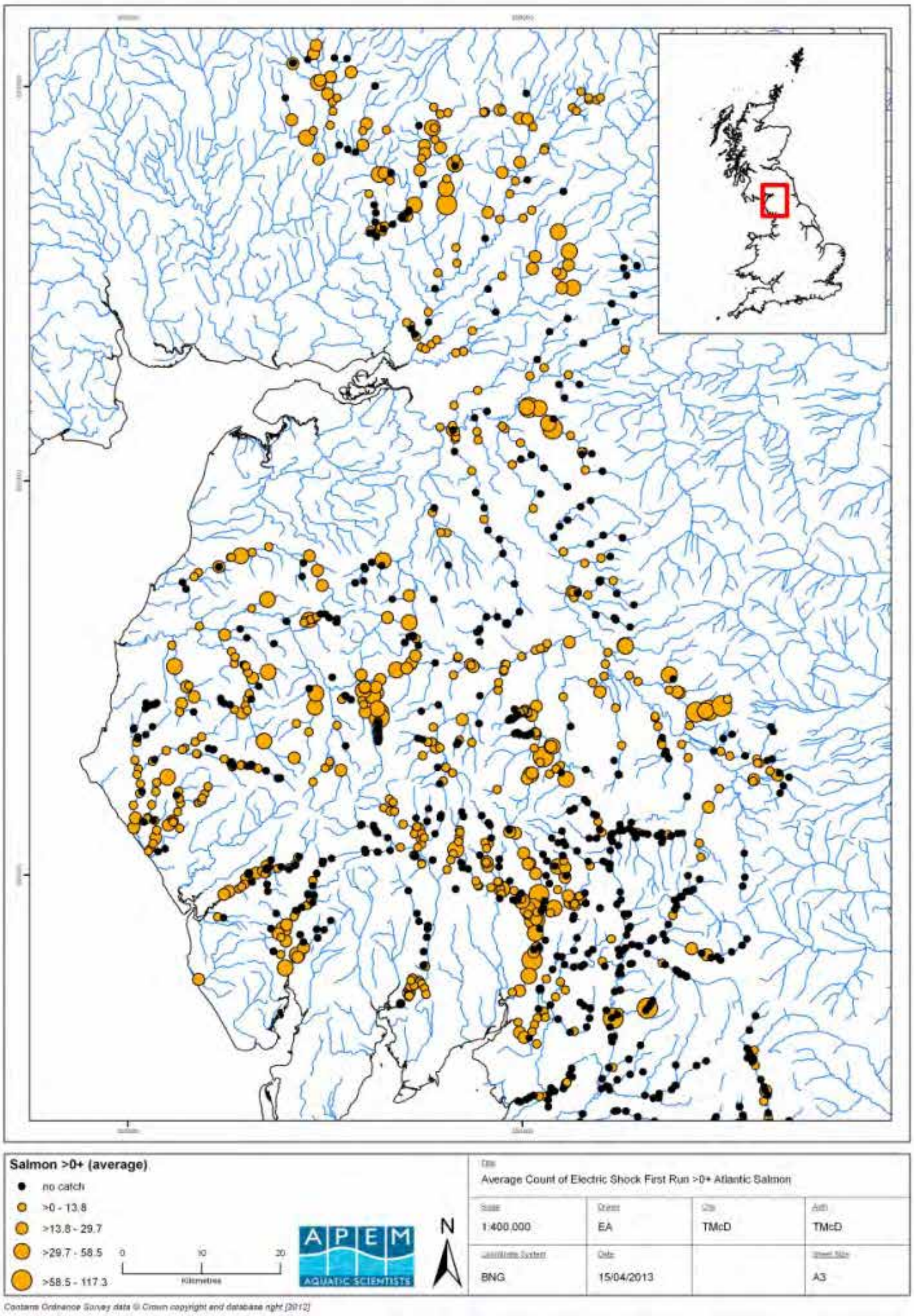

Figure A64. 17 Density of >0+ salmon in CSTP rivers in the Scottish Solway and NW England areas.

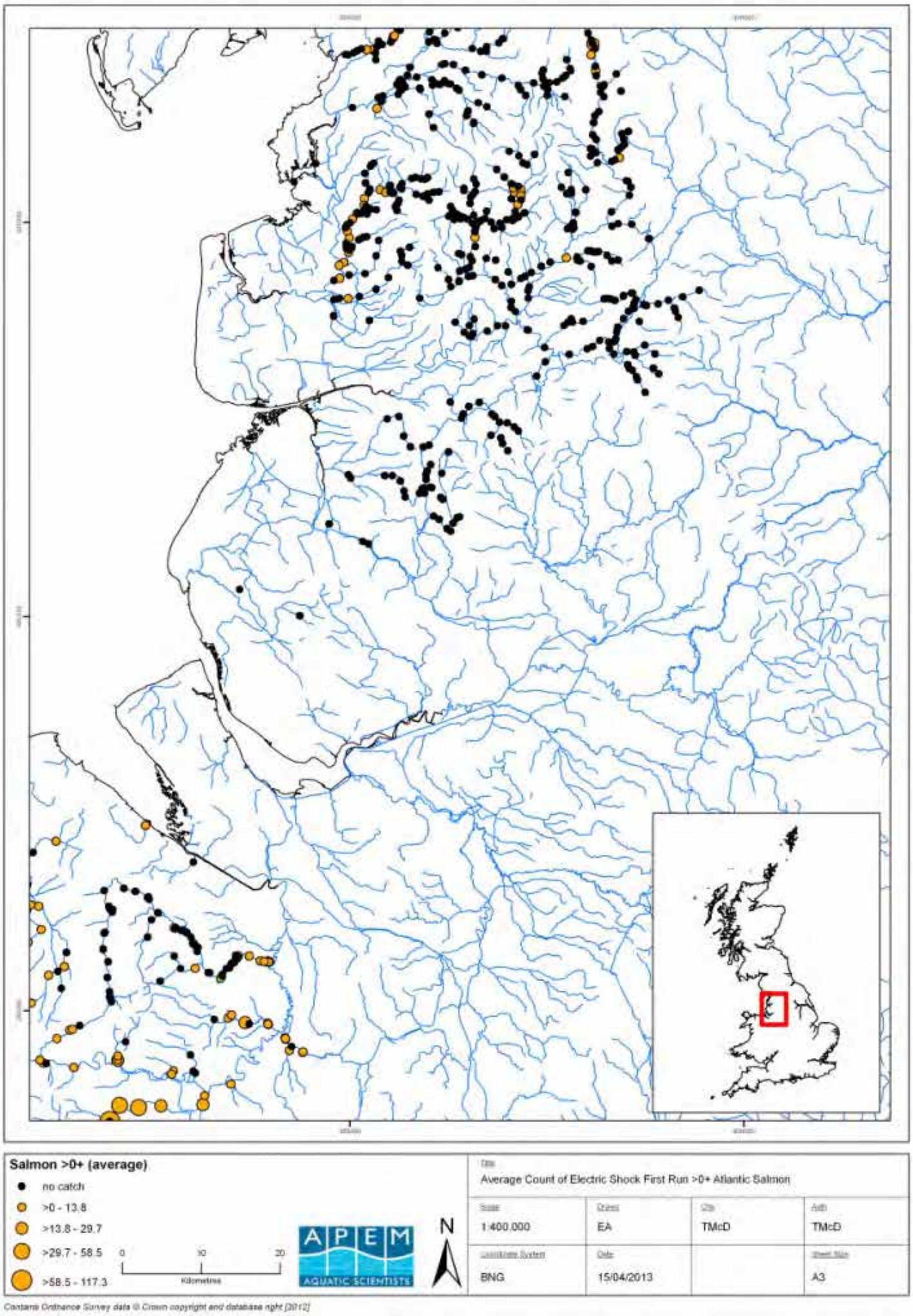

Figure A6.4. 18 Density of >0+ salmon in CSTP rivers in the NW England and N Wales areas.

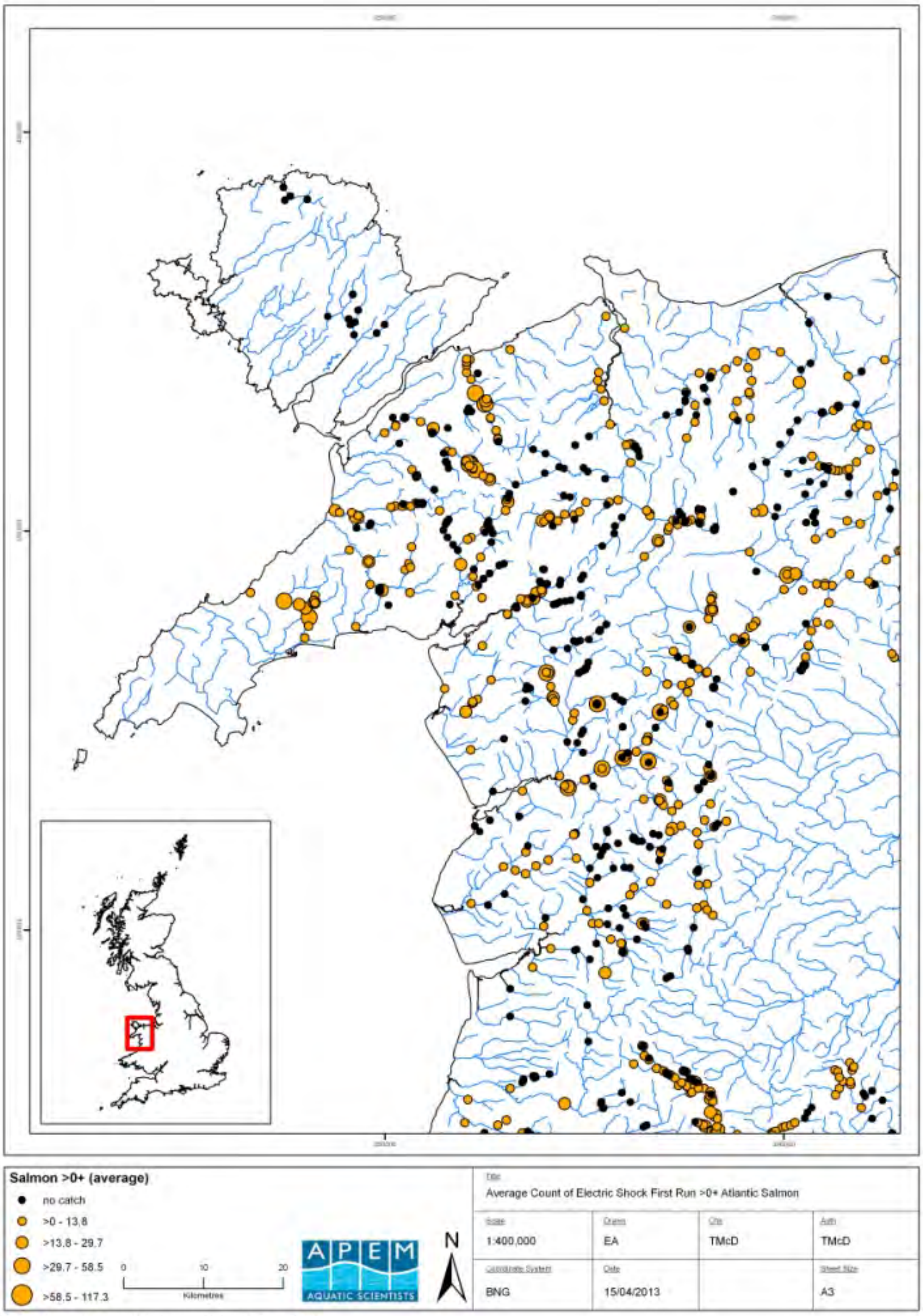

Figure A6.4. 19 Density of >0+ salmon in CSTP rivers in the NW Wales area.

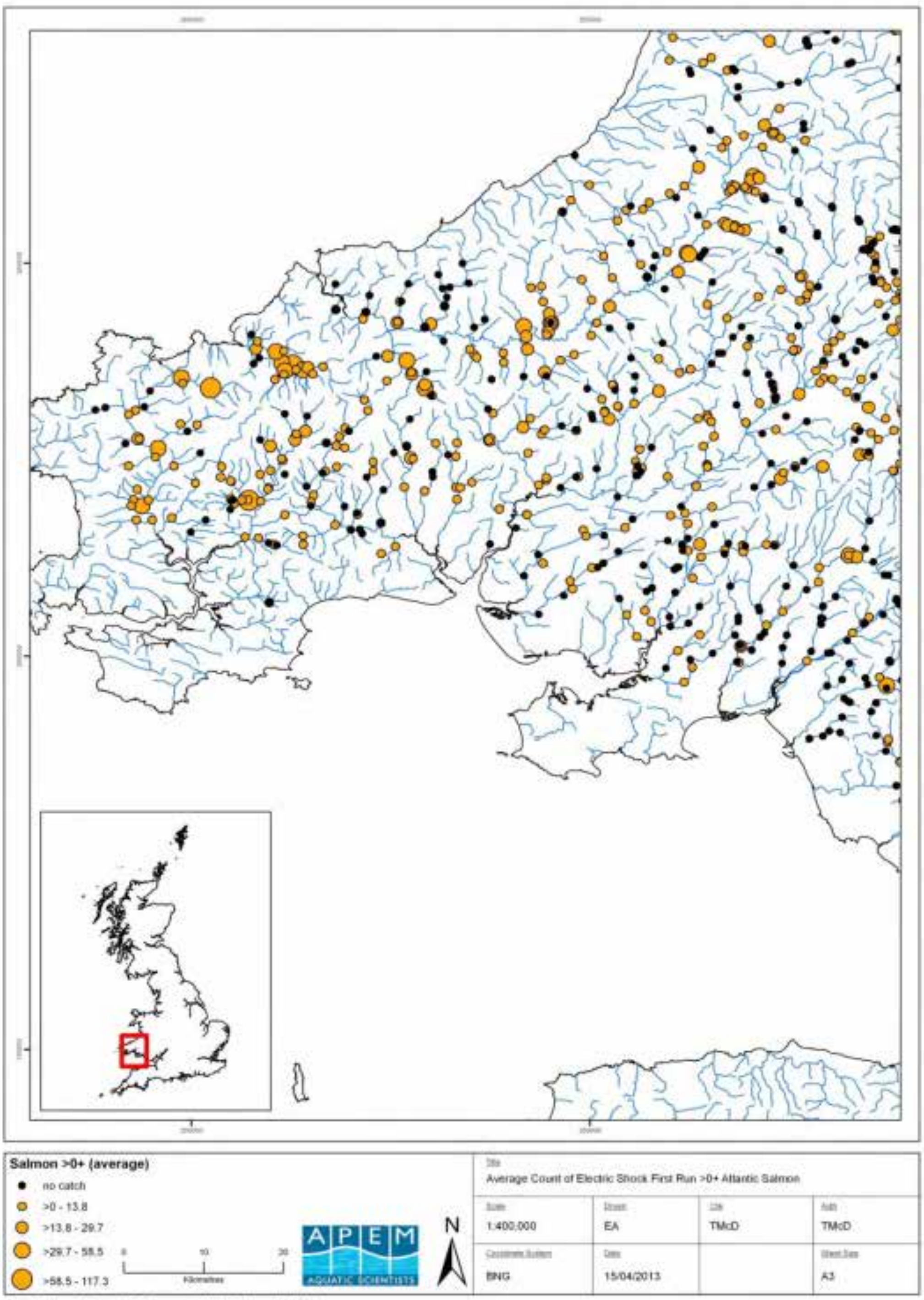

Figure A6.4. 20 Density of >0+ salmon in CSTP rivers in the SW Wales area.

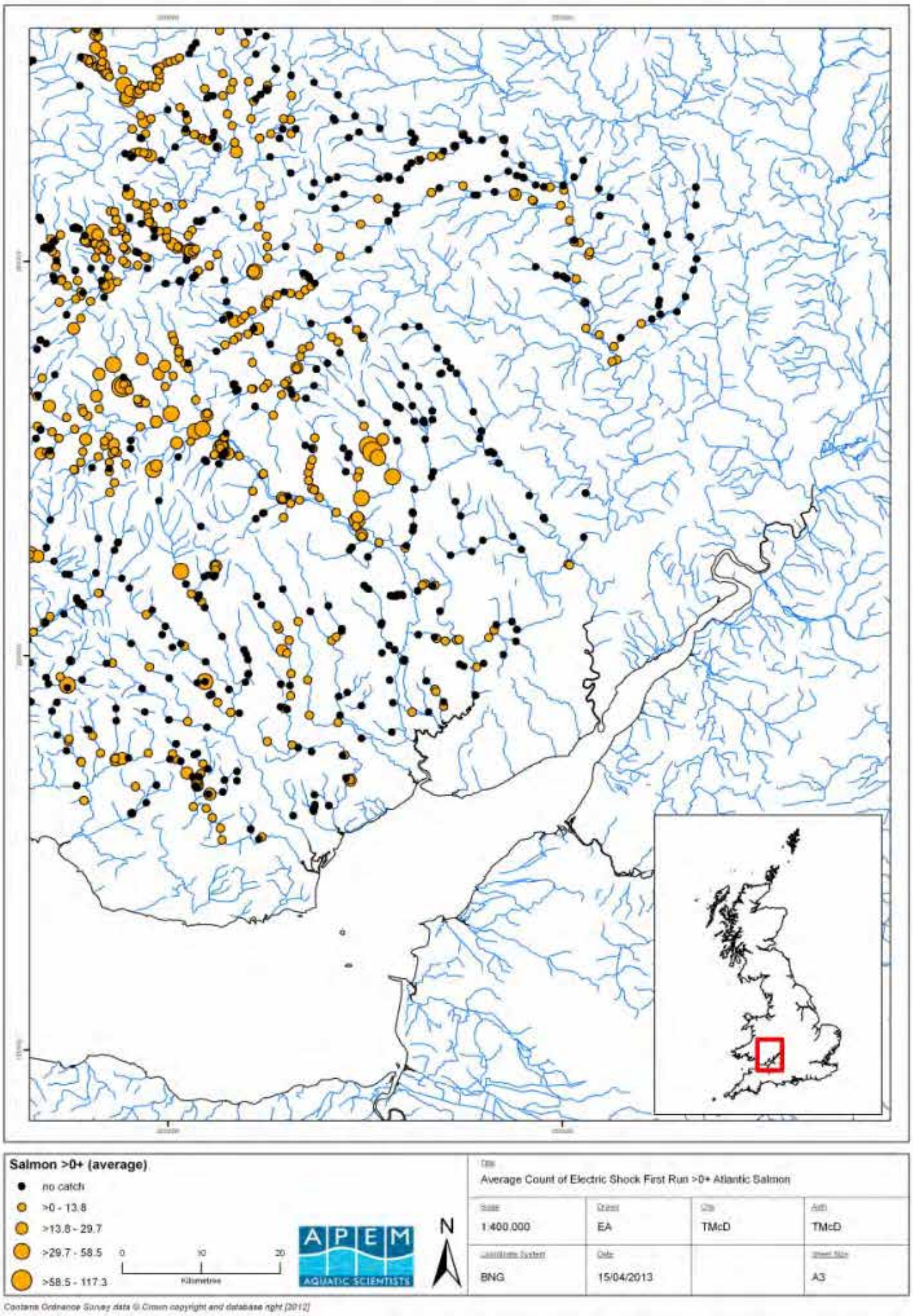

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Figure A6.4. 21 Density of >0+ salmon in CSTP rivers in the SE Wales area.

Appendix 7

Section 7.1 Summary smolt size data

					(SIZE IN CMS)					
SOURCE	RIVER	TIME.START	TIME.PEAK	TIME.END	SIZE.MIN	SIZE.MEAN	SIZE.MAX	%devmin	%devmax	COMMENTS
Fahy 1978	B Isles				130	195	260			max est (3yr olds) undefined
Gargan et al 2006	Owengowla	MAR	MidAPR	MidMAY	150	210	270	28.6	28.6	
Davidson et al 2006	Dee				170	195	220	12.8	12.8	size estd Fig 6.8
Hay and Hatton-Ellis 2006	Shieldaig				110	155	200	29.0	29.0	from Fig 23.1
Euzenat et al 2006	Bresle				140	198	320	29.3	61.6	mean from Table 20.1.1
Elliott and Elliott 2006	Black Bows Beck				0	0	0			
					0	0	0			
Scott et al 2007	Conwy	MAR		MAY	145	175	207	17.1	18.3	wtd mean of 3 age grps (min1+, max3+)
W. Riley pers comm	Ceiriog (W Dee)				95	126	185	24.6	46.8	3yrs < NB v small fish, truncated sampling
Bareham 1987	Eden(Mawddach)		APR	MAY	140.72	171.24	201.76	17.8	17.8	fyke net sampling
Ayreshire RT report 2010	Ayr (Ayrshire)	29-Mar	MID MAY	27-May	119	192	251	38.0	30.7	RST; mean as quoted by RT
R. Kennedy pers comm	Bush	mid MAR		late MAY	0	0	0			
W. Roche (unpublished)	Currane	mid Apr	Late Apr	early May	205	254	295	19.3	16.1	
Gargan et al 2006	Invermore	mid MAR	MidAPR	early May	170	205	270	17.1	31.7	66% 2yo, 32% 3yo 1993/1994
STWG	Erriff	late Mar	late MAY	early June	152	207	280	26.6	35.3	
STWG	Crumlin	late Mar	Late Apr	mid May	0	0	0			
STWG	Costello	late Mar	mid Apr	mid May	0	0	0			
R Kennedy (unpublished data)	Shimna	late Mar		early June	102	142	210	28.2	47.9	
R. Poole (pers comm.)	Burrishoole 2005-2010	MAR	early May	early June	136	204	300	33.3	47.1	25th %ile: 18.8, 75th %ile: 21.9
	Burrishoole	Start 5%	Peak 50%	End 95%	0	0	0			all trap data
	2001	8-Apr	4-May	21-Jun						all trap data
	2002	16-Feb	26-Apr	25-May						all trap data
	2003	11-Mar	9-May	25-May						all trap data
	2004	22-Mar	24-Apr	24-Jun						all trap data
	2005	2-Apr	29-Apr	26-May						all trap data
	2006	4-Apr	4-May	22-May						all trap data
	2007	22-Apr	30-Apr	31-May						all trap data
	2008	25-Apr	30-Apr	30-Jun						all trap data
				Statistic (ex Fahy)	Min	Mean	Max	%devmin	%devmax	
				mean	96.6	128.1	168.9	24.7	32.6	
				n	18	18	18			
				sd	69.89	90.75	119.94			
				Minium val	0	0	0			
				Maximum val	205	254	320			

Section 7.2 Fishing effort adjustment data

Based on two surveys of angler effort in 1996 and 2006. Some rivers had no surveys (Rhymney, Afan, Neath, Gwendraeth, Aeron, Ystwyth, Artro, Llyfni, Gwyfai) and were given 100% sea trout effort. Other (Lougher, Cleddau, Dyfi, Eden and Border Esk) had no survey in 1996 and for those the 2006 values were used. All others used mean of the two years.

	1996 survey					2006 Survey					
River	EffortSAL	EffortST	EffortTOTAL	%SAL	%ST	EffortSAL	EffortST	EffortTOTAL	%SAL	%ST	Mean%
Wye	10966	74	11040	99.3	1	3494	188	3682	94.9	5.1	2.9
Usk	3492	151	3643	95.9	4	3438	216	3654	94.1	5.9	5.0
Taff	67	80	147	45.6	54	118	25	143	82.3	17.7	36.1
Rhymney											100.0
Ogmore	87	771	858	10.1	90	776	797	1573	49.3	50.7	70.3
Afan											100.0
Neath											100.0
Tawe	320	505	825	38.8	61	862	768	1630	52.9	47.1	54.2
Loughor						390	531	921	42.4	57.6	57.6
Gwendraeth											100.0
Tywi						5457	4414	9871	55.3	44.7	44.7
Taf	515	555	1070	48.1	52	925	292	1217	76.0	24.0	37.9
Cleddau						734	634	1368	53.6	46.4	46.4
Nevern	43	341	384	11.2	89	431	499	930	46.3	53.7	71.2
Teifi	2910	2092	5002	58.2	42	4158	3384	7542	55.1	44.9	43.3
Aeron											100.0
Ystwyth											100.0
Rheidol	231	386	617	37.4	63	357	916	1273	28.0	72.0	67.3
Dyfi/Dovey						760	668	1428	53.2	46.8	46.8
Dysynni	103	284	387	26.6	73	375	361	736	50.9	49.1	61.2
Mawddach	809	676	1485	54.5	46	1586	620	2206	71.9	28.1	36.8
Artro											0.0
Dwyryd	66	192	258	25.6	74	158	32	190	82.9	17.1	45.7
Glaslyn	193	309	502	38.4	62	405	327	732	55.3	44.7	53.1
Dwyfawr	111	404	515	21.6	78	575	389	964	59.6	40.4	59.4
Llyfni											100.0
Gwyrfai											100.0
Seiont	398	133	531	75.0	25	457	65	522	87.5	12.5	18.8
Ogwen	582	136	718	81.1	19	530	66	596	88.9	11.1	15.0
Conwy	1420	623	2043	69.5	30	1356	444	1800	75.3	24.7	27.6
Clwyd	734	1130	1864	39.4	61	760	975	1735	43.8	56.2	58.4
Dee	6671	312	6983	95.5	4	5048	641	5689	88.7	11.3	7.9
Ribble	7657	2857	10514	72.8	27	6380	1361	7741	82.4	17.6	22.4
Wyre						53	13	66	80.1	19.9	19.9
Lune	9138	4654	13792	66.3	34	6424	2147	8571	75.0	25.0	29.4
Kent	2109	1114	3223	65.4	35	2039	494	2533	80.5	19.5	27.0
Leven	1056	335	1391	75.9	24	170	66	236	72.0	28.0	26.0
Duddon	186	114	300	62.0	38	275	134	409	67.3	32.7	35.4
Cumbrian Esk						429	105	534	80.3	19.7	19.7
Irt	506	156	662	76.4	24	549	35	584	94.0	6.0	14.8
Calder	116	109	225	51.6	48	247	15	261	94.4	5.6	27.0
Ehen	1588	695	2283	69.6	30	1793	323	2116	84.7	15.3	22.9
Derwent	2685	269	2954	90.9	9	3849	388	4237	90.8	9.2	9.1
Ellen	221	66	287	77.0	23	143	53	196	72.8	27.2	25.1
Eden						7416	1075	8491	87.3	12.7	12.7
Border Esk						3560	1097	4657	76.4	23.6	23.6

Section 7.3 Declared sea trout catches for Welsh and English river from catch returns, 1994-2011

CwE=catch with effort, CPUE=catch per licence day, Effort=annual effort (licence days), mean.C.dec = mean declared catch (including those with no effort reported)

RIVER	REGION	mean CwE94-11	mean CPUE94-11	mean Effort	mean.C.dec
Wye	W	35	0.22	181	39
Usk	W	226	0.91	260	247
Taff	W	78	0.48	166	106
Rhymney	W	16	0.26	67	16
Ogmore	W	477	0.32	1,535	559
Afan	W	144	0.24	617	170
Neath	W	309	0.20	1,476	402
Tawe	W	256	0.27	985	304
Loughor	W	249	0.33	759	310
Gwendraet	W	60	0.20	309	85
Tywi	W	2,719	0.47	5,932	3357
Taf	W	258	0.42	621	324
E&W Cled	W	584	0.56	1,054	692
Nevern	W	511	0.59	872	687
Teifi	W	2,319	0.55	4,261	2932
Aeron	W	250	0.39	633	294
Ystwyth	W	186	0.46	462	204
Rheidol	W	484	0.58	881	569
Dyfi	W	1,358	1.32	1,067	1598
Dysynni	W	395	0.64	677	459
Mawddach	W	796	0.68	1,220	957
Artro	W	37	0.24	157	39
Dwyryd	W	125	0.74	163	142
Glaslyn	W	444	0.96	534	558
Dwyfawr	W	582	0.86	643	684
Llyfni	W	282	0.46	583	335
Gwyrfai	W	5	0.11	47	7
Seiont	W	47	0.34	145	61
Ogwen	W	118	1.00	120	137
Conwy	W	382	0.67	597	442
Clwyd	W	779	0.49	1,716	875
Dee	W	230	0.38	610	269
Ribble	E	1,047	0.48	2,249	1024
Wyre	E	33	0.72	61	137
Lune	E	1,473	0.49	3,143	1632
Kent	E	393	0.42	994	473
Leven	E	68	0.64	144	102
Duddon	E	99	0.75	132	99
Esk (Cumb	E	115	1.27	88	124
Irt	E	136	0.99	144	146
Calder	E	10	0.15	74	23
Ehen	E	433	0.68	760	427
Derwent	E	353	0.75	474	416
Ellen	E	48	0.73	71	74
Eden	E	410	0.30	1,482	441
Esk (Borde	E	1,003	1.24	880	1120

Statistic	mean CwE94-11	mean CPUE94-11	mean Effort	mean.C.dec
Mean	443	0.56	870.5	524
Standard Error	83	0.04	165.2	101
Median	257	0.49	613.7	317
Standard Deviation	564	0.30	1120.3	683
Kurtosis	7	0.26	10.1	9
Skewness	3	0.80	2.9	3
Range	2713	1.22	5885.6	3350
Minimum	5	0.11	46.8	7
Maximum	2719	1.32	5932.4	3357
Count	46	46	46	46

Section 7.4 River Specific data on total declared annual sea trout rod catches from principal rivers around the Irish Sea.

Country	year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	mean	geometric mean
WL	Usk	265	170	227	190	410	611	520	125	290	320	238	244	184	129	191	100	119	113	**247**	216
WL	Taff	111	92	133	91	236	229	105	174	90	71	62	55	12	45	115	69	54	162	**106**	88
WL	Ogmore	583	334	479	810	911	646	677	547	878	572	584	784	193	386	420	468	212	586	**559**	517
WL	Afan	295	115	254	223	286	195	188	166	103	162	168	153	63	158	161	120	112	142	**170**	159
WL	Neath	313	73	138	194	332	340	535	673	782	400	532	393	298	487	318	492	493	444	**402**	355
WL	Tawe	677	247	246	447	294	404	136	373	424	272	173	372	153	243	144	242	426	196	**304**	276
WL	Loughor	314	28	108	184	392	509	322	258	550	577	369	538	184	277	366	258	205	147	**310**	258
WL	Tywi	4946	2300	1838	2462	4593	6242	4134	2056	4554	4175	2587	4698	2091	3271	2579	2845	2448	2609	**3357**	3149
WL	Taf	273	18	79	250	481	540	273	224	562	475	204	528	205	280	447	377	292	331	**324**	265
WL	EWCleddau	1214	433	425	578	1123	1297	755	651	869	738	439	937	227	511	682	499	551	530	**692**	635
WL	Nevern	1182	414	598	180	756	893	584	1078	846	1125	606	722	539	415	684	488	755	500	**687**	633
WL	Teifi	3704	1212	2325	2146	3605	3809	3235	3694	4841	3997	3126	4342	1990	1774	1771	2076	2142	2981	**2932**	2748
WL	Aeron	537	54	152	196	481	568	280	364	777	422	396	205	35	306	151	96	126	144	**294**	223
WL	Ystwyth	218	50	49	150	593	259	211	223	256	83	276	107	19	376	186	166	185	261	**204**	158
WL	Rheidol	717	772	536	390	431	927	473	693	703	961	551	741	744	587	233	238	197	354	**569**	517
WL	Dyfi	1987	718	752	1316	1787	2070	2032	2185	1793	1474	1362	1439	1054	1459	1217	1425	2047	2646	**1598**	1513
WL	Dysynni	670	221	499	552	729	464	435	406	343	688	471	502	284	410	337	420	396	439	**459**	440
WL	Mawddach	1338	808	1145	714	934	1448	1020	1974	1529	1196	1127	1024	387	594	325	411	396	858	**957**	849
WL	Dwyryd	191	294	200	101	153	181	124	367	381	147	70	50	57	48	78	60	26	25	**142**	105
WL	Glaslyn	536	491	491	553	393	436	383	240	1096	534	567	592	489	682	521	533	824	680	**558**	532
WL	Dwyfawr	1261	228	775	389	1337	765	1027	1261	1111	1246	347	691	235	455	145	187	557	295	**684**	545
WL	Llyfni	808	328	358	288	1035	182	384	542	290	518	187	221	108	257	72	85	134	229	**335**	262
WL	Ogwen	36	63	99	129	182	88	104	112	193	148	130	177	86	170	65	163	287	238	**137**	122
WL	Conwy	295	435	304	232	514	351	391	583	630	572	464	489	282	585	434	423	483	482	**442**	426
WL	Clwyd	597	491	528	717	1730	765	708	1319	868	982	1085	782	490	728	949	880	1160	968	**875**	828
WL	Dee	398	141	150	148	265	159	177	283	414	249	265	303	253	276	192	181	485	506	**269**	248
EN	Ribble	952	431	686	952	1635	1423	1511	499	1553	1296	1294	1313	683	1174	826	1281	921	1838	**1126**	1048
EN	Lune	2161	1513	1601	1701	2730	2091	2833	1426	2549	2268	1760	1380	962	1120	1068	1262	896	1090	**1690**	1587
EN	Kent	633	333	450	299	576	284	527	214	403	426	431	570	294	456	335	469	728	494	**440**	420
EN	Duddon	50	29	42	33	115	29	60	128	38	54	143	181	132	159	183	179	182	148	**105**	85
EN	Esk (Cumbrian)	13	37	68	102	254	236	203	93	189	88	112	140	93	199	29	39	194	267	**131**	100
EN	Irt	68	320	149	94	244	184	195	20	209	95	110	125	29	142	84	113	185	227	**144**	119
EN	Ehen	345	313	215	117	631	184	854	49	1131	1113	466	688	516	193	353	179	325	543	**456**	349
EN	Derwent	465	413	399	299	561	1049	978	405	321	250	384	294	214	212	159	237	305	332	**404**	356
EN	Eden	497	894	629	348	338	345	703	330	370	881	427	705	238	241	186	347	410	303	**455**	412
EN	Esk (Border)	826	1327	1357	1135	1671	1239	2174	1122	1107	1260	749	1138	581	933	1221	1271	752	1059	**1162**	1112
SC	Annan	996	1124	1132	1871	2734	1689	1976	505	1240	533	831	526	298	389	455	540	467	447	**986**	802
SC	Cree	382	569	843	328	615	421	210	125	147	180	65	150	45	183	121	96	98	122	**261**	192
SC	Luce	63	90	216	182	249	174	274	71	232	83	190	151	28	79	53	104	73	141	**136**	115
SC	Nith	1795	1425	1914	3215	3384	1555	2695	1385	2117	1739	1217	755	653	938	811	1075	865	489	**1557**	1355
IR	Castletown	400	350	300	400	500	400	500	1000	200	200	500	2000	1500	1250	1550	1600	1400	1500	**864**	1455
IR	Fane	400	250	350	300	500	500	500	750	200	250	250	100	200	250	200	200	210	200	**312**	211
IR	Boyne	3500	3800	2500	2500	2000	3000	1900	1300	2000	1200	1700	2500	3000	1300	2500	2300	2000	3200	**2344**	2167
IR	Ballymascanion	350	200	250	250	150	200	300	400	100	100	150	150	150	175	200	140	100	100	**193**	137
IR	Dargle	258	489	250	150	330	242	180	50	150	150	100	120	80		50	100	100	100	**171**	84
IR	Vartry	200	250	150	125	150	150	80	70	60	70	100	120	60		100	150	130	100	**121**	118
IR	Slaney	1800	3500	2250	1800	2000	4000	1200	1300	1500	1200	1200	1000	400		400	700	1100	100	**1497**	419
IR	Dee		300	400	600	500	3000	3000	2000	300	150	200	180	150	200	220	130	240	200	**692**	194
IR	Colligan	1700	1600	1700	1550	2500	2100	1500	1600	1800	1850	2100	1550	1450	1700	1950	2400	1500	2100	**1814**	1905
IR	Bride	2000	1500	1650	1600	2000	1500	1100	1000	1200	1230	1730	830	400	800	550	350	650	500	**1144**	549
IR	Bandon	986	1450	1800	600	1015	2000	2000	600	1400	1200	1500	400	300	400	600	600	600	800	**1014**	586
IR	Argideen	530	265	400	150	200	700	700	220	1200	650	400	250	150	150	350	350	350	400	**412**	303
IR	Ilen	530	265	400	150	200	700	700	220	1200	650	400	250	150	150	350	350	350	400	**412**	303
IR	Currane	1655	5410	6899	3820	4583	6073	4440	3500	3300	2500	2300	2200	2400	1900	2300	3000	3250	3000	**3474**	2638
IR	Inny			100	20	110	120	125	100	170	400	300	350	300		150	160	170	150	**182**	157
IR	Owenmore	470	250	100	60	200	250	260	150	150	200	200	310	320	432	240	213	147	180	**230**	226

Section 7.5 Data used to derive catch-area relationships for Welsh and North West Region rivers, including additional catchment features of wetted area and Average Daily Flow (ADF)

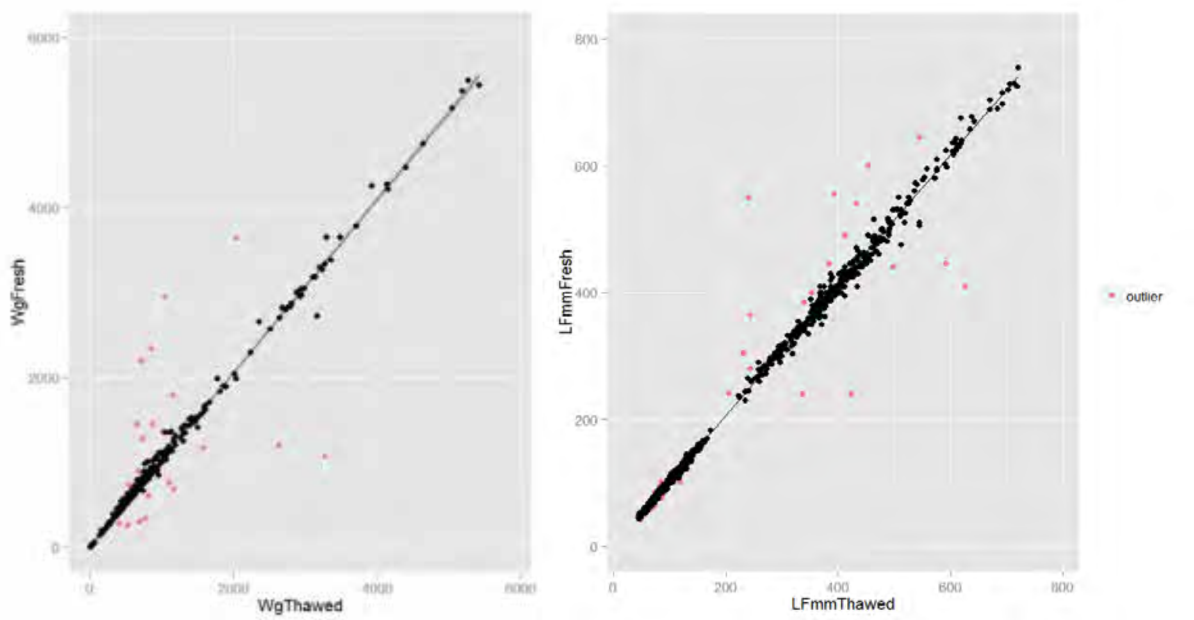
Ref	RIVER	Country	Catchment Area (km^2)	Wetted Area (Ha)	ADF (m^3s^{-1})	Rod catch 2007-11 adjusted	omit from final regression (*)
1	Wye	W	4077.8	1402	77.47	46	*
2	Usk	W	1309.5	407	37.09	143	*
3	Taff	W	520.3	84	22.29	98	*
4	Ogmore	W	277.3	35	9.17	456	
5	Afan	W	91.7	17	4.42	152	
6	Neath	W	253.0	37	11.61	491	
7	Tawe	W	231.8	76	10.63	275	
8	Loughor	W	176.8	35	6.56	276	
10	Tywi	W	1107.8	500	38.84	3025	
11	Taf	W	249.3	90	6.94	380	
12	CleddauE+W	W	423.3	110	10.89	610	
14	Teifi	W	948.0	296	25.83	2364	
15	Aeron	W	163.3	35	4.02	181	
16	Ystwyth	W	196.0	46	6.04	258	
17	Rheidol	W	186.8	50	7.53	354	
18	Dyfi	W	479.8	179	21.32	1935	
19	Dysynni	W	106.5		4.73	440	
20	Mawddach	W	169.5	57	8.74	568	
21	Artro	W	82.0	9	2.89	25	
22	Dwyryd	W	81.0	9	4.78	52	
23	Glaslyn	W	129.5	25	8.70	713	
26	Gwyrfai	W	76.5	33	3.70	6	*
27	Seiont	W	82.5	21	5.04	68	
28	Ogwen	W	87.3	24	5.47	203	
29	Conwy	W	377.3	50	20.68	530	
30	Clwyd	W	443.0	84	6.23	1031	
31	Dee	W	1793.3	617	38.47	361	
140	Ribble	NW	1154.4		30.68	1329	
141	Wyre	E	280.6		6.40	44	*
142	Lune	NW	988.2		34.11	1196	
145	Kent	NW	214.8		8.96	546	
148	Leven	NW	254.8		14.32	68	
150	Duddon	NW	88.1		5.21	187	
152	Esk (Cumbria)	NW	71.5		4.33	160	
154	Irt	NW	45.6		3.23	165	
155	Calder	NW				16	
156	Ehen	NW	131.7		5.78	350	
157	Derwent	NW	677.3		33.27	274	
158	Ellen	NW	103.2			91	
161	Eden	E	2294.5		59.41	327	*
162	Esk (Border)	NW	851.5		27.81	1152	

Section 7.6 Sea trout size data management
Data description, variable management:

The initial dataset contained 20,902 individuals for which there was a maximum of 116 variables, although many of them were only collected for subsets of individuals (i.e. sex only collected for adult sea trout). The variables river and marine zone were given a specific geographical order: starting from the west of Ireland, around the Irish Sea, and finishing in the south east of Wales. The sequence of months from January to December was specified for the variable Month. All missing data was set to NA.

Data checking:

Sea trout weight and length measurements were collected fresh, thawed, or both fresh and thawed. The individuals with both fresh and thawed measurements were used to inspect the effects of freezing and thawing on the weight and length measurements (N=1295 for weight; N=1603 for length). For some of these individuals the relationships between fresh and thawed measurement was very skewed and are most likely due to data input errors. These outliers were removed by creating an index (fresh/thawed) for each individual, assigning a standard score (z-score) to each index, and removing individuals with standard scores over 2 and below -2.



Models predicting fresh measurements from thawed measurements were constructed from the remaining individuals and used to estimate fresh measurements for all individuals with only thawed measurements (N=2699 for weight; N=2405 for length):

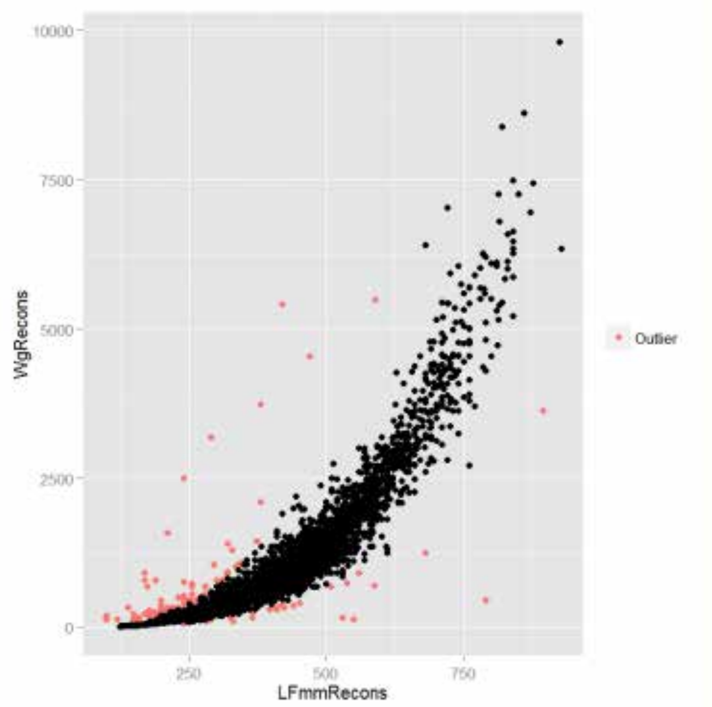
$$\text{WgEstimated} = 2.526 + 1.032 * \text{WgThawed}$$

$$\text{LFmmEstimated} = -0.2195 + 1.0294 * \text{LFmmThawed}$$

The relationship between length and weight of adult sea trout (N=9753) was also studied to check for input errors. Some individuals had no data for either length or weight (N=2772) or had unlikely lengths for an adult (< 50 mm; N=3) and were thus not included for evaluation of the weight-length relationship. k-factors were calculated for all remaining individuals (N=6979).

$$k = \frac{Wg * 100000}{LFmm^3}$$

Each k-factors was assigned a z-score, and only individuals with z-score between -1 and 1.8 were considered to be realistic (N=6839). The trimmed dataset was used for all analysis involving weight or length.

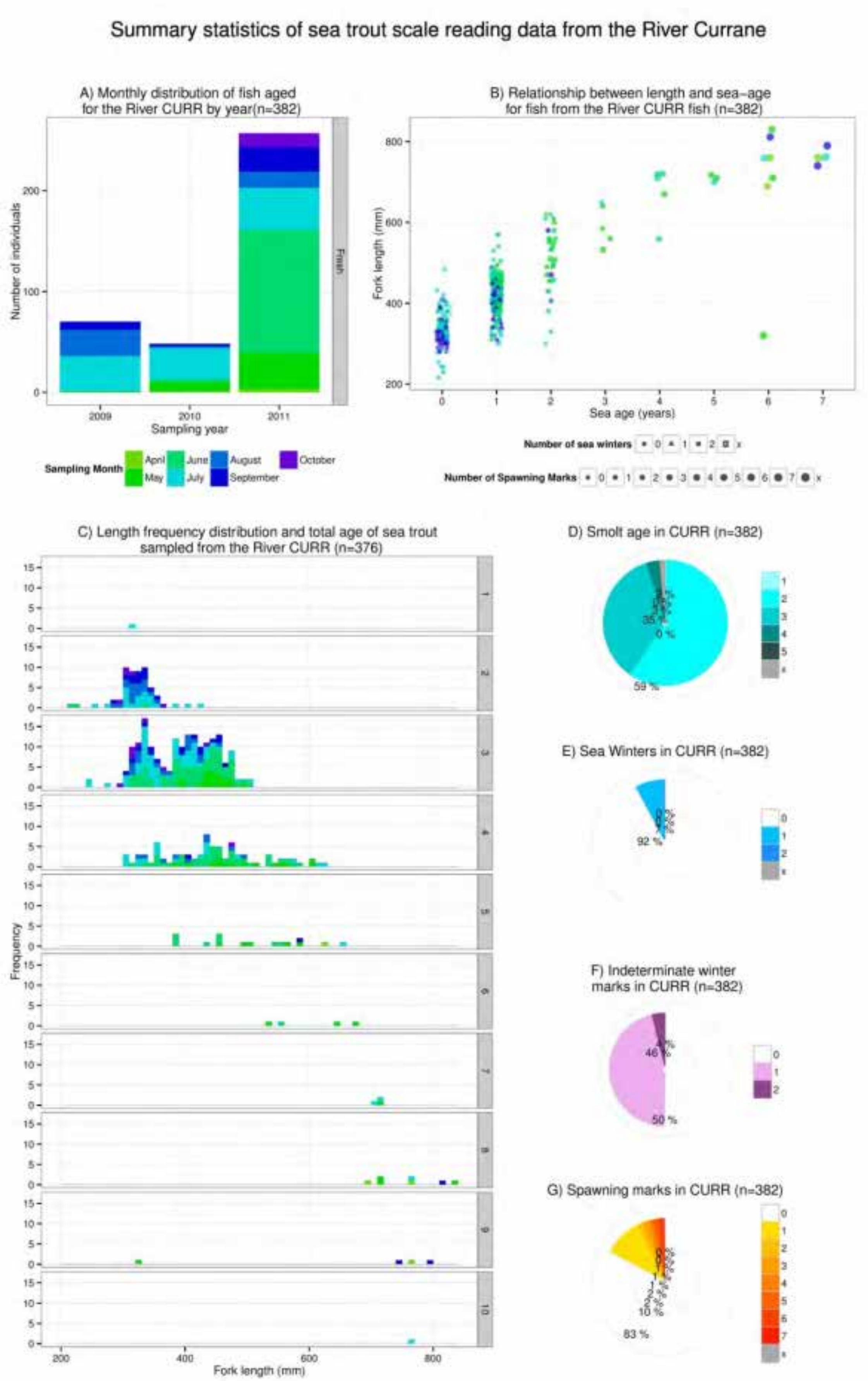


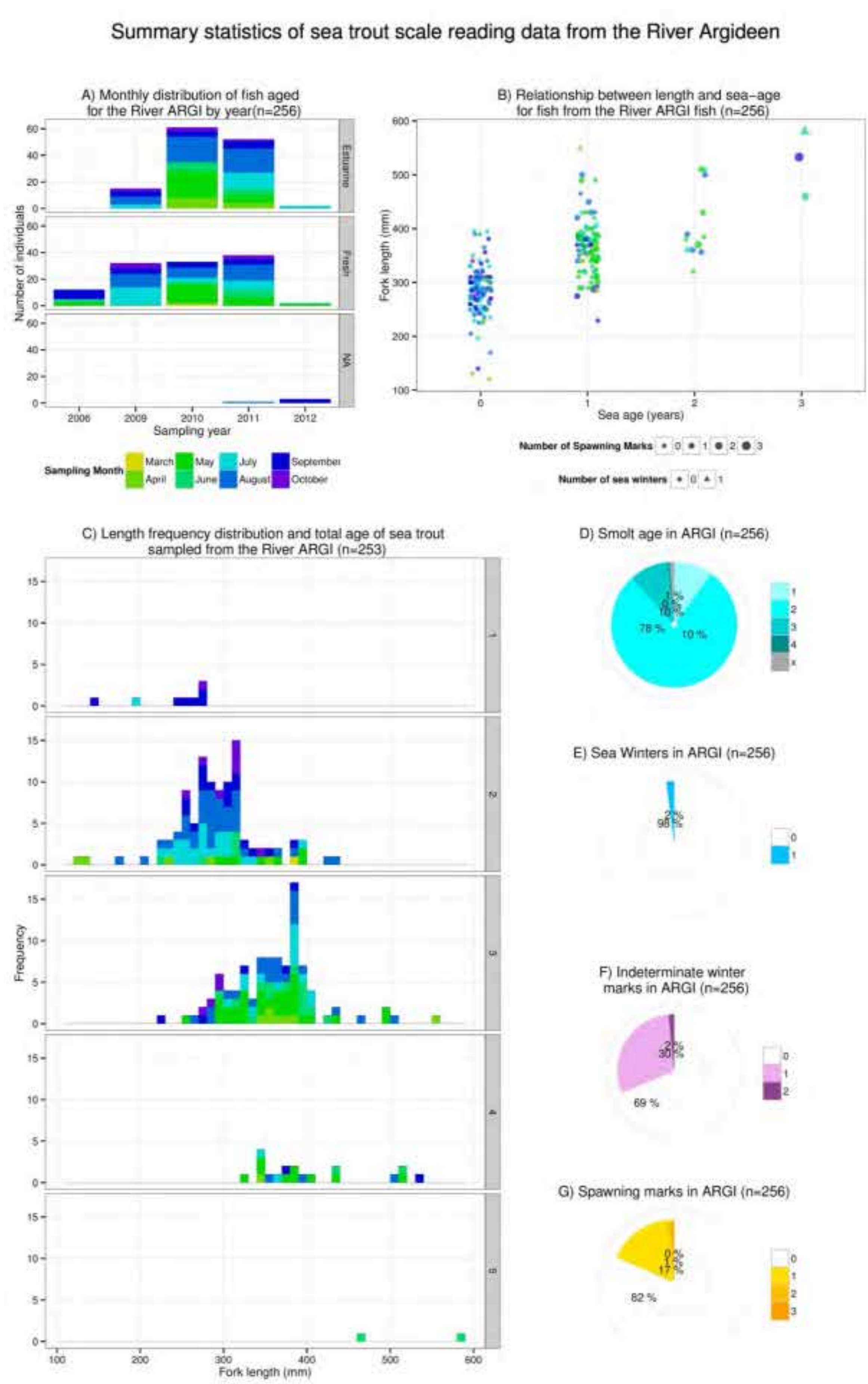
Of the individuals included in the trimmed adult dataset, 4966 had ageing data. However, ages derived from scale readings were sometimes flagged as unreliable (e.g. mismatch between scales, patterns too unclear, or very unlikely age for size), and individuals with clearly unreliable ages were excluded from the adult aged dataset.

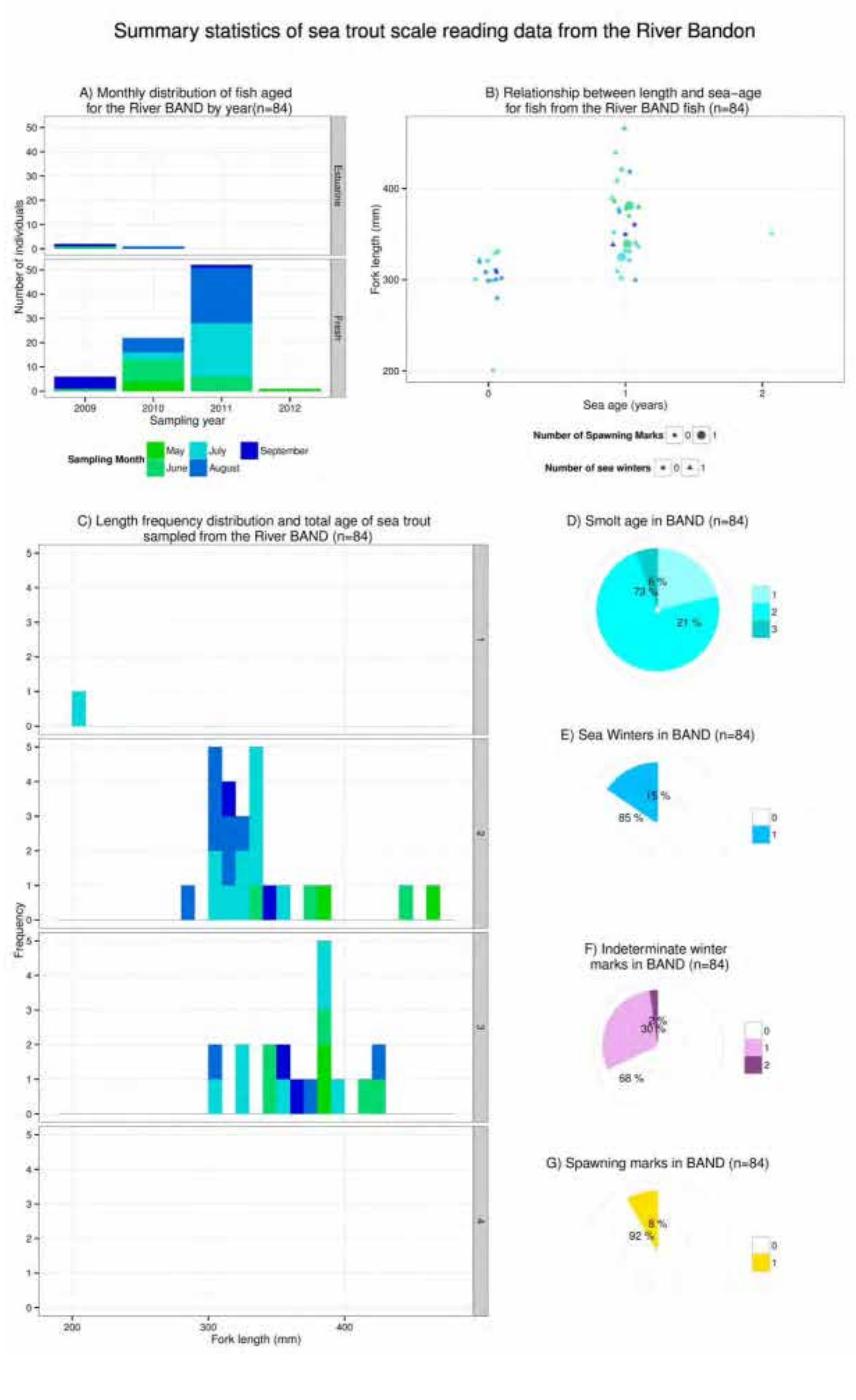
The final dataset (N=4718) included individuals from 42 rivers and marine zones, though the distribution of individuals among locations was heterogeneous. Each river was analysed independently. Among the sea trout captured in rivers (N=3762), there were 89 different life history patterns, although the three most common life histories (2.0+, 2.1+, and 2.0+1IM) were found in 2338 individuals.

River	N	Marine Zone	N	
CURR	346	MZ04	32	
ARGI	223	MZ05	105	
BAND	44	MZ06	167	
SLAN	126	MZ07	64	
DARG	66	MZ08	74	
BOYN	205	MZ09	69	
DEWR	217	MZ10	107	
CAST	54	MZ11	18	
SHIM	181	MZ12	114	
IOM	59	MZ13	28	
LUCE	205	MZ14	33	
FLEE	95	MZ15	7	
NITH	204	MZ16	15	
ESKB	378	MZ18	5	
EHEN	20	MZ23	33	
LUNE	319	MZ29	14	
RIBB	72	MZ30	44	
DEEw	117			
CLWY	65			
CONW	64			
DYFI	236			
TEIF	103			
TYWI	357			
LOUG	1			
TAWE	32			Total
Total	3789	0	929	4718

Section 7.7 Summary sheets for CSTP scale samples from principal rivers

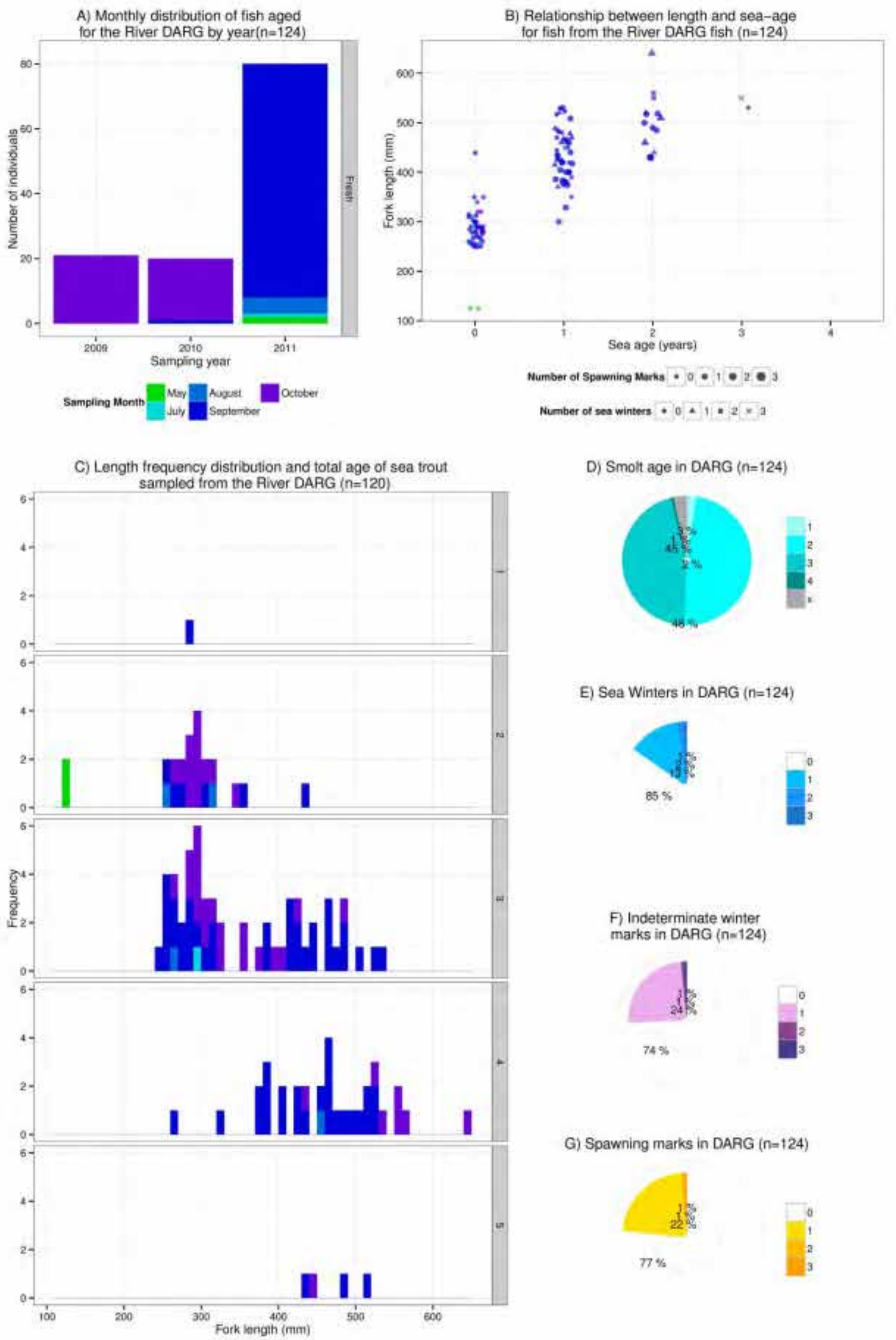



Summary statistics of sea trout scale reading data from the River Argideen
A) Monthly distribution of fish aged for the River ARGI by year(n=256)
Number of individuals
Estuarine
Fresh
NA
Sampling year
Sampling Month
March
April
May
June
July
August
September
October
B) Relationship between length and sea-age for fish from the River ARGI fish (n=256)
Fork length (mm)
Sea age (years)
Number of Spawning Marks
Number of sea winters
C) Length frequency distribution and total age of sea trout sampled from the River ARGI (n=253)
Frequency
Fork length (mm)
D) Smolt age in ARGI (n=256)
78 %
10 %
E) Sea Winters in ARGI (n=256)
2%
98%
F) Indeterminate winter marks in ARGI (n=256)
2%
30%
69 %
G) Spawning marks in ARGI (n=256)
0%
1%
17%
82 %

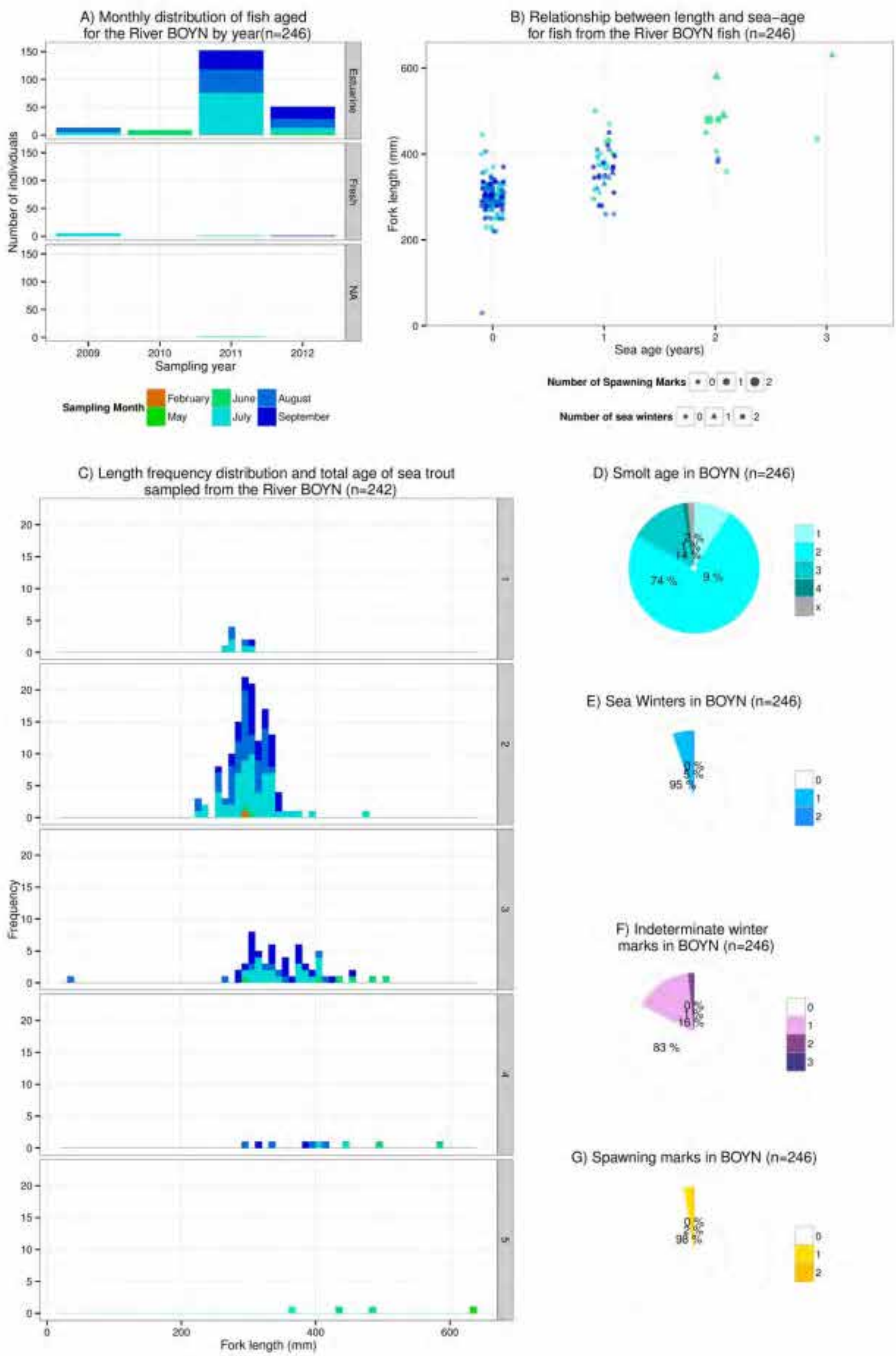

Summary statistics of sea trout scale reading data from the River Bandon
A) Monthly distribution of fish aged for the River BAND by year(n=84)
Number of individuals
Estuarine
Fresh
Sampling year
Sampling Month
May
June
July
August
September
B) Relationship between length and sea-age for fish from the River BAND fish (n=84)
Fork length (mm)
Sea age (years)
Number of Spawning Marks
Number of sea winters
C) Length frequency distribution and total age of sea trout sampled from the River BAND (n=84)
Frequency
Fork length (mm)
D) Smolt age in BAND (n=84)
E) Sea Winters in BAND (n=84)
F) Indeterminate winter marks in BAND (n=84)
G) Spawning marks in BAND (n=84)

Summary statistics of sea trout scale reading data from the River Slaney

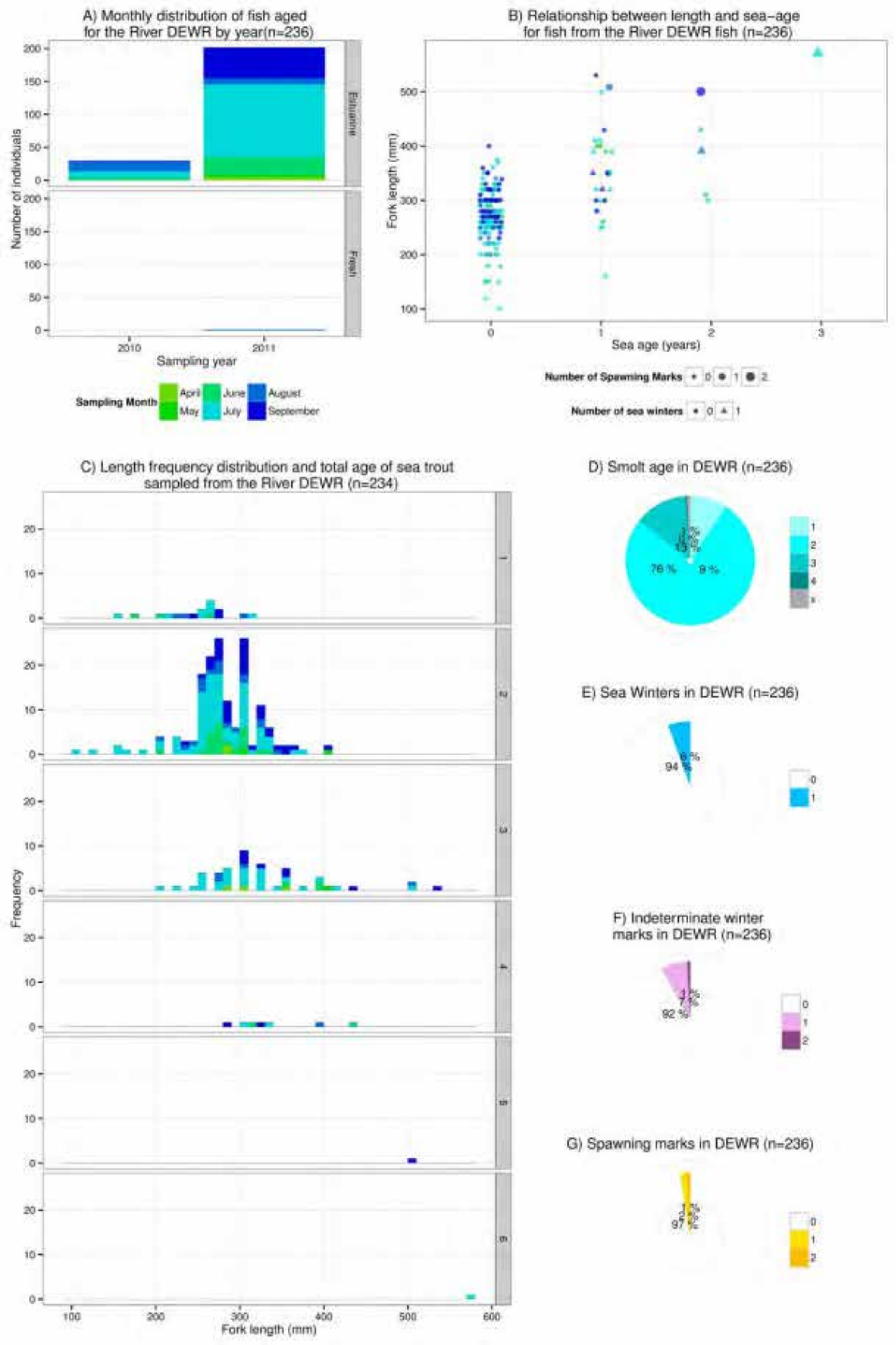
Summary statistics of sea trout scale reading data from the River Dargle



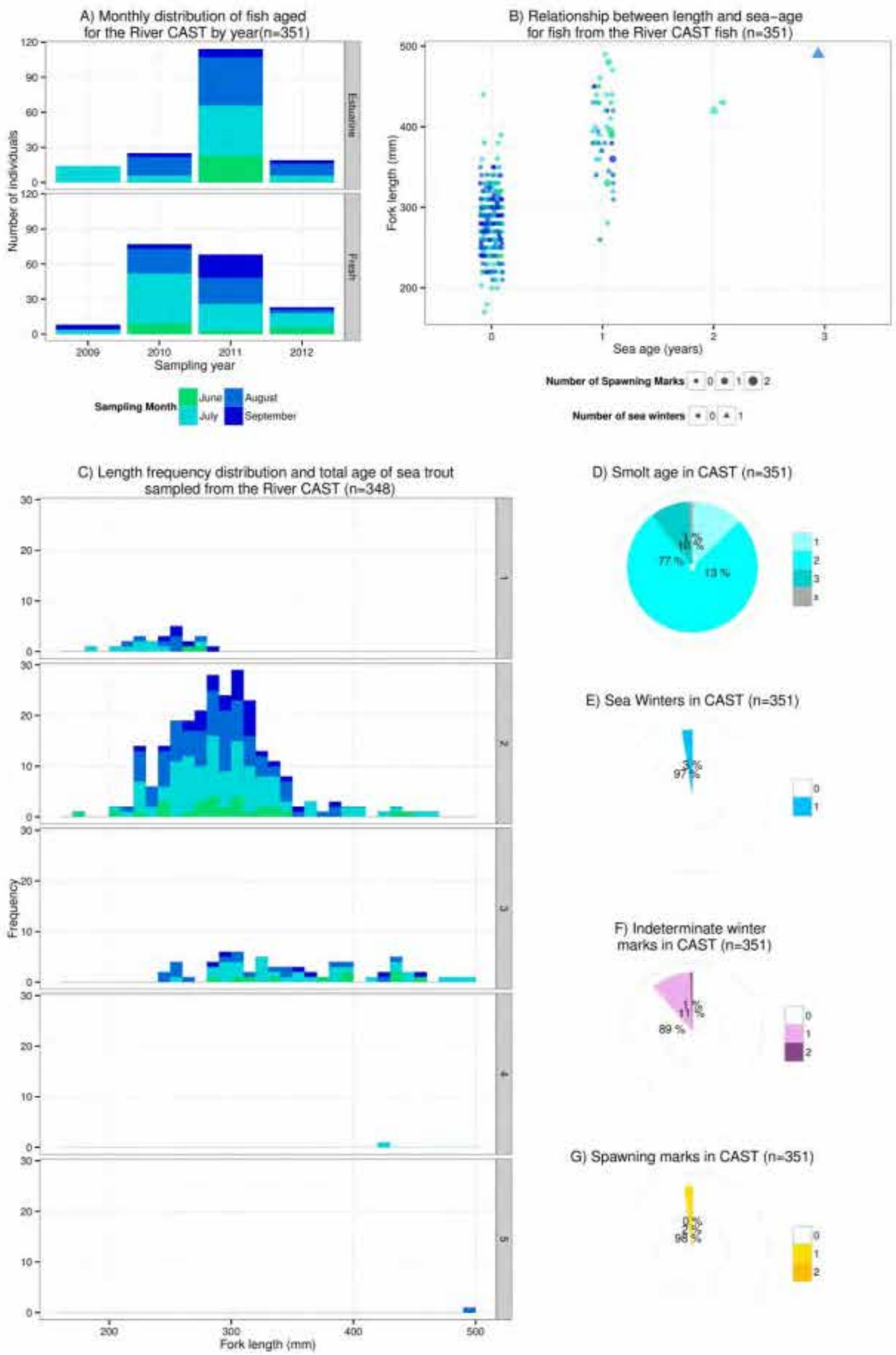
Summary statistics of sea trout scale reading data from the River Boyne



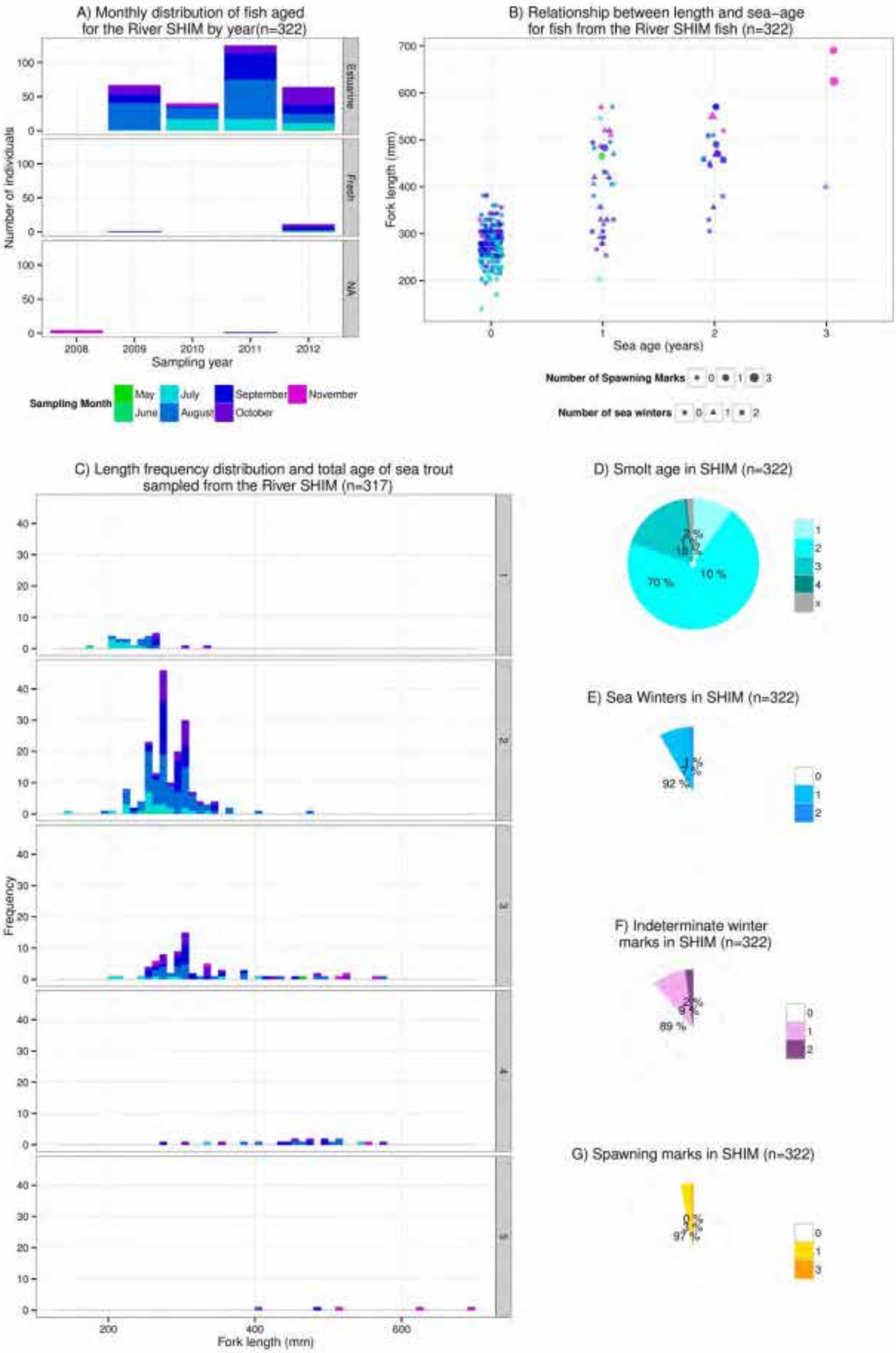
Summary statistics of sea trout scale reading data from the River Derwent



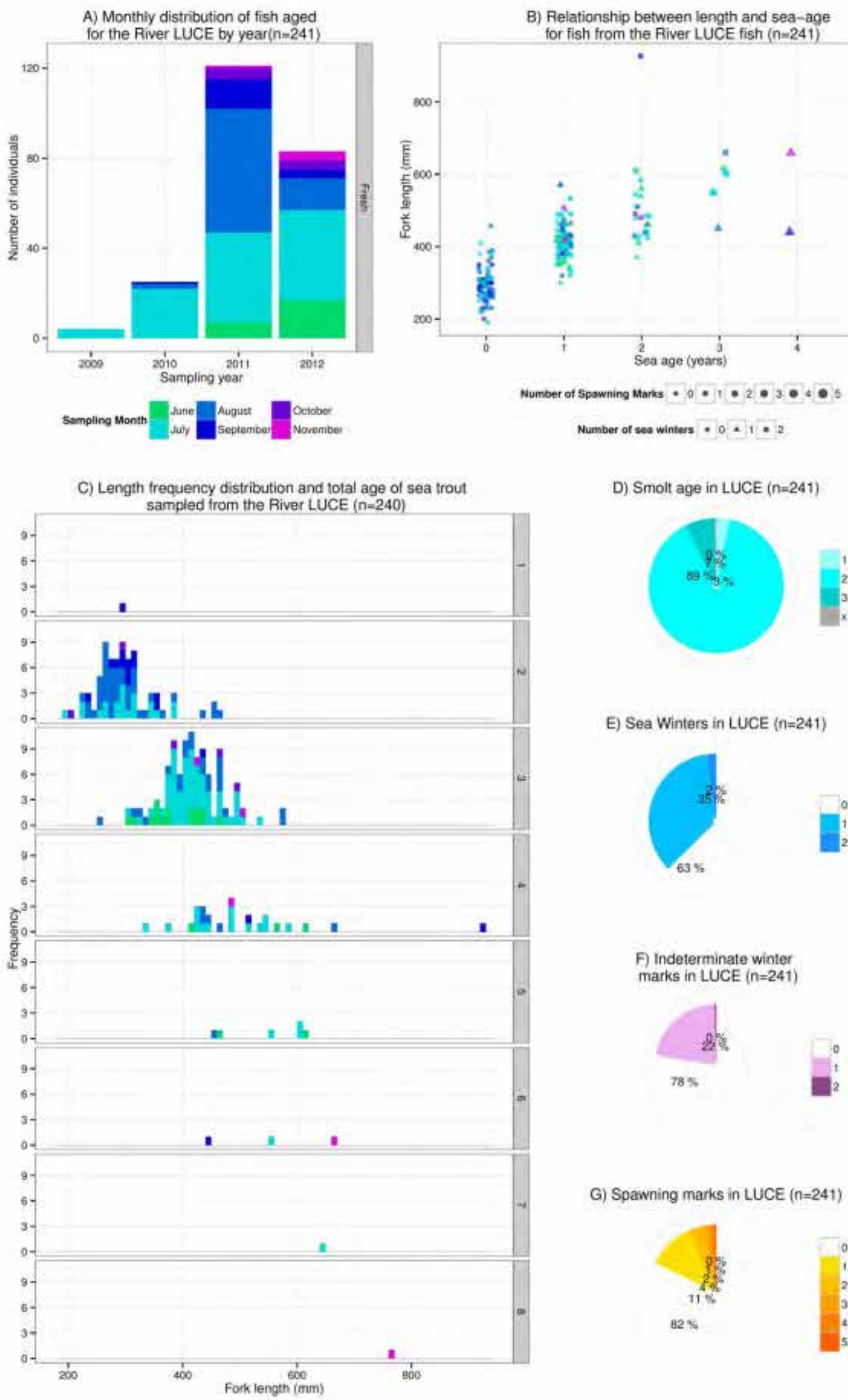
Summary statistics of sea trout scale reading data from the River Castletown



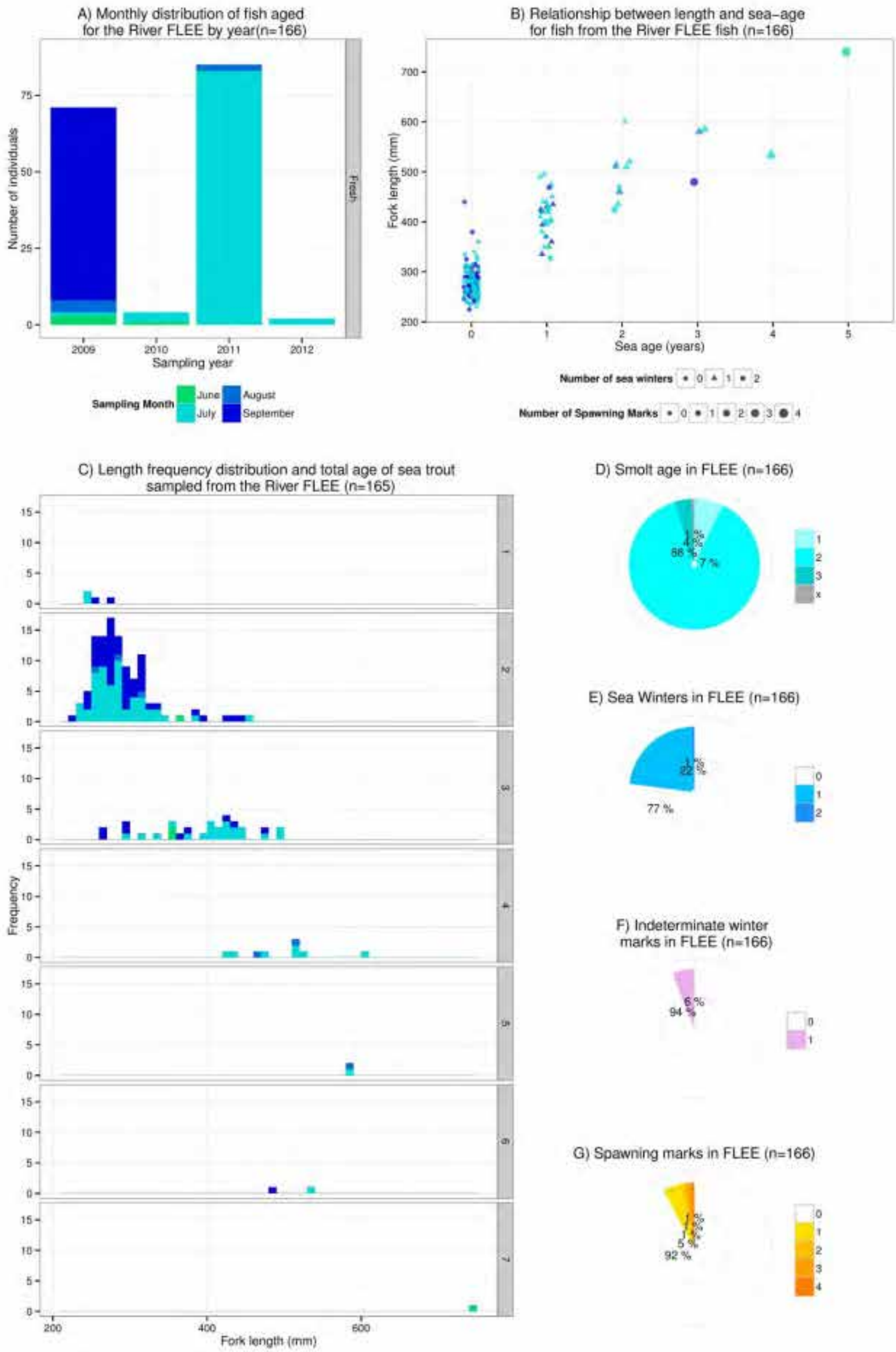
Summary statistics of sea trout scale reading data from the River Shimna

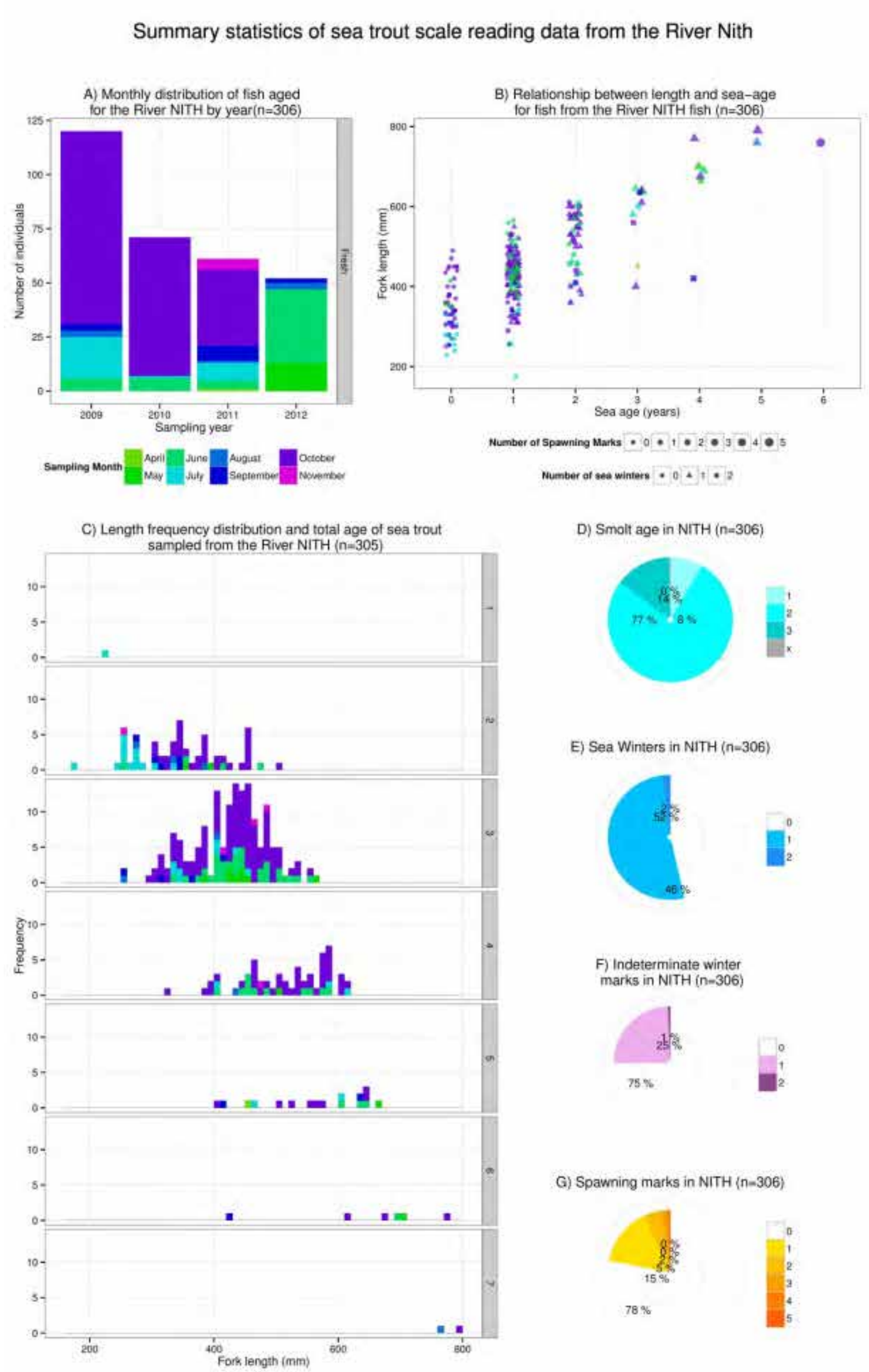


Summary statistics of sea trout scale reading data from the River Luce

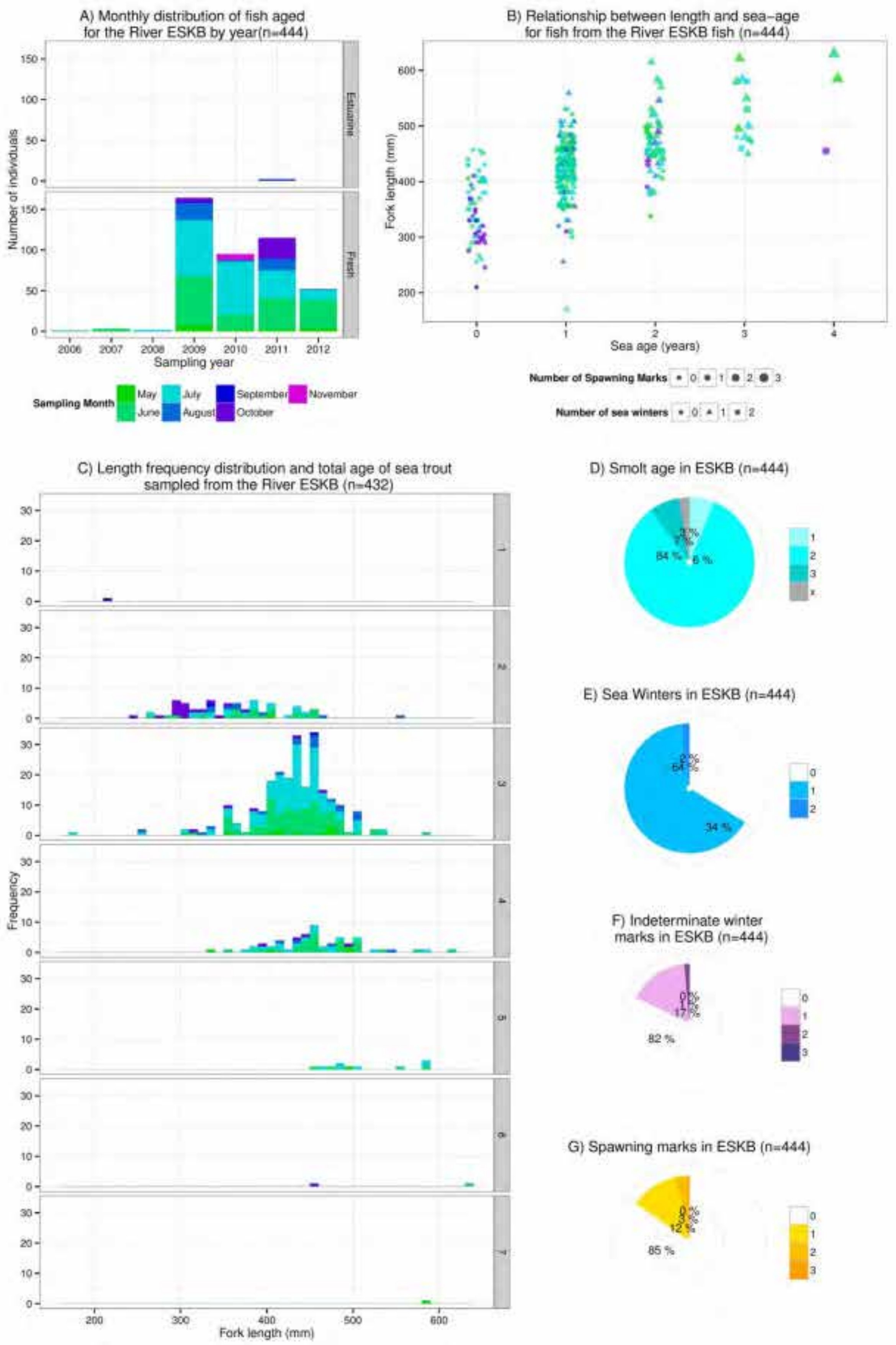


Summary statistics of sea trout scale reading data from the River Fleet

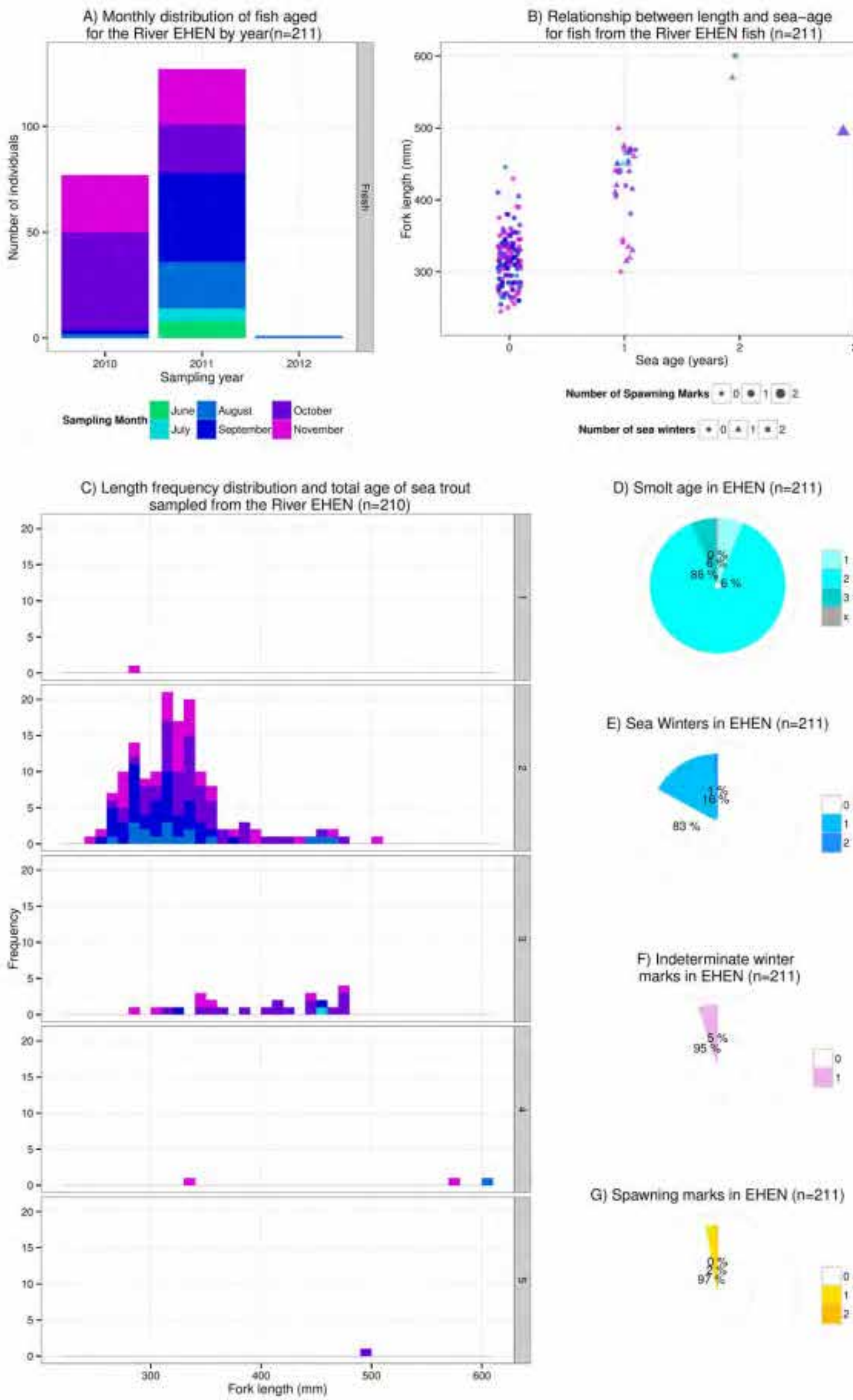



Summary statistics of sea trout scale reading data from the River Nith
A) Monthly distribution of fish aged for the River NITH by year(n=306)
Number of individuals
Sampling year
Fresh
Sampling Month
April
May
June
July
August
September
October
November
B) Relationship between length and sea−age for fish from the River NITH fish (n=306)
Fork length (mm)
Sea age (years)
Number of Spawning Marks
Number of sea winters
C) Length frequency distribution and total age of sea trout sampled from the River NITH (n=305)
Frequency
Fork length (mm)
D) Smolt age in NITH (n=306)
77 %
8 %
14 %
E) Sea Winters in NITH (n=306)
46 %
F) Indeterminate winter marks in NITH (n=306)
75 %
25 %
G) Spawning marks in NITH (n=306)
78 %
15 %

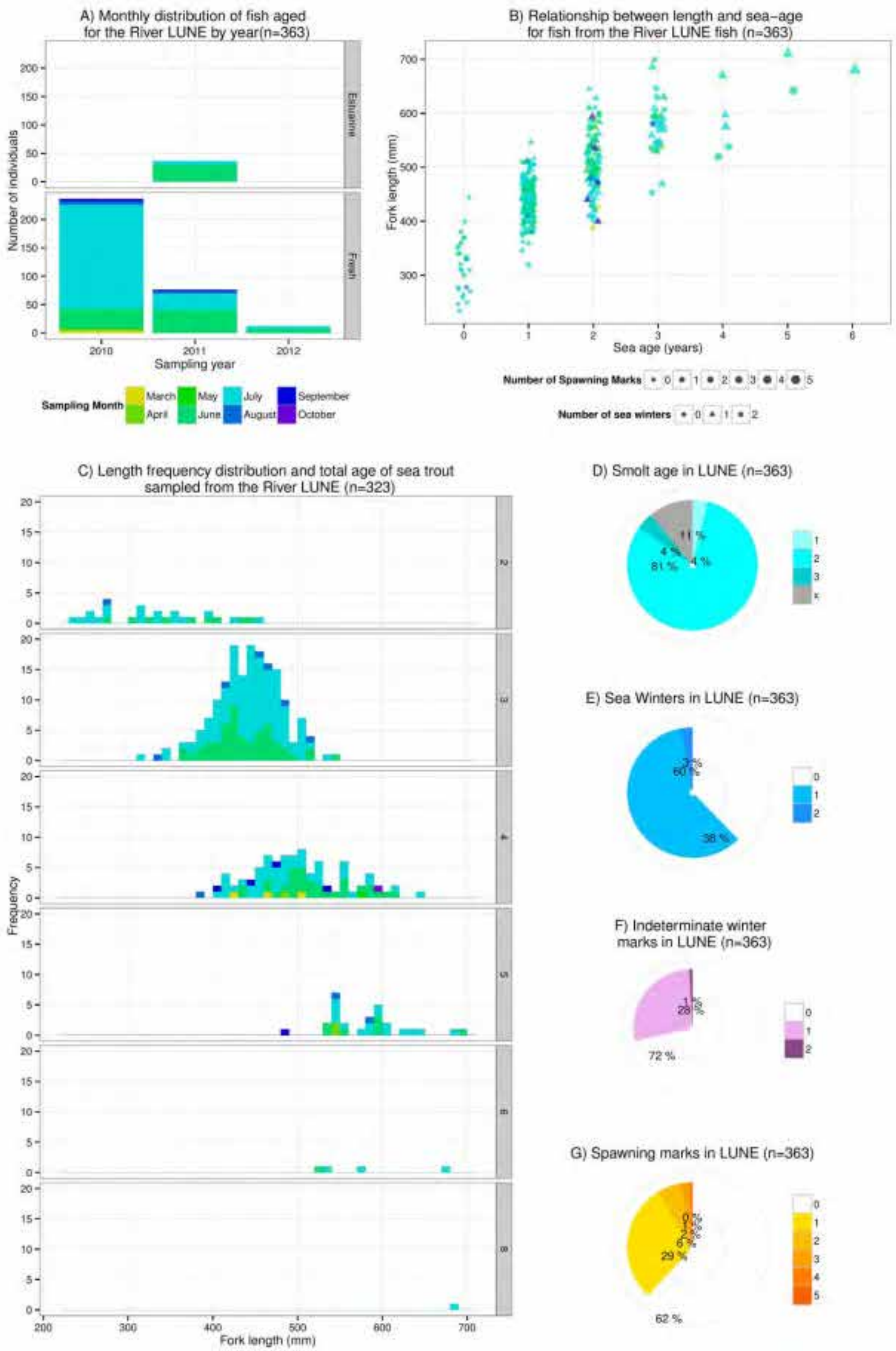
Summary statistics of sea trout scale reading data from the River Border Esk

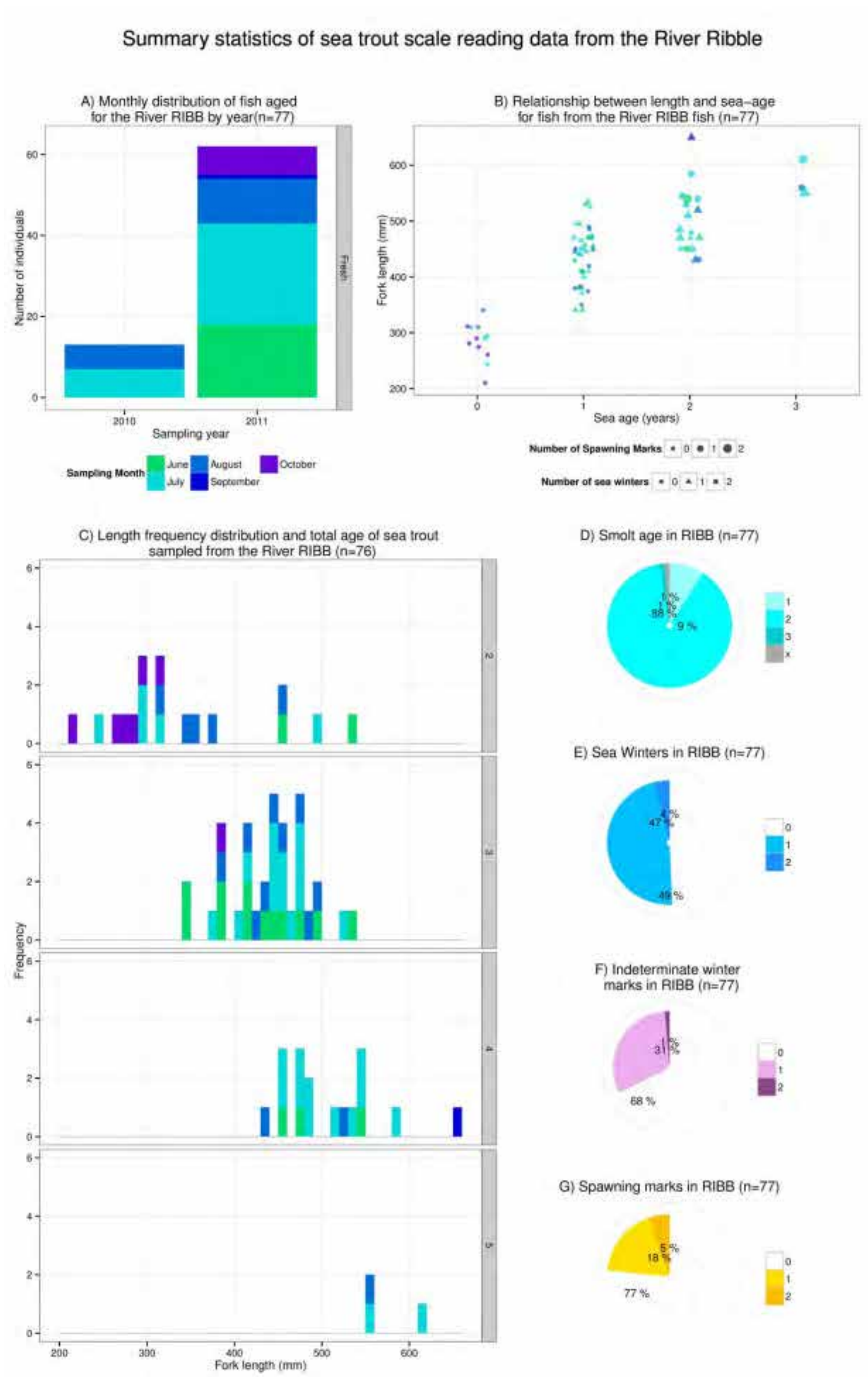


Summary statistics of sea trout scale reading data from the River Ehen

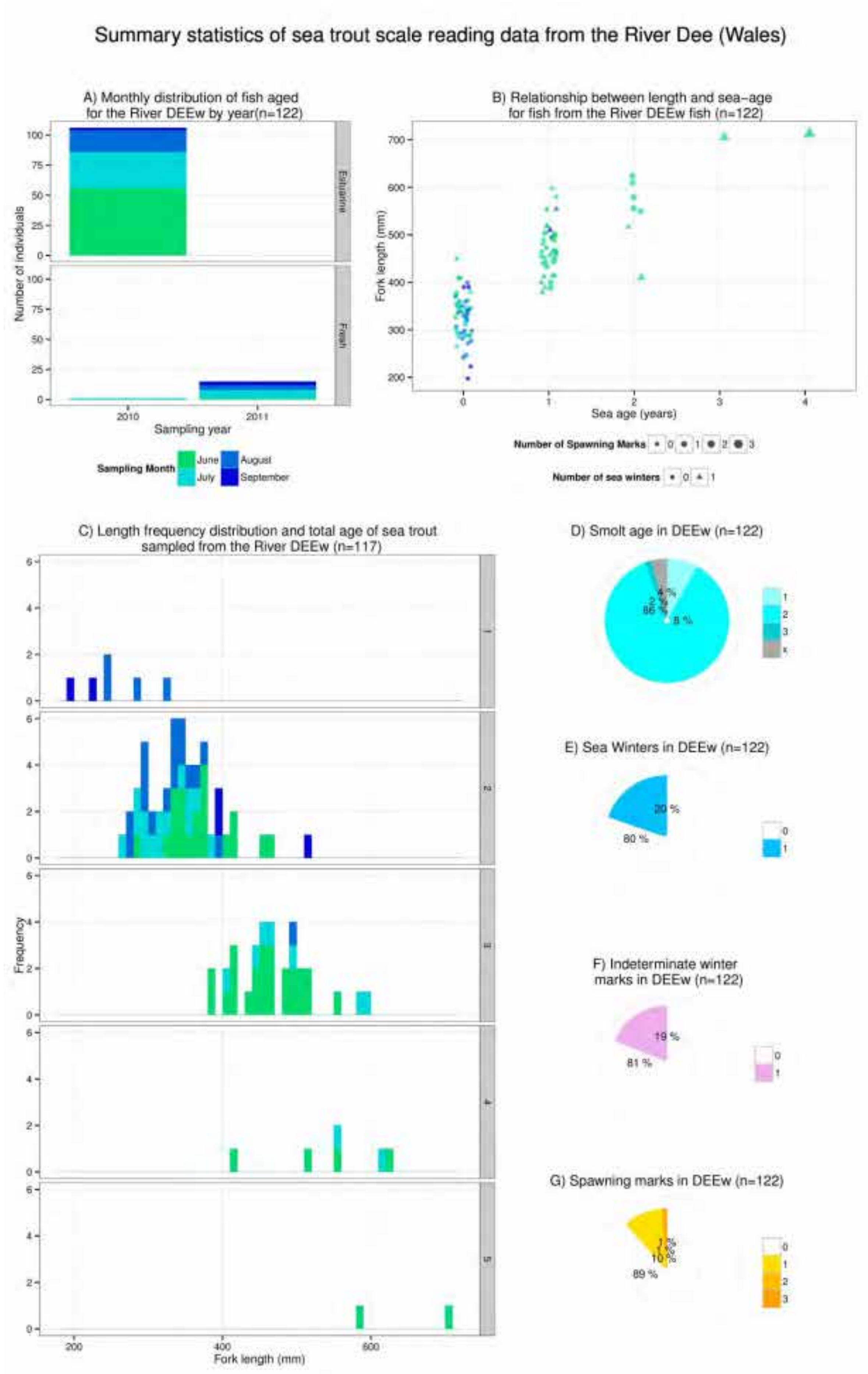


Summary statistics of sea trout scale reading data from the River Lune

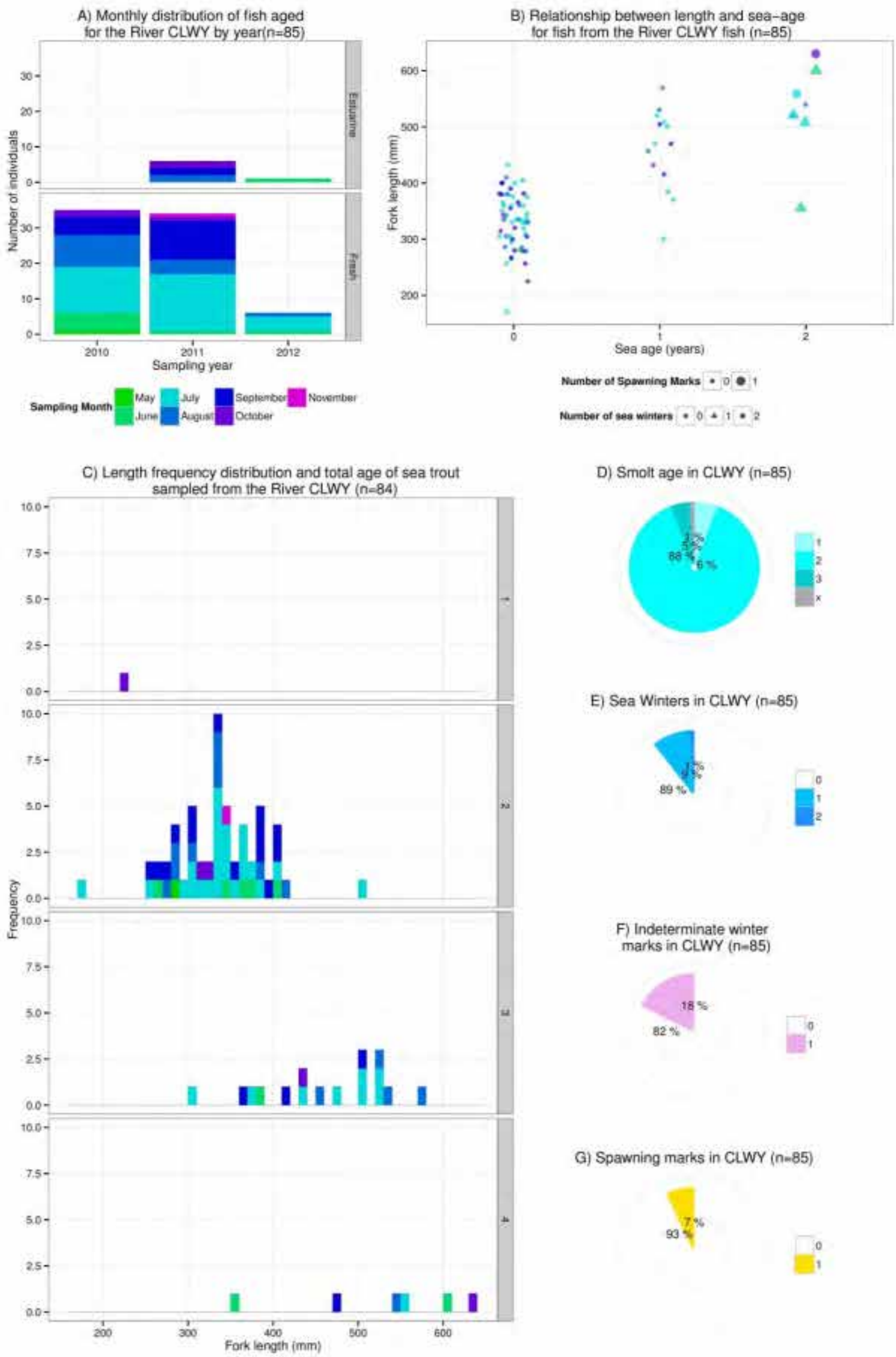


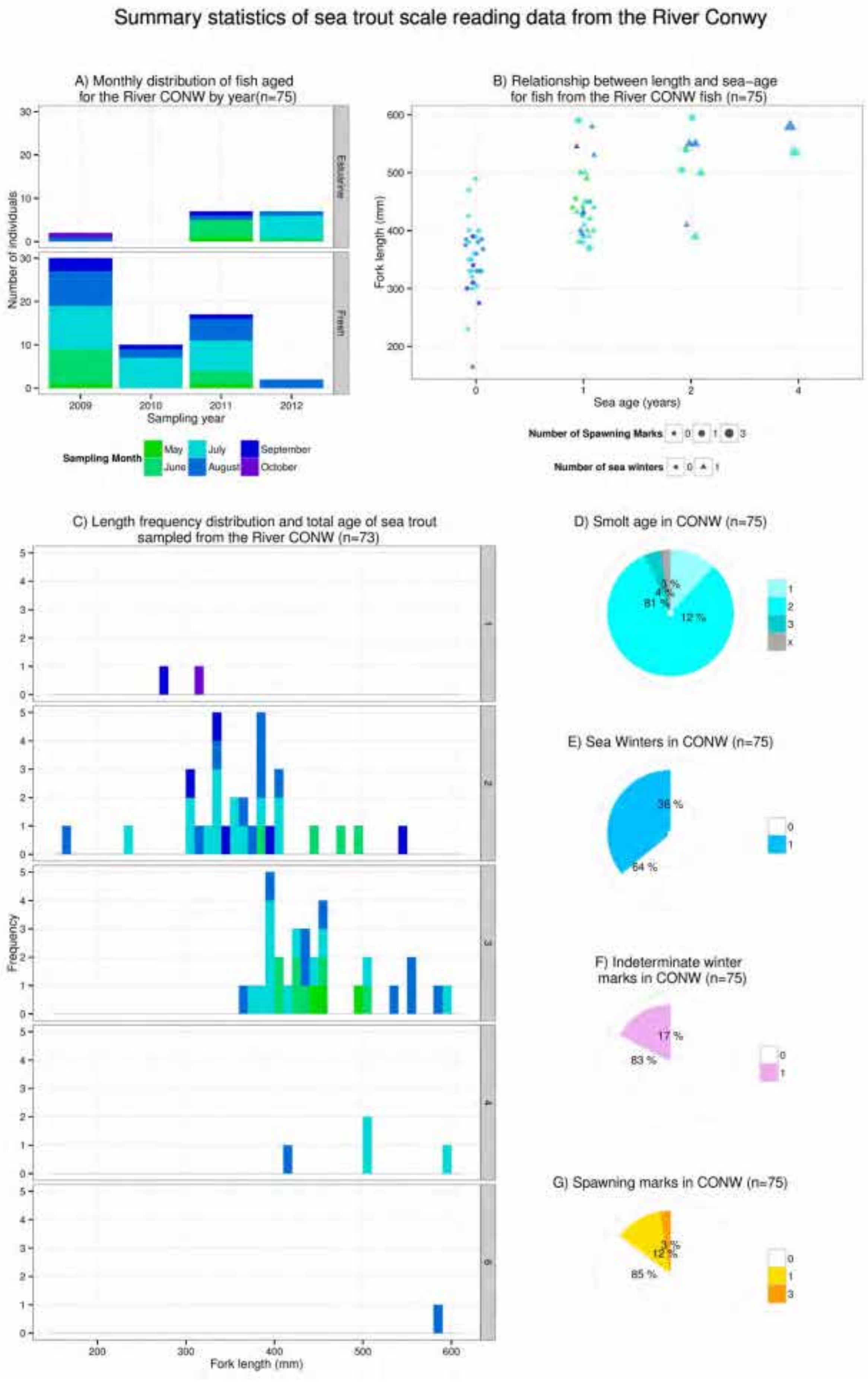


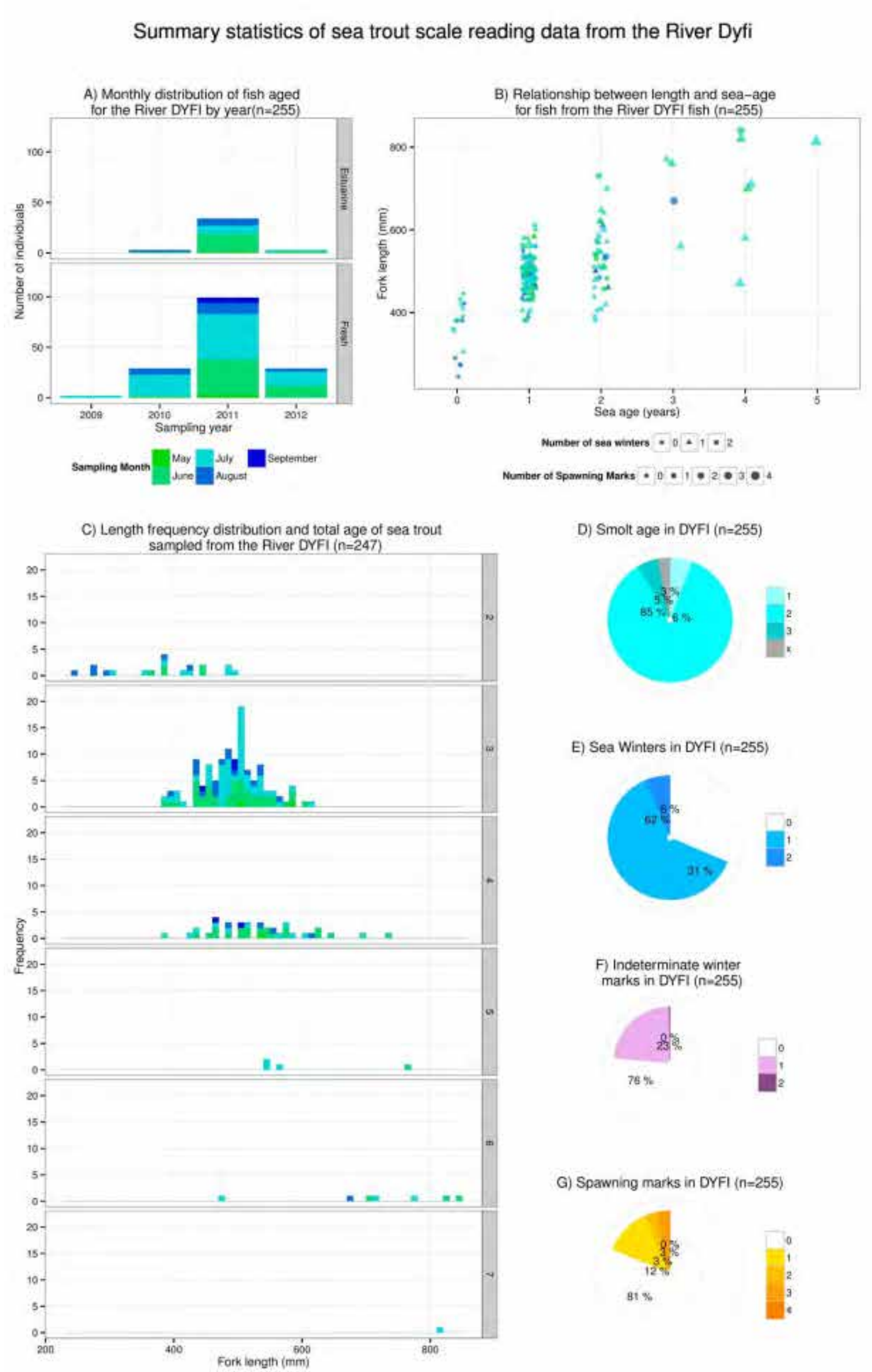
Summary statistics of sea trout scale reading data from the River Ribble
A) Monthly distribution of fish aged for the River RIBB by year(n=77)
Number of individuals
Fresh
Sampling year
Sampling Month
June
July
August
September
October
B) Relationship between length and sea−age for fish from the River RIBB fish (n=77)
Fork length (mm)
Sea age (years)
Number of Spawning Marks
Number of sea winters
C) Length frequency distribution and total age of sea trout sampled from the River RIBB (n=76)
Frequency
Fork length (mm)
D) Smolt age in RIBB (n=77)
88 %
9 %
E) Sea Winters in RIBB (n=77)
47 %
49 %
F) Indeterminate winter marks in RIBB (n=77)
68 %
G) Spawning marks in RIBB (n=77)
5 %
18 %
77 %


Summary statistics of sea trout scale reading data from the River Dee (Wales)
A) Monthly distribution of fish aged for the River DEEw by year(n=122)
Number of individuals
Estuarine
Fresh
Sampling year
Sampling Month
June
July
August
September
B) Relationship between length and sea-age for fish from the River DEEw fish (n=122)
Fork length (mm)
Sea age (years)
Number of Spawning Marks
Number of sea winters
C) Length frequency distribution and total age of sea trout sampled from the River DEEw (n=117)
Frequency
Fork length (mm)
D) Smolt age in DEEw (n=122)
E) Sea Winters in DEEw (n=122)
F) Indeterminate winter marks in DEEw (n=122)
G) Spawning marks in DEEw (n=122)

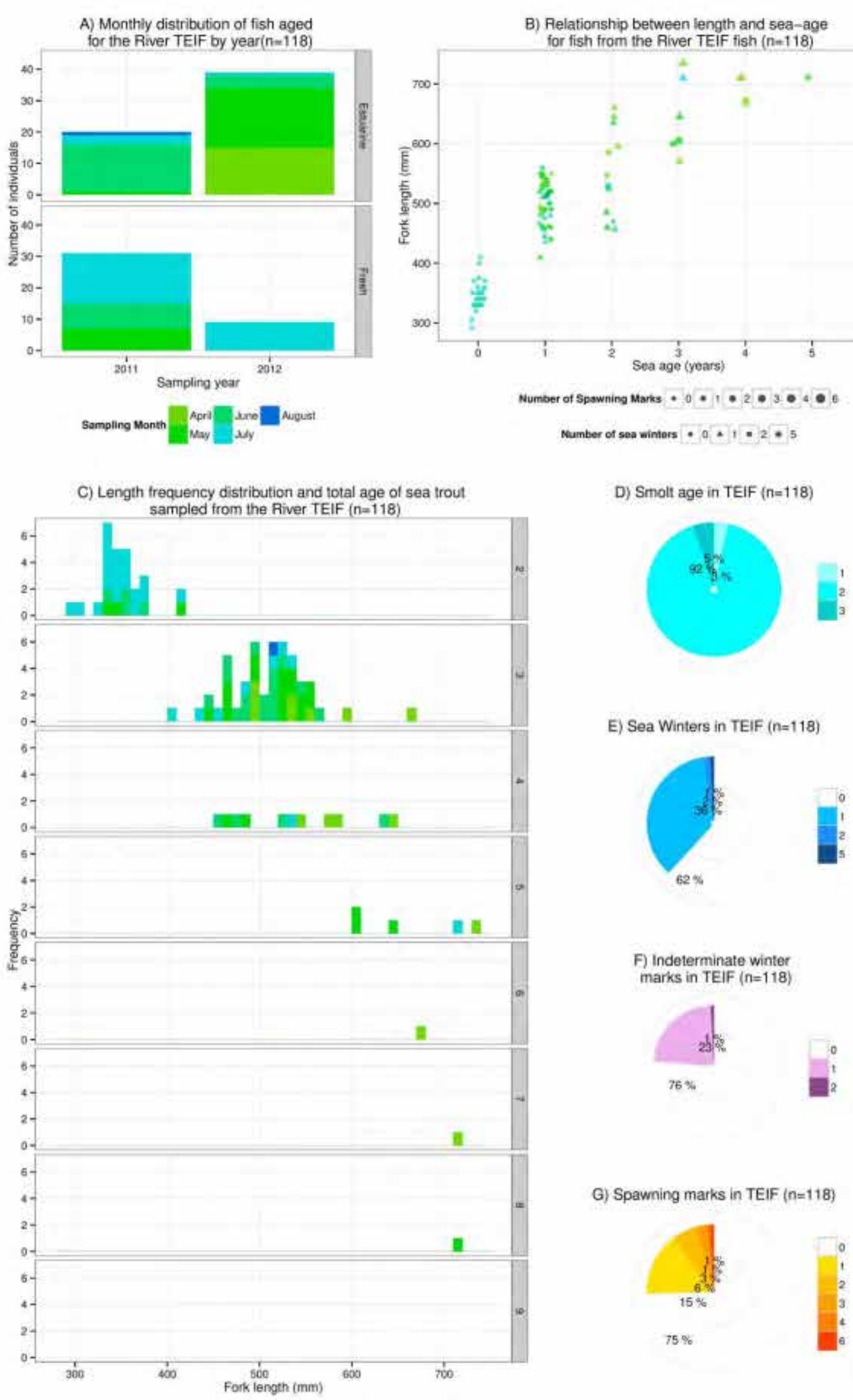
Summary statistics of sea trout scale reading data from the River Clwyd

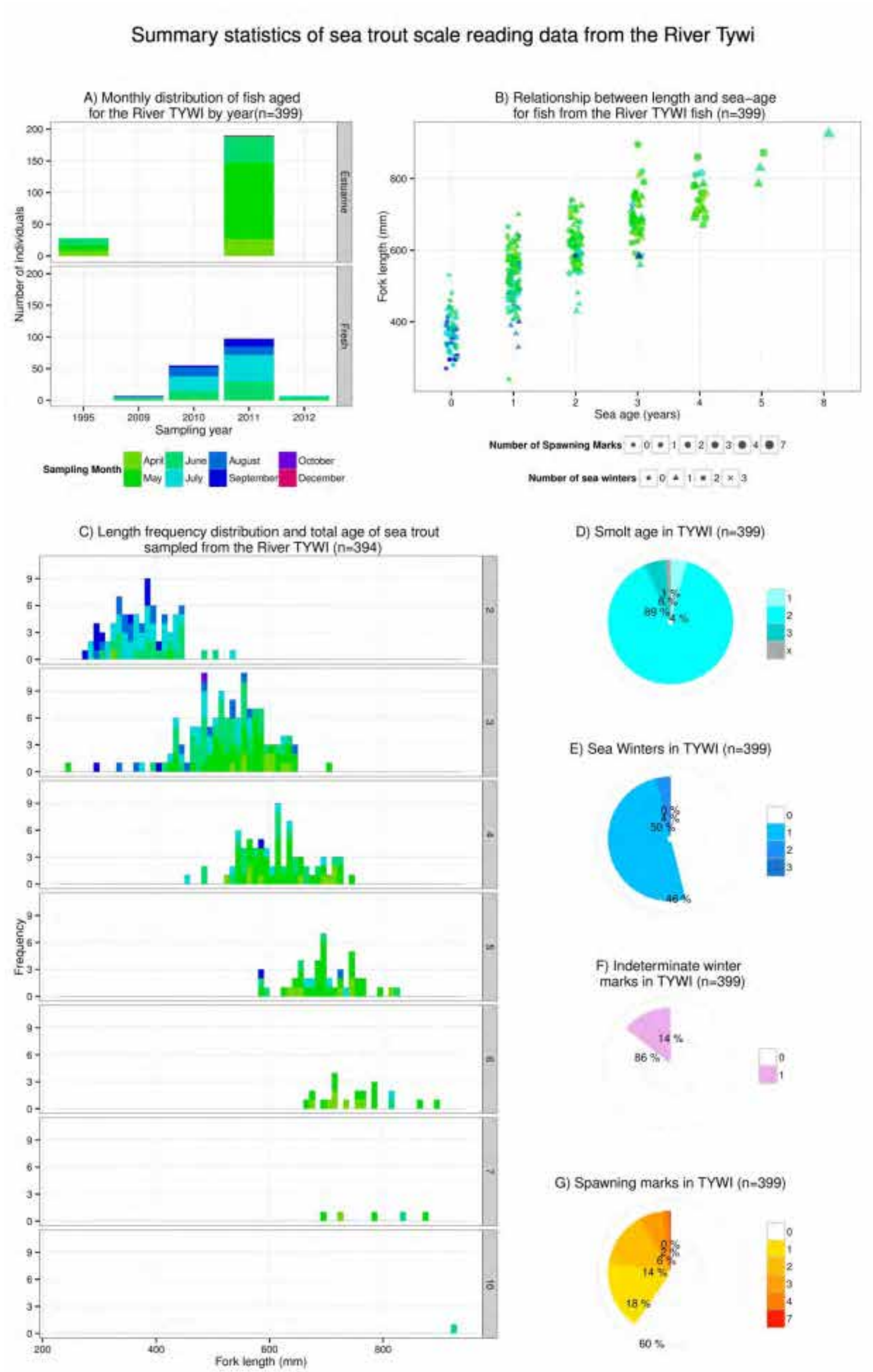



Summary statistics of sea trout scale reading data from the River Conwy
A) Monthly distribution of fish aged for the River CONW by year(n=75)
Number of individuals
Estuarine
Fresh
Sampling year
Sampling Month
May
June
July
August
September
October
B) Relationship between length and sea-age for fish from the River CONW fish (n=75)
Fork length (mm)
Sea age (years)
Number of Spawning Marks
Number of sea winters
C) Length frequency distribution and total age of sea trout sampled from the River CONW (n=73)
Frequency
Fork length (mm)
D) Smolt age in CONW (n=75)
E) Sea Winters in CONW (n=75)
F) Indeterminate winter marks in CONW (n=75)
G) Spawning marks in CONW (n=75)


Summary statistics of sea trout scale reading data from the River Dyfi
A) Monthly distribution of fish aged for the River DYFI by year(n=255)
Number of individuals
Estuarine
Fresh
Sampling year
Sampling Month
May
June
July
August
September
B) Relationship between length and sea-age for fish from the River DYFI fish (n=255)
Fork length (mm)
Sea age (years)
Number of sea winters
Number of Spawning Marks
C) Length frequency distribution and total age of sea trout sampled from the River DYFI (n=247)
Frequency
Fork length (mm)
D) Smolt age in DYFI (n=255)
E) Sea Winters in DYFI (n=255)
F) Indeterminate winter marks in DYFI (n=255)
G) Spawning marks in DYFI (n=255)

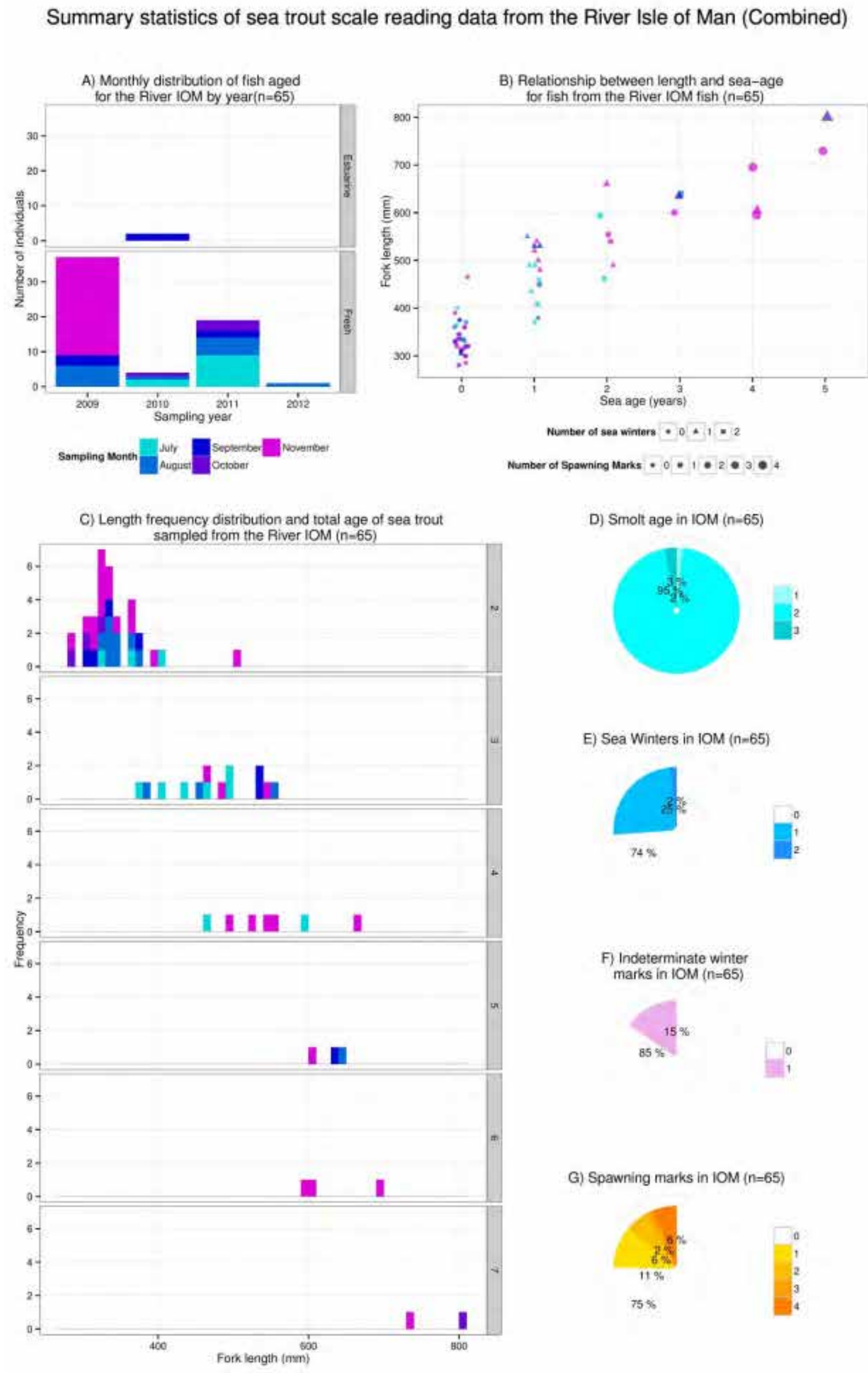
Summary statistics of sea trout scale reading data from the River Teifi





Summary statistics of sea trout scale reading data from the River Tywi
A) Monthly distribution of fish aged for the River TYWI by year(n=399)
Number of individuals
Estuarine
Fresh
Sampling year
Sampling Month
April
May
June
July
August
September
October
December
B) Relationship between length and sea-age for fish from the River TYWI fish (n=399)
Fork length (mm)
Sea age (years)
Number of Spawning Marks
Number of sea winters
C) Length frequency distribution and total age of sea trout sampled from the River TYWI (n=394)
Frequency
Fork length (mm)
D) Smolt age in TYWI (n=399)
E) Sea Winters in TYWI (n=399)
F) Indeterminate winter marks in TYWI (n=399)
G) Spawning marks in TYWI (n=399)

Summary statistics of sea trout scale reading data from the River Tawe



Summary statistics of sea trout scale reading data from the River Isle of Man (Combined)
A) Monthly distribution of fish aged for the River IOM by year(n=65)
Number of individuals
Estuarine
Fresh
Sampling year
Sampling Month
July
August
September
October
November
B) Relationship between length and sea-age for fish from the River IOM fish (n=65)
Fork length (mm)
Sea age (years)
Number of sea winters
Number of Spawning Marks
C) Length frequency distribution and total age of sea trout sampled from the River IOM (n=65)
Frequency
Fork length (mm)
D) Smolt age in IOM (n=65)
E) Sea Winters in IOM (n=65)
74 %
F) Indeterminate winter marks in IOM (n=65)
15 %
85 %
G) Spawning marks in IOM (n=65)
11 %
75 %

Section 7.8 Pooled scale formulae/age splits from all marine samples

	Count of sea.yrs, by scale formulae (marine zone data) *{MZ.LWK}*								
Scale formula	**0**	**1**	**2**	**3**	**4**	**7**	**NA**	**Total**	
1.0+	30							30	
1.0+1IM		19						19	
1.0+1IM+1SM+			4					4	
1.0+1IM+2SM+				1				1	
1.0+1SM+		5						5	
1.0+2IM			3					3	
1.1		2						2	
1.1+		69						69	
1.1+1IM			5					5	
1.1+1SM+			9					9	
1.1+2SM+				1				1	
1.1+3SM+					1			1	
1.2			1					1	
1.2+1SM+				1				1	
2	19							19	
2.0	28							28	
2.0+	149							149	
2.0+1IM		87						87	
2.0+1IM+1SM+			11					11	
2.0+1IM+2SM+				2				2	
2.0+1IM+3SM+					1			1	
2.0+1SM+		48						48	
2.0+2IM			7					7	
2.0+2SM+			8					8	
2.0+3IM				1				1	
2.0+7SM+						1		1	
2.1		4						4	
2.1+		129						129	
2.1+1IM			10					10	
2.1+1IM+1SM+				2				2	
2.1+1SM+			30					30	
2.1+2SM+				8				8	
2.1+3SM+					2			2	
2.2			1					1	
2.2+			12					12	
2.2+1SM+				2				2	
2.2+2SM+					1			1	
3.0+	13							13	
3.0+1IM		12						12	
3.0+1SM+		16						16	
3.0+2SM+			4					4	
3.0+3SM+				1				1	
3.1		1						1	
3.1+		11						11	
3.1+1IM			1					1	
3.1+1SM+			1					1	
3.1+2SM+				1				1	
3.2+			2					2	
4.0+1SM+		1						1	
x.0+1SM+		4						4	
x.0+2SM+			1					1	
x.1+		1						1	
x.1+1SM+			2					2	
x.1+2SM+				1				1	
#N/A							0	0	
Grand Total	239	409	112	21	5	1	0	787	
Smolt age group									**%**
1.n	30	95	22	3	1	0	0	151	19.4
2.n	196	268	79	15	4	1	0	563	72.4
3.n	13	40	8	2	0	0	0	63	8.1
4.n	0	1	0	0	0	0	0	1	0.1
NA	0	5	3	1	0	0	0	9	

Section 7.9 Long term data on size at age and growth from historical and CSTP scale samples

River	Source	Latitude	Longitude	Period	Allocated year	sample size	Length .0+	sample size	Length .1+	sample size	Length .2+	sample size	Length .3+	Annual increment yrs0-1	Annual increment yrs0-1
Afan	Solomon.1994	51.582	-3.807	1980-82	1981	16	315	10	455	7	555	2	640	140	100
Border Esk	Solomon.1994	54.96	-3.234	1930-31	1931	547	271	487	370	201	443	NA	NA	99	73
Border Esk	Harris.2002	54.96	-3.234	1996-98	1997	152	356	231	435	2	610	NA	NA	79	175
Border Esk	CSTP	54.96	-3.234	2006-2012	2011	NA	339	NA	428	NA	428	NA	NA	89	NA
Clwyd	Harris.2002	53.32	-3.503	1996-98	1997	111	347	24	490	NA	NA	NA	NA	143	NA
Clwyd	CSTP	53.32	-3.503	2006-2012	2011	NA	332	NA	443	NA	NA	NA	NA	111	NA
Conwy	Solomon.1994	53.298	-3.84	1988-91	1990	8	356	55	436	16	470	NA	NA	80	34
Conwy	CSTP	53.298	-3.84	2006-2012	2011	NA	348	NA	428	NA	NA	NA	NA	80	NA
Dee	Solomon.1994	53.242	-3.095	1991-93	1992	519	345	628	441	85	555	NA	NA	96	114
Dee	Harris.2002	53.242	-3.095	1996-98	1997	751	322	293	468	22	619	NA	NA	146	151
Dee	CSTP	53.242	-3.095	2006-2012	2011	NA	338	NA	472	NA	NA	NA	NA	134	NA
Duddon	Solomon.1994	54.262	-3.224	1934	1934	129	292	15	379	NA	NA	NA	NA	87	NA
Dwyfawr	Harris.2002	52.911	-4.264	1996-98	1997	184	329	30	490	NA	NA	NA	NA	161	NA
Dyfi	Solomon.1994	52.536	-4.062	1915-32	1923	238	296	193	472	52	586	NA	NA	176	114
Dyfi	Solomon.1994	52.536	-4.062	1967-69	1968	493	291	387	505	29	622	NA	NA	214	117
Dyfi	Harris.2002	52.536	-4.062	1996-98	1997	124	355	355	487	6	712	NA	NA	132	225
Dyfi	CSTP	52.536	-4.062	2006-2012	2011	NA	365	NA	487	NA	495	NA	NA	122	8
Dysynni	Solomon.1994	52.607	-4.126	1967-69	1968	26	315	54	517	5	592	1	610	202	75
Glaslyn	Solomon.1994	52.891	-4.16	1967	1967	7	302	19	414	1	500	NA	NA	112	86
Gwrfai	Solomon.1994	53.121	-4.316	1975-77	1976	55	299	8	421	NA	NA	NA	NA	122	NA
Kent	Solomon.1994	54.246	-2.808	1935	1935	154	307	26	406	NA	NA	NA	NA	99	NA
Kent	Harris.2002	54.246	-2.808	1996-98	1997	48	354	77	454	NA	NA	NA	NA	100	NA
Leven	Solomon.1994	54.223	-3.045	1933-34	1934	570	268	52	368	NA	NA	NA	NA	100	NA
Loughor	Solomon.1994	51.654	-4.264	1982-83	1983	19	330	9	452	65	544	4	637	122	92
Lune	Solomon.1994	53.991	-2.873	1993	1993	61	292	79	361	28	443	1	559	69	82
Lune	Harris.2002	53.991	-2.873	1996-98	1997	49	331	98	447	1	673	NA	NA	116	226
Lune	CSTP	53.991	-2.873	2006-2012	2011	NA	302	NA	439	NA	450	NA	NA	137	11
Nith	CSTP	54.927	-3.554	2006-2012	2011	NA	330	NA	432	NA	477	NA	NA	102	45
Ogmore	Solomon.1994	51.468	-3.645	1992	1992	76	356	50	549	2	680	NA	NA	193	131
Rheidol	Solomon.1994	52.408	-4.09	1967	1967	75	299	39	458	4	540	NA	NA	159	82
Ribble	Solomon.1994	53.727	-2.926	1935	1935	55	278	65	370	2	370	NA	NA	92	NA
Ribble	Harris.2002	53.727	-2.926	1996-98	1997	33	341	129	460	1	749	NA	NA	119	289
Taff	Solomon.1994	51.446	-3.163	1992	1992	83	375	85	480	35	550	2	685	105	70
Tawe	Solomon.1994	51.61	3.928	1991-92	1992	104	391	439	537	16	629	NA	NA	146	92
Tawe	CSTP	51.61	3.928	2006-2012	2011	NA	436	NA	568	NA	NA	NA	NA	132	NA
Teifi	Solomon.1994	52.102	-4.689	1967-69	1968	111	305	35	492	4	623	NA	NA	187	131
Teifi	Harris.2002	52.102	-4.689	1996-98	1997	227	327	23	492	1	660	NA	NA	165	168
Teifi	CSTP	52.102	-4.689	2006-2012	2011	NA	349	NA	503	NA	547	NA	NA	154	44
Tywi	Solomon.1994	51.741	4.398	1967-69	1968	69	299	102	512	11	603	2	705	213	91
Tywi	Solomon.1994	51.741	4.398	1989	1989	89	320	163	530	4	635	NA	NA	210	105
Tywi	Harris.2002	51.741	4.398	1996-98	1997	233	354	168	527	9	665	NA	NA	173	138
Tywi	CSTP	51.741	4.398	2006-2012	2011	NA	367	NA	530	NA	577	NA	NA	163	47
Wyre	Solomon.1994	53.93	-3.004	1935	1935	74	310	12	367	NA	NA	NA	NA	57	NA

Section 7.10 Comparison of fishery impacts on Afon Tywi, 2010 using alternative metrics; Catch numbers, weight (lbs), total eggs lost in that yeat and future egg deposoits (a) assuming constant P_x (b) assuming variable P_x

	Age structure of catch				Percentage catch		
Sea age (yrs)	Rod	Coracles	Seines	Total	Rods	Coracles	Seines
0	1,000	2	10	1,012	99	0	1
1	1,082	162	115	1,359	80	12	8
2	441	226	91	758	58	30	12
3	133	111	40	284	47	39	14
4	63	77	25	165	38	47	15
5	20	28	9	56	35	49	16
6	19	33	11	62	30	53	17
7	5	11	6	22	24	49	27
8	1	3	2	7	20	42	38
9	1	1	2	4	28	31	42
Totals	2,764	653	311	3,728	74	18	8

	Weight of catch (lbs)				Percentage catch		
Sea age (yrs)	Rods	Coracles	Seines	Total	Rods	Coracles	Seines
0	1002	2	11	1,016	99	0	1
1	2175	523	307	3,005	72	17	10
2	1863	1078	420	3,361	55	32	13
3	769	731	258	1,758	44	42	15
4	477	635	203	1,315	36	48	15
5	174	247	83	504	35	49	16
6	177	355	111	643	27	55	17
7	57	128	76	261	22	49	29
8	15	35	32	82	18	43	39
9	12	13	23	48	25	27	48
Totals	6,721	3,747	1,524	11,992	56	31	13

	Total eggs in year					Percentage		
Sea age (yrs)	Eggs/fsh	Rods	Coracles	Seines	Total	Rods	Coracles	Seines
0	117	117,364	214	1,225	118,803	99	0	1
1	509	550,499	82,625	58,359	691,483	80	12	8
2	1,207	532,025	272,130	110,353	914,508	58	30	12
3	2,171	287,733	241,610	87,911	617,254	47	39	14
4	2,681	168,255	206,570	66,275	441,100	38	47	15
5	2,939	58,447	80,934	26,223	165,604	35	49	16
6	3,207	60,796	105,315	33,686	199,797	30	53	17
7	3,639	19,049	39,193	21,083	79,324	24	49	27
8	3,603	4,804	9,849	8,888	23,541	20	42	38
9	3,790	3,790	4,169	5,685	13,643	28	31	42
Totals		1,802,761	1,042,608	419,688	3,265,057	55	32	13

(A) ASSUMING CONSTANT PX

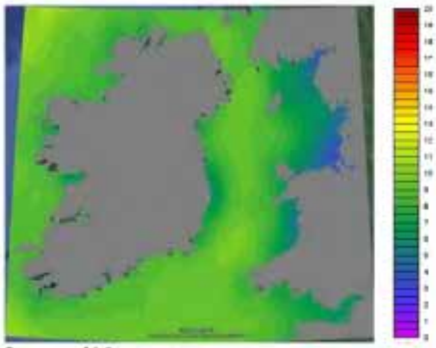
	Future life time eggs (inc year x)					Percentage		
Sea age (yrs)	eggs /fish	Rods	Coracles	Seines	Total	Rods	Coracles	Seines
0	349	348,800	635	3,641	353,076	99	0	1
1	1,489	1,610,998	241,798	170,782	2,023,578	80	12	8
2	3,874	1,707,986	873,632	354,273	2,935,891	58	30	12
3	8,560	1,134,316	952,488	346,569	2,433,373	47	39	14
4	9,920	622,575	764,349	245,230	1,632,154	38	47	15
5	10,721	213,240	295,279	95,671	604,189	35	49	16
6	11,393	215,984	374,145	119,675	709,804	30	53	17
7	11,644	60,955	125,416	67,464	253,835	24	49	27
8	10,429	13,905	28,506	25,725	68,136	20	42	38
9	7,580	7,580	8,338	11,370	27,287	28	31	42
Totals		5,936,339	3,664,586	1,440,401	11,041,325	54	33	13

(b) ASSUMING VARYING PX

	Future life time eggs (inc year x)					Percentage		
Sea age (yrs)	per FISH	Rods	Coracles	Seines	Total	Rods	Coracles	Seines
0	141	140,875	256	1,471	142,602	99	0	1
1	1,240	1,340,835	201,248	142,142	1,684,226	80	12	8
2	4,188	1,846,668	944,567	383,039	3,174,273	58	30	12
3	10,093	1,337,365	1,122,989	408,607	2,868,961	47	39	14
4	11,885	745,891	915,747	293,804	1,955,443	38	47	15
5	12,432	247,268	342,400	110,937	700,605	35	49	16
6	11,058	209,634	363,145	116,157	688,935	30	53	17
7	11,214	58,702	120,781	64,971	244,454	24	49	27
8	9,877	13,169	26,997	24,363	64,529	20	42	38
9	7,580	7,580	8,338	11,370	27,287	28	31	42
Totals		5,947,986	4,046,467	1,556,860	11,551,314	51	35	13

Section 7.11 Irish Sea temperature maps 2010-2012

APPENDIX A7.11 Irish Sea temperature maps 2010-2012



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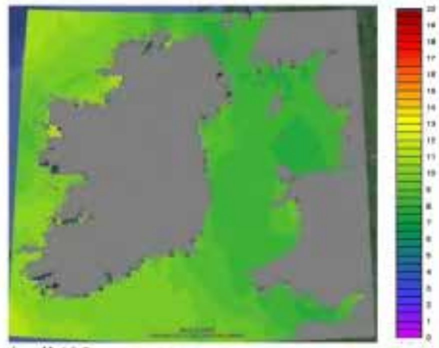

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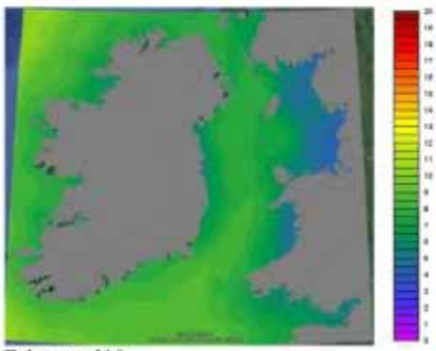

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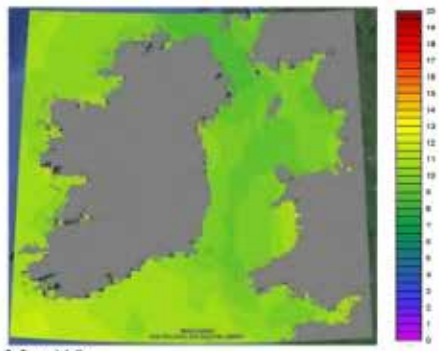

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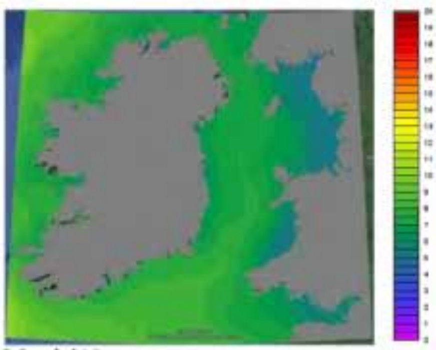

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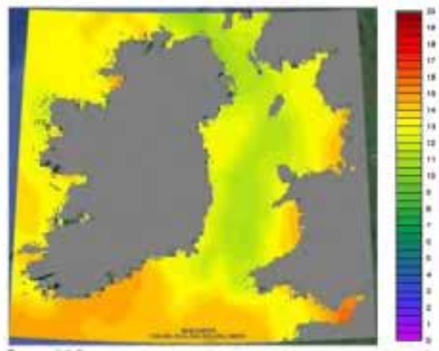

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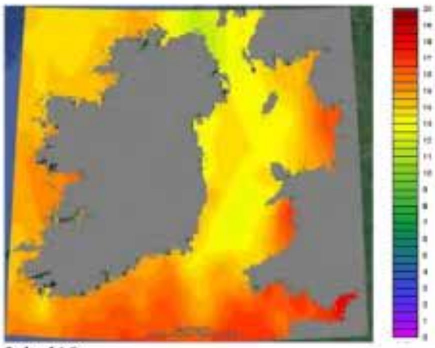
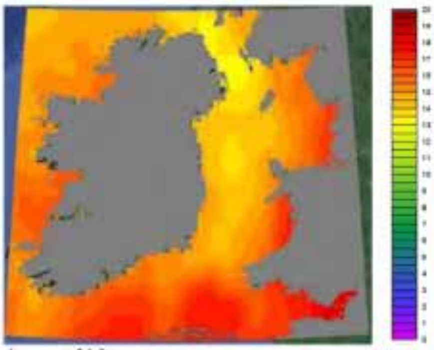


July '10

October '10



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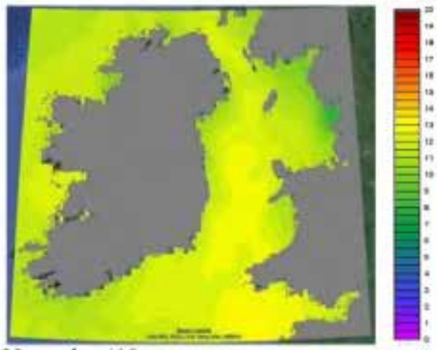

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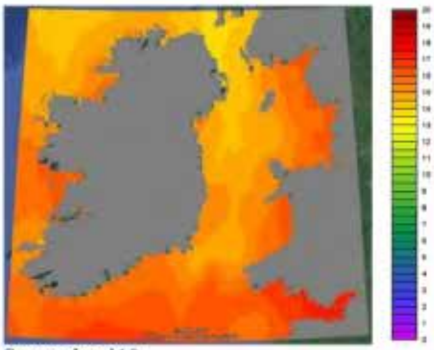

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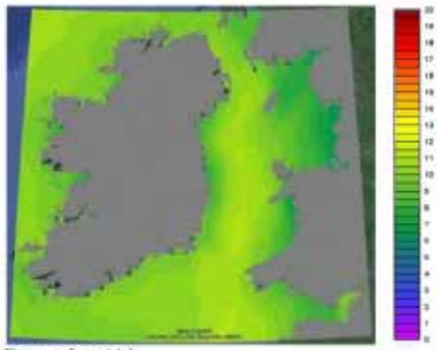

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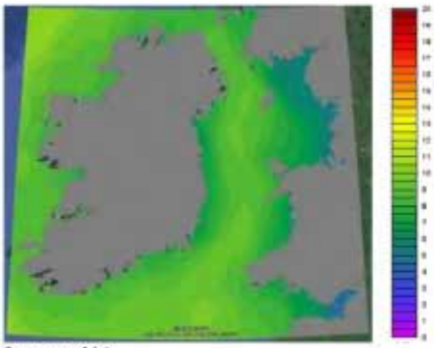
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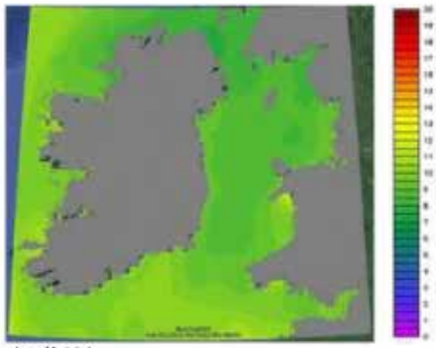
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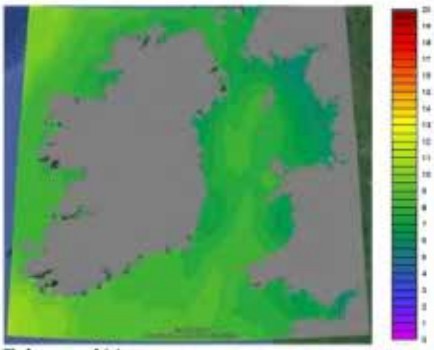
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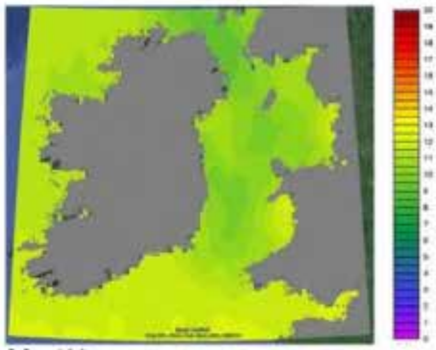
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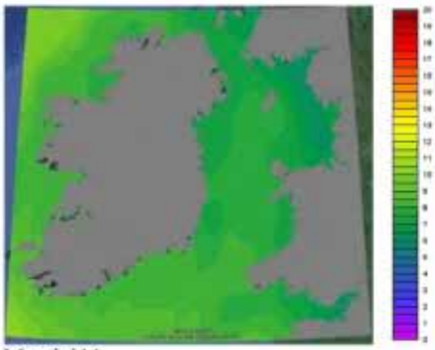
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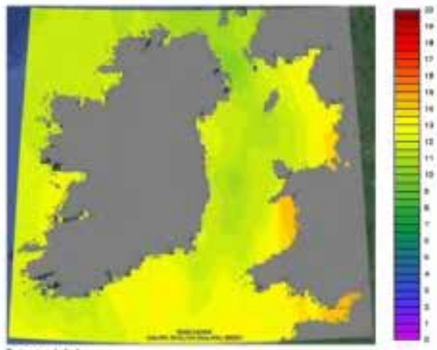
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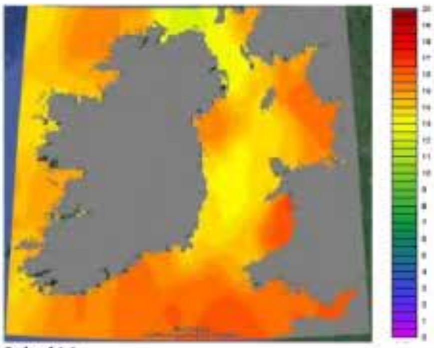

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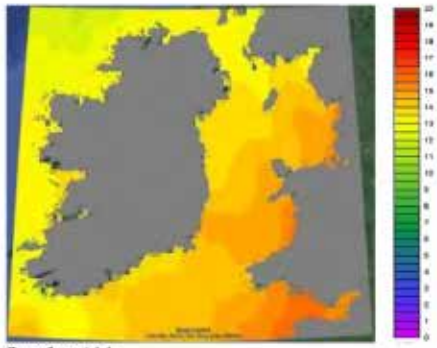

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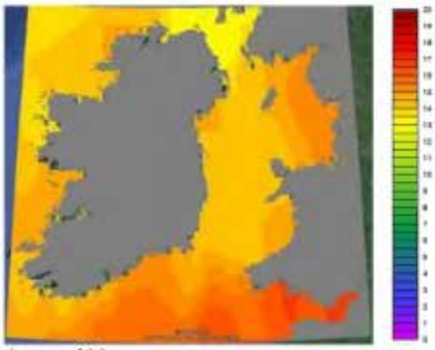

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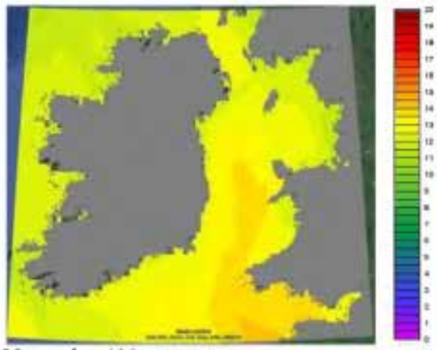

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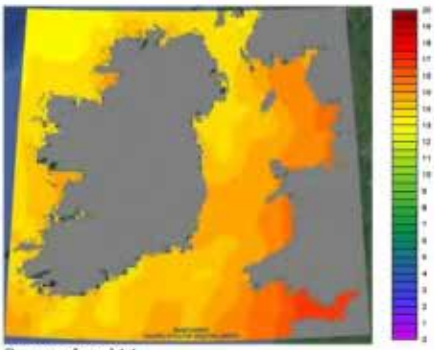

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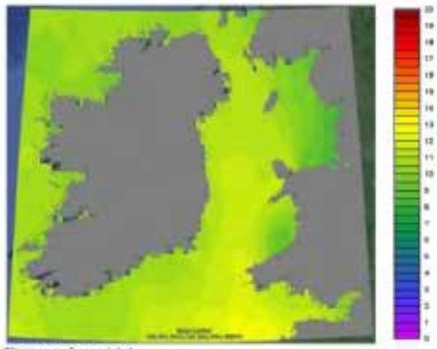

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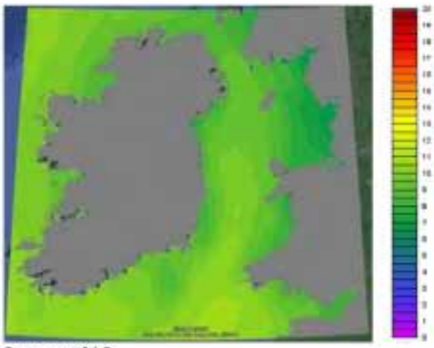
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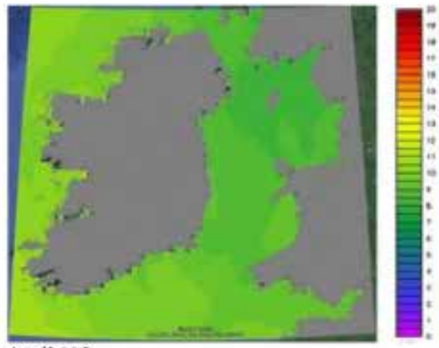
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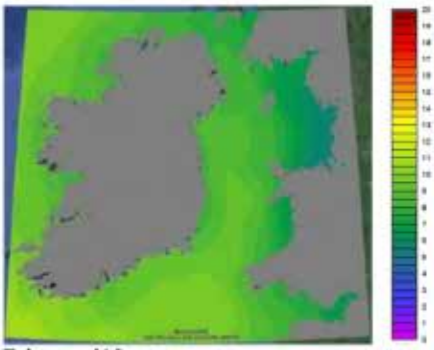
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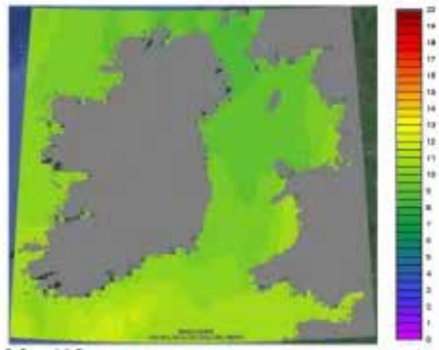
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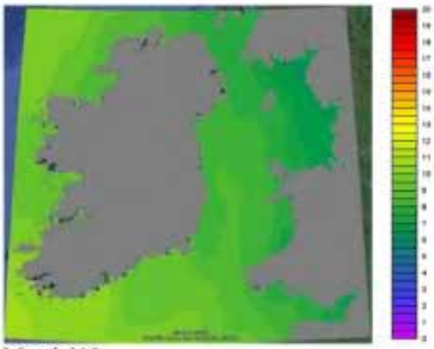
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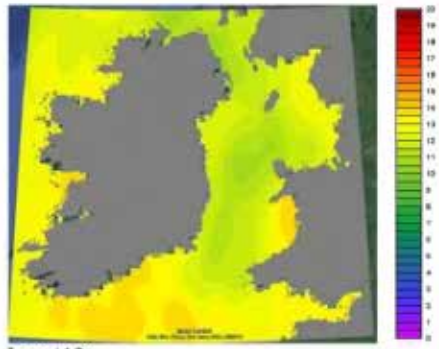
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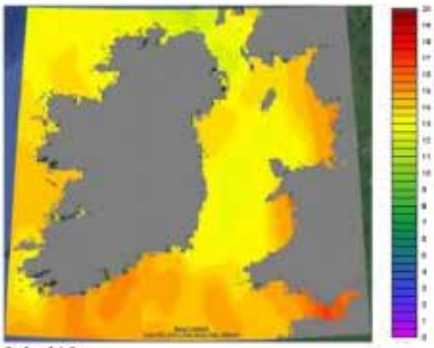
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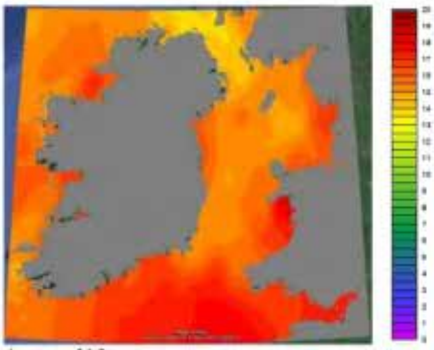
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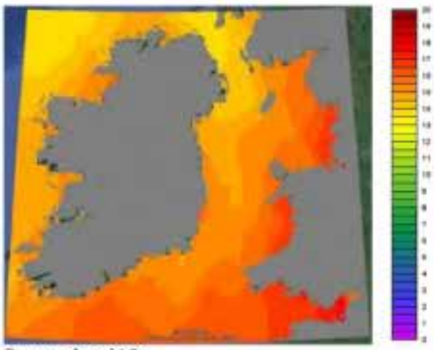
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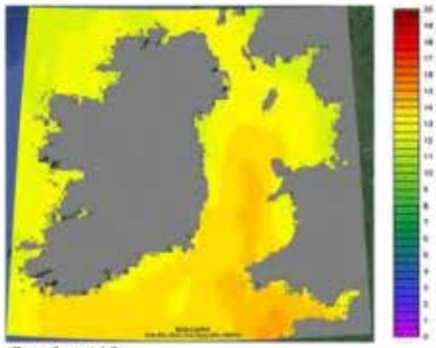
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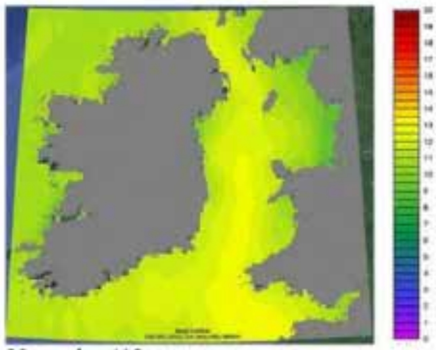
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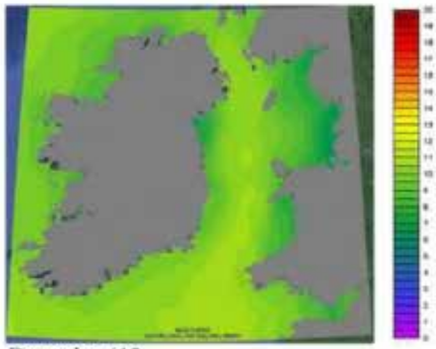

December '12

Section 7.12 A : GSI of female sea trout from the Irish Sea by month 2007-2012

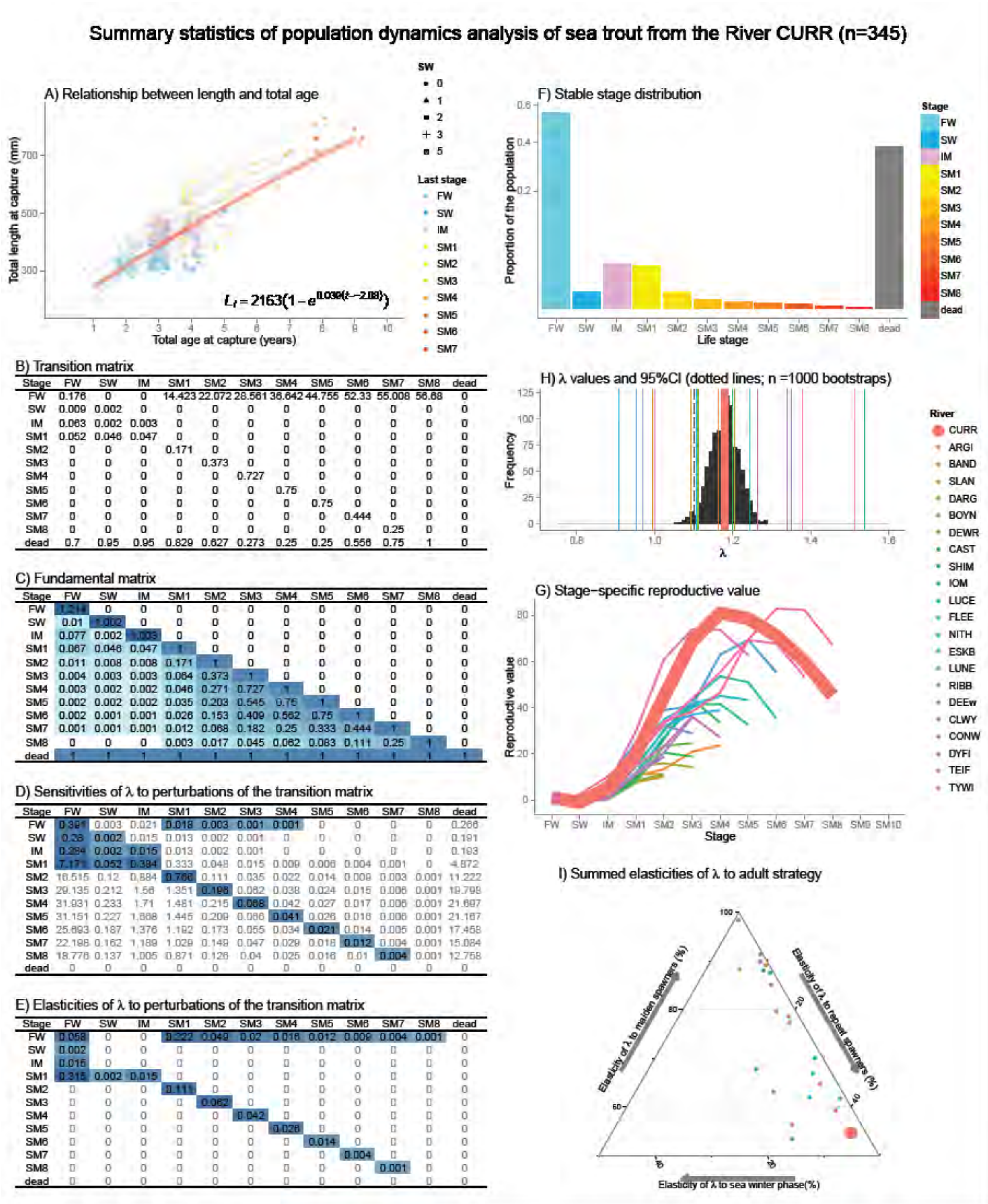
Month	Mean GSI	GSI SD	n
January	0.163	-	1
February	0.310	0.094	18
March	0.294	0.133	117
April	0.264	0.181	63
May	0.461	0.289	97
June	0.494	0.221	147
July	0.843	0.752	50
August	1.554	2.364	117
September	7.404	5.109	26
October	10.862	5.965	11
November	0.619	0.872	4
No Data	*1.352*	*2.812*	*33*
Total			684

B: GSI of female sea trout from the Irish Sea by month 2007-2012.

Month	Mean GSI	SD	n
February	0.076	0.027	7
March	0.074	0.053	20
April	0.057	0.032	24
May	0.144	0.131	28
June	0.133	0.140	34
July	0.221	0.191	14
August	0.662	0.750	38
September	4.075	2.382	9
October	0.206	0.194	3
November	0.089	0.022	2
No Data	*0.075*	*0.074*	*17*
Total			196

Section 7.13 Matrix modelling outputs for selected river catchments

River Currane:



B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	dead
FW	0.176	0	0	14.423	22.072	28.561	36.642	44.755	52.33	55.008	56.68	0
SW	0.009	0.002	0	0	0	0	0	0	0	0	0	0
IM	0.063	0.002	0.003	0	0	0	0	0	0	0	0	0
SM1	0.052	0.046	0.047	0	0	0	0	0	0	0	0	0
SM2	0	0	0	0.171	0	0	0	0	0	0	0	0
SM3	0	0	0	0	0.373	0	0	0	0	0	0	0
SM4	0	0	0	0	0	0.727	0	0	0	0	0	0
SM5	0	0	0	0	0	0	0.75	0	0	0	0	0
SM6	0	0	0	0	0	0	0	0.75	0	0	0	0
SM7	0	0	0	0	0	0	0	0	0.444	0	0	0
SM8	0	0	0	0	0	0	0	0	0	0.25	0	0
dead	0.7	0.95	0.95	0.829	0.627	0.273	0.25	0.25	0.556	0.75	1	0

C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	dead
FW	1.214	0	0	0	0	0	0	0	0	0	0	0
SW	0.01	1.002	0	0	0	0	0	0	0	0	0	0
IM	0.077	0.002	1.003	0	0	0	0	0	0	0	0	0
SM1	0.067	0.046	0.047	1	0	0	0	0	0	0	0	0
SM2	0.011	0.008	0.008	0.171	1	0	0	0	0	0	0	0
SM3	0.004	0.003	0.003	0.064	0.373	1	0	0	0	0	0	0
SM4	0.003	0.002	0.002	0.046	0.271	0.727	1	0	0	0	0	0
SM5	0.002	0.002	0.002	0.035	0.203	0.545	0.75	1	0	0	0	0
SM6	0.002	0.001	0.001	0.026	0.153	0.409	0.562	0.75	1	0	0	0
SM7	0.001	0.001	0.001	0.012	0.068	0.182	0.25	0.333	0.444	1	0	0
SM8	0	0	0	0.003	0.017	0.045	0.062	0.083	0.111	0.25	1	0
dead	1	1	1	1	1	1	1	1	1	1	1	1

D) Sensitivities of λ to perturbations of the transition matrix

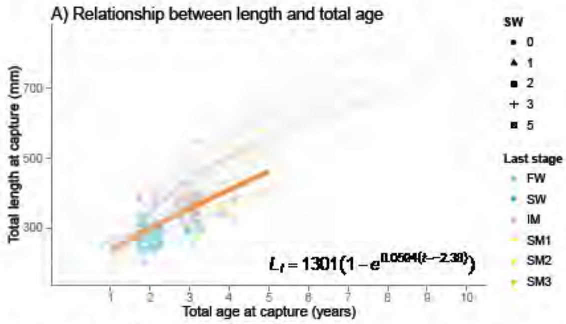
Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	dead
FW	0.391	0.003	0.021	0.018	0.003	0.001	0.001	0	0	0	0	0.266
SW	0.28	0.002	0.015	0.013	0.002	0.001	0	0	0	0	0	0.191
IM	0.284	0.002	0.015	0.013	0.002	0.001	0	0	0	0	0	0.193
SM1	7.171	0.052	0.384	0.333	0.048	0.015	0.009	0.006	0.004	0.001	0	4.872
SM2	16.515	0.12	0.884	0.766	0.111	0.035	0.022	0.014	0.009	0.003	0.001	11.222
SM3	29.135	0.212	1.56	1.351	0.196	0.062	0.038	0.024	0.015	0.006	0.001	19.798
SM4	31.931	0.233	1.71	1.481	0.215	0.068	0.042	0.027	0.017	0.006	0.001	21.697
SM5	31.151	0.227	1.668	1.445	0.209	0.066	0.041	0.026	0.016	0.006	0.001	21.167
SM6	25.693	0.187	1.376	1.192	0.173	0.055	0.034	0.021	0.014	0.005	0.001	17.458
SM7	22.198	0.162	1.189	1.029	0.149	0.047	0.029	0.018	0.012	0.004	0.001	15.084
SM8	18.776	0.137	1.005	0.871	0.126	0.04	0.025	0.016	0.01	0.004	0.001	12.758
dead	0	0	0	0	0	0	0	0	0	0	0	0

E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	dead
FW	0.058	0	0	0.222	0.049	0.02	0.016	0.012	0.009	0.004	0.001	0
SW	0.002	0	0	0	0	0	0	0	0	0	0	0
IM	0.016	0	0	0	0	0	0	0	0	0	0	0
SM1	0.316	0.002	0.015	0	0	0	0	0	0	0	0	0
SM2	0	0	0	0.111	0	0	0	0	0	0	0	0
SM3	0	0	0	0	0.062	0	0	0	0	0	0	0
SM4	0	0	0	0	0	0.042	0	0	0	0	0	0
SM5	0	0	0	0	0	0	0.026	0	0	0	0	0
SM6	0	0	0	0	0	0	0	0.014	0	0	0	0
SM7	0	0	0	0	0	0	0	0	0.004	0	0	0
SM8	0	0	0	0	0	0	0	0	0	0.001	0	0
dead	0	0	0	0	0	0	0	0	0	0	0	0

River Argideen:

Summary statistics of population dynamics analysis of sea trout from the River ARGI (n=221)



B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.151	0	0	9.539	13.37	21.06	26.88	0
SW	0.003	0	0	0	0	0	0	0
IM	0.051	0	0.003	0	0	0	0	0
SM1	0.095	0.05	0.048	0	0	0	0	0
SM2	0	0	0	0.195	0	0	0	0
SM3	0	0	0	0	0.093	0	0	0
SM4	0	0	0	0	0	0.25	0	0
dead	0.7	0.95	0.95	0.805	0.907	0.75	1	0

C) Fundamental matrix

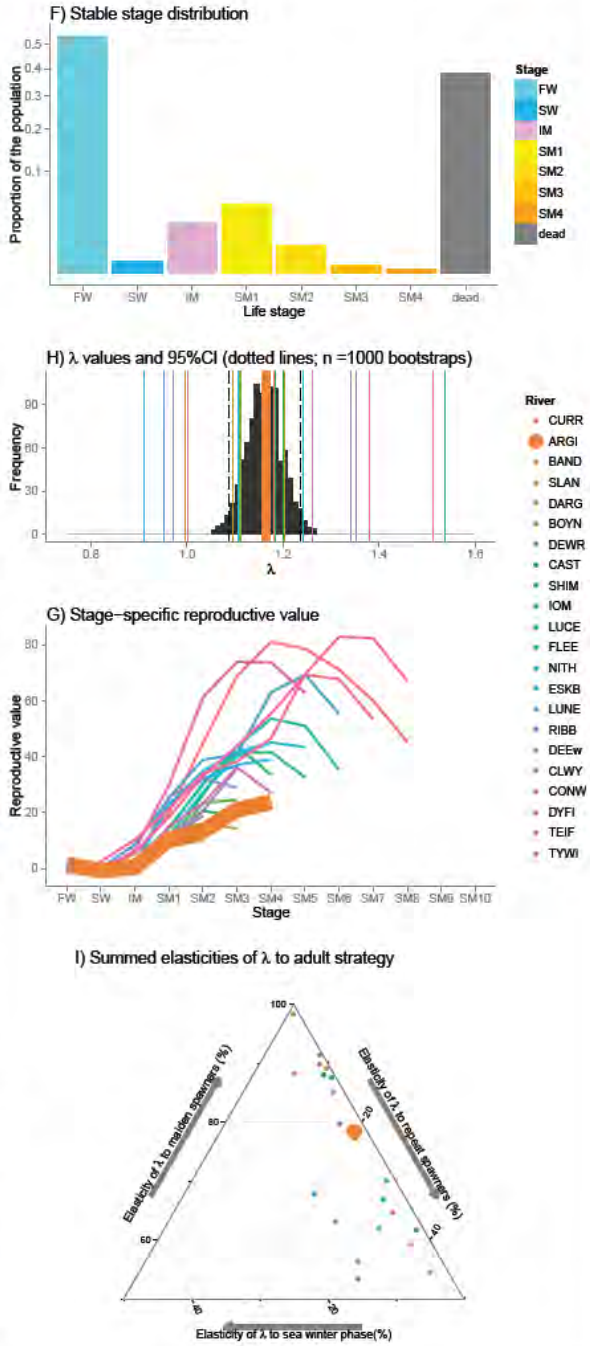
Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	1.178	0	0	0	0	0	0	0
SW	0.003	1	0	0	0	0	0	0
IM	0.06	0	1.003	0	0	0	0	0
SM1	0.115	0.05	0.048	1	0	0	0	0
SM2	0.022	0.01	0.009	0.195	1	0	0	0
SM3	0.002	0.001	0.001	0.018	0.093	1	0	0
SM4	0.001	0	0	0.005	0.023	0.25	1	0
dead	1	1	1	1	1	1	1	1

D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.475	0.001	0.021	0.04	0.007	0.001	0	0.337
SW	0.213	0	0.009	0.018	0.003	0	0	0.151
IM	0.203	0	0.009	0.017	0.003	0	0	0.144
SM1	4.946	0.011	0.218	0.413	0.069	0.008	0.001	3.509
SM2	6.329	0.015	0.279	0.528	0.088	0.007	0.002	4.488
SM3	10.947	0.025	0.482	0.913	0.153	0.012	0.003	7.762
SM4	10.965	0.025	0.483	0.915	0.153	0.012	0.003	7.775
dead	0	0	0	0	0	0	0	0

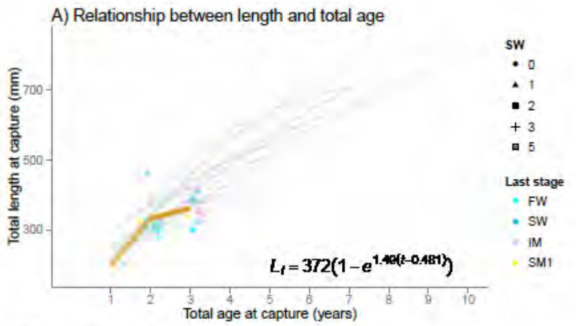
E) Elasticities of λ to perturbations of the transition matrix

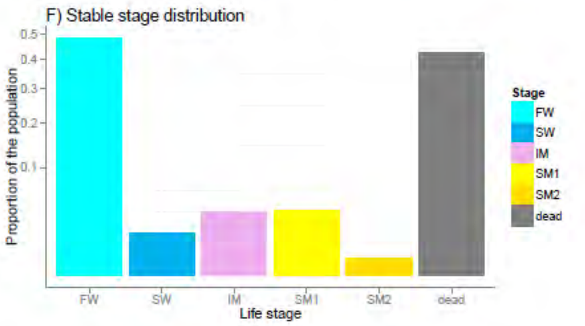
Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.062	0	0	0.325	0.076	0.01	0.003	0
SW	0	0	0	0	0	0	0	0
IM	0.009	0	0	0	0	0	0	0
SM1	0.403	0	0.009	0	0	0	0	0
SM2	0	0	0	0.088	0	0	0	0
SM3	0	0	0	0	0.012	0	0	0
SM4	0	0	0	0	0	0.003	0	0
dead	0	0	0	0	0	0	0	0



River Bandon:

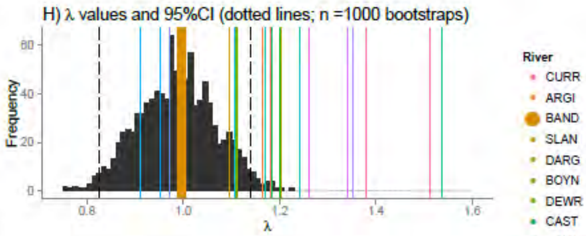
Summary statistics of population dynamics analysis of sea trout from the River BAND (n=44)





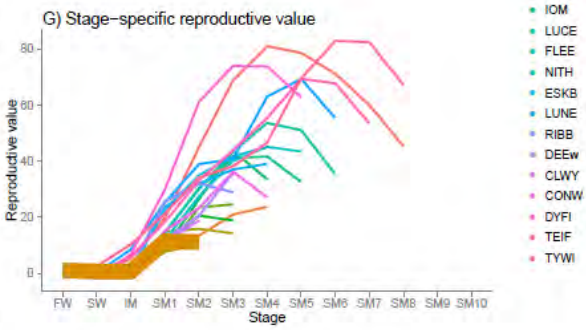
B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	0.126	0	0	10.636	11.05	0
SW	0.032	0	0	0	0	0
IM	0.071	0	0.003	0	0	0
SM1	0.071	0.05	0.047	0	0	0
SM2	0	0	0	0.068	0	0
dead	0.7	0.95	0.95	0.932	1	0



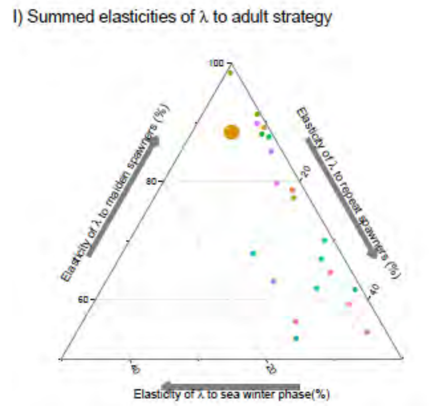
C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	1.145	0	0	0	0	0
SW	0.036	1	0	0	0	0
IM	0.082	0	1.003	0	0	0
SM1	0.087	0.05	0.047	1	0	0
SM2	0.006	0.003	0.003	0.068	1	0
dead	1	1	1	1	1	1



D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	0.503	0.016	0.036	0.038	0.003	0.442
SW	0.289	0.009	0.021	0.022	0.002	0.254
IM	0.274	0.009	0.02	0.021	0.001	0.241
SM1	5.753	0.182	0.411	0.439	0.03	5.051
SM2	5.58	0.177	0.399	0.426	0.029	4.899
dead	0	0	0	0	0	0

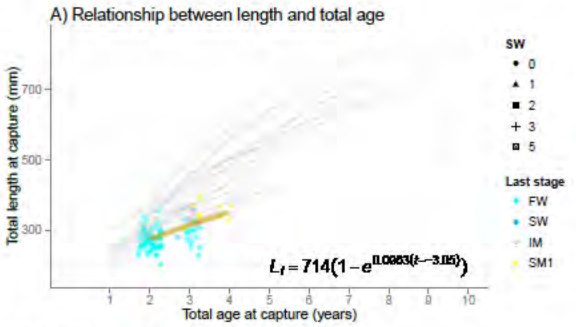


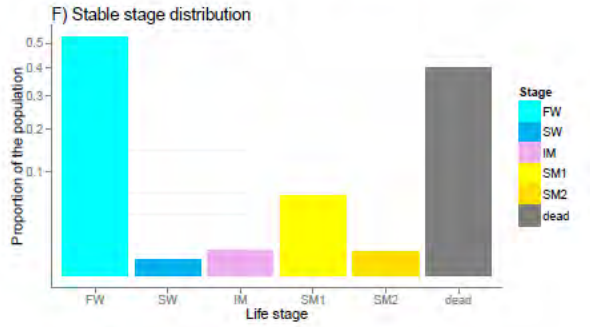
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	0.064	0	0	0.41	0.029	0
SW	0.009	0	0	0	0	0
IM	0.02	0	0	0	0	0
SM1	0.41	0.009	0.02	0	0	0
SM2	0	0	0	0.029	0	0
dead	0	0	0	0	0	0

River Slaney:

Summary statistics of population dynamics analysis of sea trout from the River SLAN (n=106)





B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	0.161	0	0	7.375	11.059	0
SW	0.005	0	0	0	0	0
IM	0.012	0	0	0	0	0
SM1	0.122	0.05	0.05	0	0	0
SM2	0	0	0	0.094	0	0
dead	0.7	0.95	0.95	0.906	1	0

C) Fundamental matrix

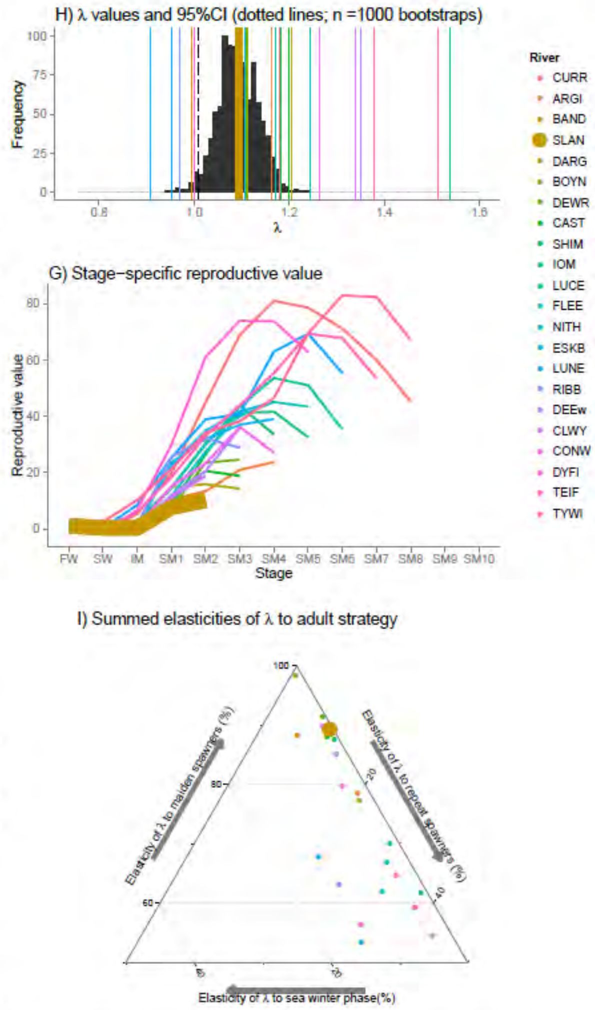
Stage	FW	SW	IM	SM1	SM2	dead
FW	1.192	0	0	0	0	0
SW	0.006	1	0	0	0	0
IM	0.014	0	1	0	0	0
SM1	0.146	0.05	0.05	1	0	0
SM2	0.014	0.005	0.005	0.094	1	0
dead	1	1	1	1	1	1

D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	0.511	0.002	0.006	0.057	0.005	0.386
SW	0.178	0.001	0.002	0.02	0.002	0.134
IM	0.178	0.001	0.002	0.02	0.002	0.134
SM1	3.891	0.019	0.042	0.438	0.038	2.937
SM2	5.167	0.025	0.056	0.579	0.05	3.9
dead	0	0	0	0	0	0

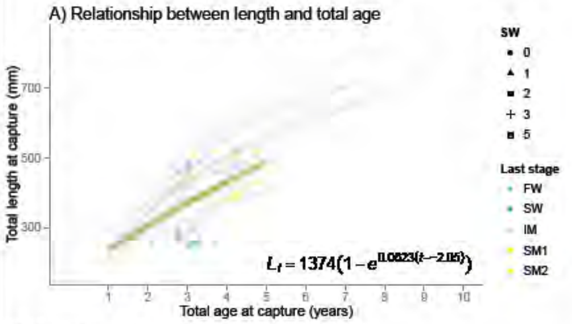
E) Elasticities of λ to perturbations of the transition matrix

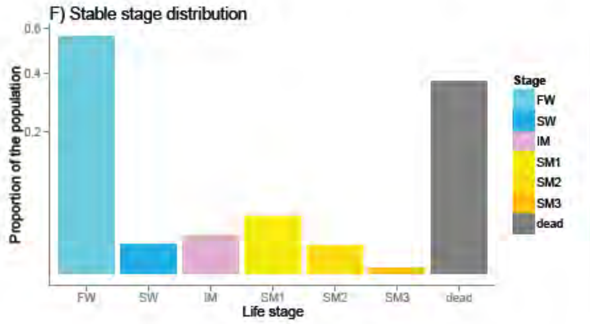
Stage	FW	SW	IM	SM1	SM2	dead
FW	0.075	0	0	0.386	0.05	0
SW	0.001	0	0	0	0	0
IM	0.002	0	0	0	0	0
SM1	0.433	0.001	0.002	0	0	0
SM2	0	0	0	0.05	0	0
dead	0	0	0	0	0	0



River Dargle:

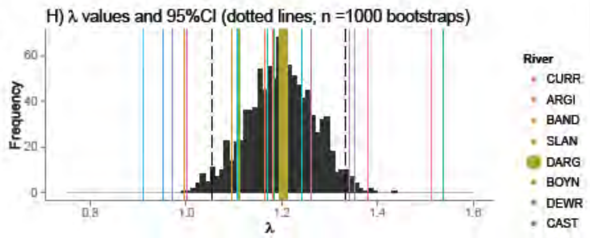
Summary statistics of population dynamics analysis of sea trout from the River DARG (n=66)





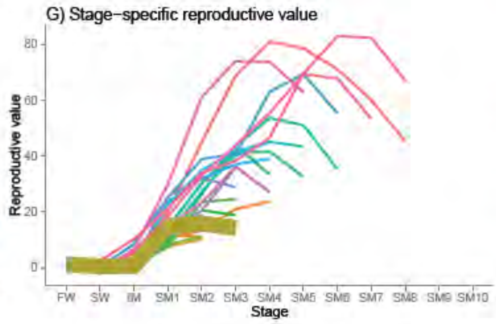
B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.184	0	0	13.245	18.272	17.12	0
SW	0.018	0	0	0	0	0	0
IM	0.032	0.005	0	0	0	0	0
SM1	0.067	0.045	0.05	0	0	0	0
SM2	0	0	0	0.288	0	0	0
SM3	0	0	0	0	0.053	0	0
dead	0.7	0.95	0.95	0.712	0.947	1	0



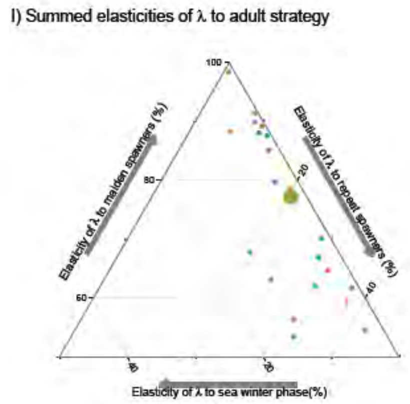
C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	[illegible]	0	0	0	0	0	0
SW	0.022	1	0	0	0	0	0
IM	0.039	0.005	1	0	0	0	0
SM1	0.085	0.045	0.05	1	0	0	0
SM2	0.024	0.013	0.014	0.288	1	0	0
SM3	0.001	0.001	0.001	0.015	0.053	1	0
dead	1	1	1	1	1	1	1



D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.477	0.007	0.013	0.027	0.007	0	0.314
SW	0.265	0.004	0.007	0.015	0.004	0	0.174
IM	0.293	0.004	0.008	0.017	0.004	0	0.193
SM1	7.048	0.103	0.186	0.404	0.097	0.004	4.645
SM2	7.534	0.11	0.199	0.432	0.103	0.005	4.965
SM3	6.781	0.099	0.179	0.389	0.093	0.004	4.469
dead	0	0	0	0	0	0	0

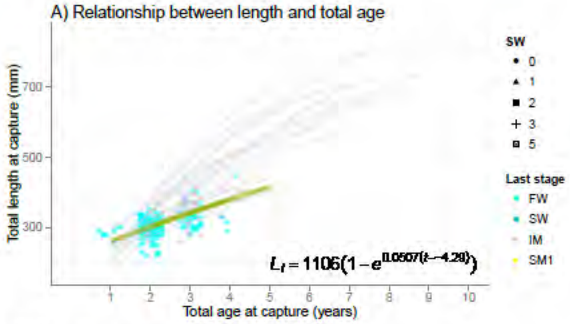


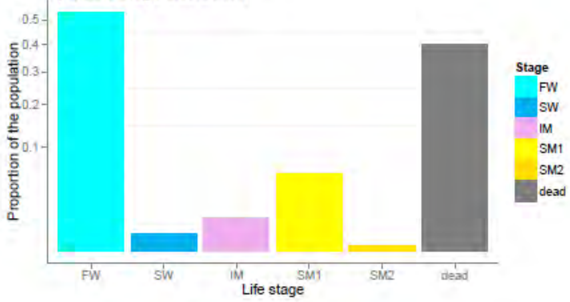
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.073	0	0	0.301	0.096	0.004	0
SW	0.004	0	0	0	0	0	0
IM	0.008	0	0	0	0	0	0
SM1	0.393	0.004	0.008	0	0	0	0
SM2	0	0	0	0.103	0	0	0
SM3	0	0	0	0	0.004	0	0
dead	0	0	0	0	0	0	0

River Boyne:

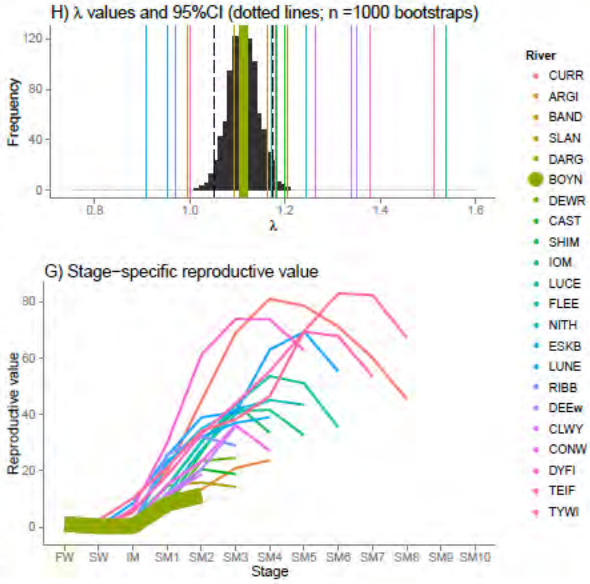
Summary statistics of population dynamics analysis of sea trout from the River BOYN (n=204)





B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	0.157	0	0	9.102	12.48	0
SW	0.006	0	0	0	0	0
IM	0.022	0.017	0.004	0	0	0
SM1	0.115	0.033	0.046	0	0	0
SM2	0	0	0	0.005	0	0
dead	0.7	0.95	0.95	0.995	1	0

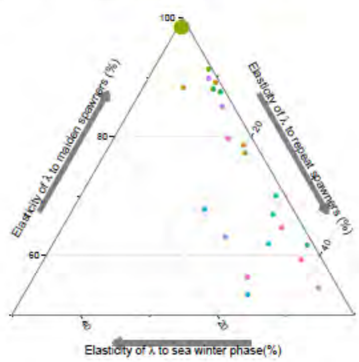


C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	1.186	0	0	0	0	0
SW	0.007	1	0	0	0	0
IM	0.026	0.017	1.004	0	0	0
SM1	0.138	0.034	0.046	1	0	0
SM2	0.001	0	0	0.005	1	0
dead	1	1	1	1	1	1

D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	0.534	0.003	0.011	0.056	0	0.397
SW	0.134	0.001	0.003	0.014	0	0.1
IM	0.182	0.001	0.004	0.019	0	0.135
SM1	4.392	0.025	0.087	0.459	0.002	3.269
SM2	5.986	0.034	0.118	0.625	0.003	4.455
dead	0	0	0	0	0	0



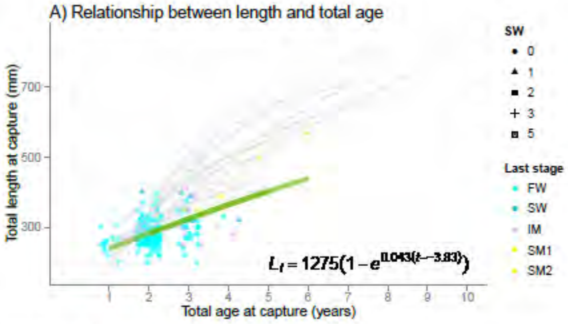
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	0.075	0	0	0.456	0.003	0
SW	0.001	0	0	0	0	0
IM	0.004	0	0	0	0	0
SM1	0.455	0.001	0.004	0	0	0
SM2	0	0	0	0.003	0	0
dead	0	0	0	0	0	0

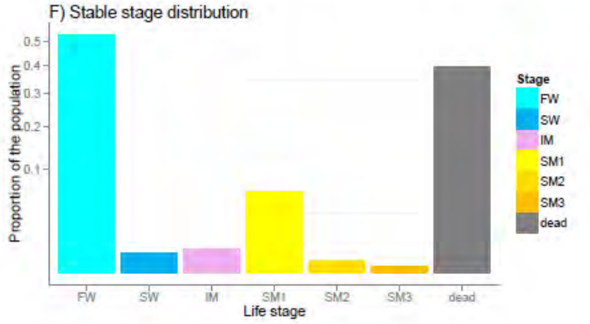
River Dee (White River) (Ireland):

Summary statistics of population dynamics analysis of sea trout from the River DEWR (n=217)

A) Relationship between length and total age



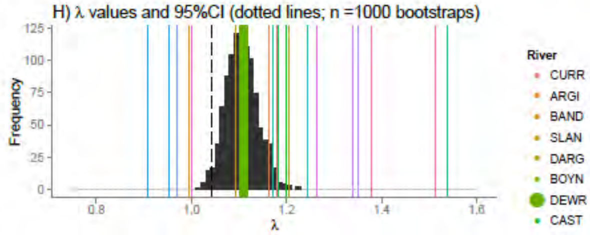
F) Stable stage distribution



B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.155	0	0	7.8	16.192	27.23	0
SW	0.007	0	0	0	0	0	0
IM	0.011	0	0.005	0	0	0	0
SM1	0.126	0.05	0.045	0	0	0	0
SM2	0	0	0	0.023	0	0	0
SM3	0	0	0	0	0.4	0	0
dead	0.7	0.95	0.95	0.977	0.6	1	0

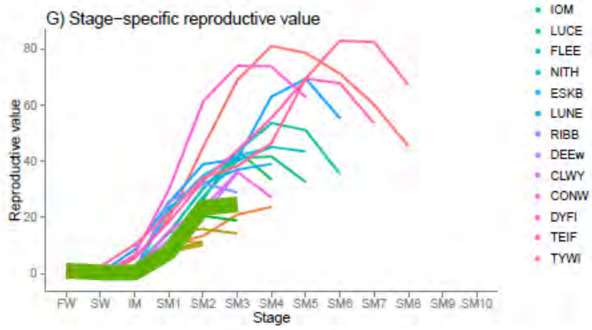
H) λ values and 95%CI (dotted lines; n =1000 bootstraps)



C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	1.183	0	0	0	0	0	0
SW	0.009	1	0	0	0	0	0
IM	0.014	0	1.005	0	0	0	0
SM1	0.15	0.05	0.045	1	0	0	0
SM2	0.003	0.001	0.001	0.023	1	0	0
SM3	0.001	0	0	0.009	0.4	1	0
dead	1	1	1	1	1	1	1

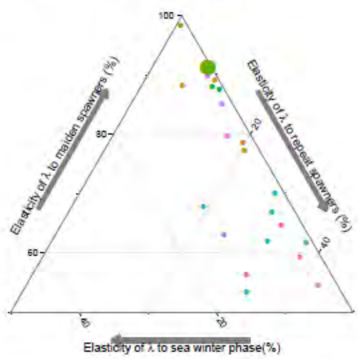
G) Stage−specific reproductive value



D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.515	0.003	0.005	0.059	0.001	0	0.385
SW	0.174	0.001	0.002	0.02	0	0	0.13
IM	0.157	0.001	0.002	0.018	0	0	0.117
SM1	3.869	0.026	0.04	0.443	0.009	0.003	2.894
SM2	12.063	0.08	0.124	1.381	0.029	0.01	9.023
SM3	12.631	0.084	0.13	1.446	0.03	0.011	9.448
dead	0	0	0	0	0	0	0

I) Summed elasticities of λ to adult strategy

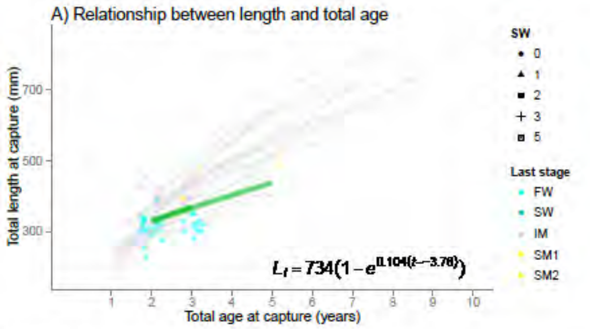


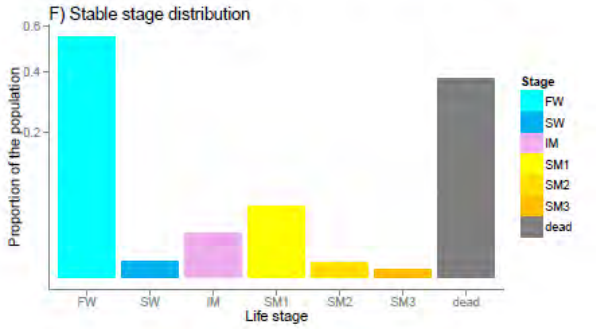
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.072	0	0	0.414	0.018	0.011	0
SW	0.001	0	0	0	0	0	0
IM	0.002	0	0	0	0	0	0
SM1	0.44	0.001	0.002	0	0	0	0
SM2	0	0	0	0.029	0	0	0
SM3	0	0	0	0	0.011	0	0
dead	0	0	0	0	0	0	0

River Castletown

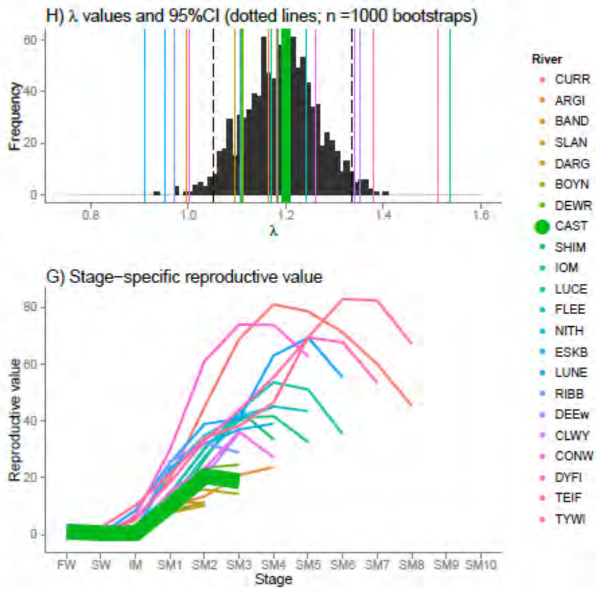
Summary statistics of population dynamics analysis of sea trout from the River CAST (n=54)





B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.151	0	0	11	18.357	22.53	0
SW	0.006	0	0	0	0	0	0
IM	0.041	0	0.003	0	0	0	0
SM1	0.102	0.05	0.047	0	0	0	0
SM2	0	0	0	0.056	0	0	0
SM3	0	0	0	0	0.333	0	0
dead	0.7	0.95	0.95	0.944	0.667	1	0

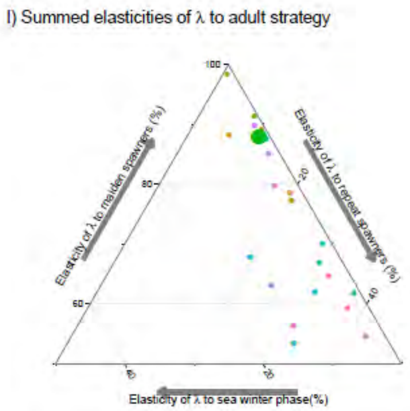


C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	1.178	0	0	0	0	0	0
SW	0.006	1	0	0	0	0	0
IM	0.049	0	1.003	0	0	0	0
SM1	0.123	0.05	0.047	1	0	0	0
SM2	0.007	0.003	0.003	0.056	1	0	0
SM3	0.002	0.001	0.001	0.019	0.333	1	0
dead	1	1	1	1	1	1	1

D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.502	0.002	0.017	0.043	0.002	0.001	0.344
SW	0.212	0.001	0.007	0.018	0.001	0	0.145
IM	0.199	0.001	0.007	0.017	0.001	0	0.136
SM1	5.077	0.023	0.175	0.439	0.02	0.006	3.479
SM2	10.295	0.047	0.355	0.689	0.041	0.011	7.055
SM3	9.423	0.043	0.325	0.814	0.038	0.01	6.458
dead	0	0	0	0	0	0	0

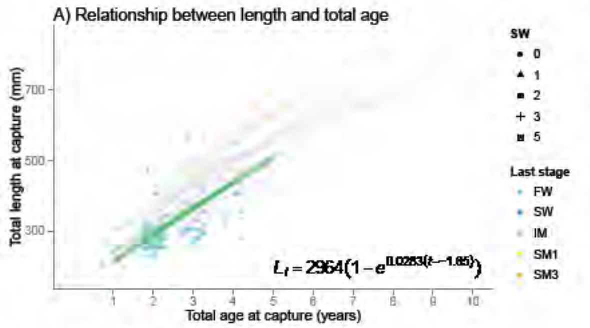


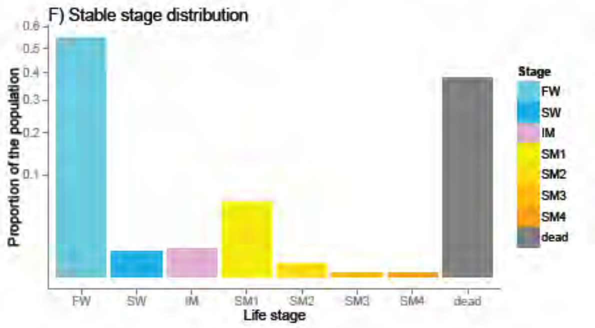
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.063	0	0	0.397	0.031	0.01	0
SW	0.001	0	0	0	0	0	0
IM	0.007	0	0	0	0	0	0
SM1	0.431	0.001	0.007	0	0	0	0
SM2	0	0	0	0.041	0	0	0
SM3	0	0	0	0	0.01	0	0
dead	0	0	0	0	0	0	0

River Shimna:

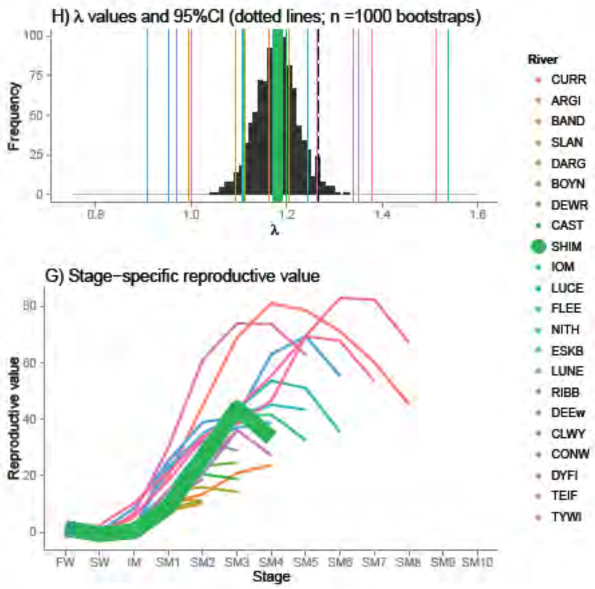
Summary statistics of population dynamics analysis of sea trout from the River SHIM (n=177)





B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.155	0	0	9.491	23.974	27.46	37.57	0
SW	0.014	0.003	0	0	0	0	0	0
IM	0.016	0.011	0.009	0	0	0	0	0
SM1	0.114	0.036	0.041	0	0	0	0	0
SM2	0	0	0	0.04	0	0	0	0
SM3	0	0	0	0	0.143	0	0	0
SM4	0	0	0	0	0	1	0	0
dead	0.7	0.95	0.95	0.96	0.857	0	1	0

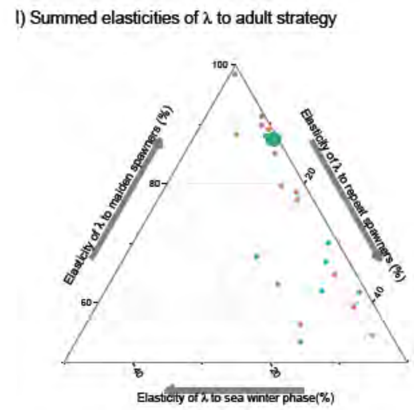


C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	[illegible]	0	0	0	0	0	0	0
SW	0.016	[illegible]	0	0	0	0	0	0
IM	0.02	0.011	[illegible]	0	0	0	0	0
SM1	0.137	0.037	0.042	1	0	0	0	0
SM2	0.005	0.001	0.002	0.04	1	0	0	0
SM3	0.001	0	0	0.006	0.143	1	0	0
SM4	0.001	0	0	0.006	0.143	1	1	0
dead	1	1	1	1	1	1	1	1

D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.602	0.008	0.007	0.049	0.002	0	0	0.348
SW	0.138	0.002	0.002	0.013	0	0	0	0.096
IM	0.157	0.002	0.002	0.015	0.001	0	0	0.109
SM1	4.488	0.053	0.063	0.436	0.015	0.002	0.001	3.102
SM2	13.205	0.155	0.185	1.289	0.043	0.005	0.004	9.168
SM3	25.123	0.298	0.353	2.452	0.082	0.01	0.008	17.443
SM4	15.939	0.188	0.224	1.555	0.052	0.006	0.005	11.066
dead	0	0	0	0	0	0	0	0

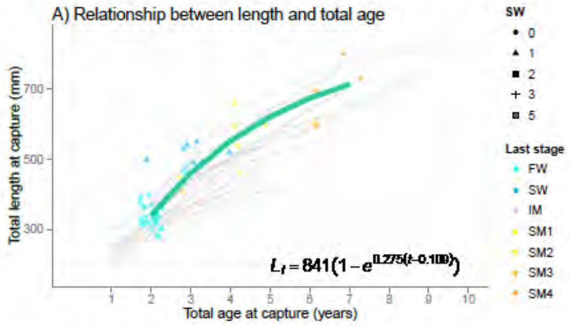


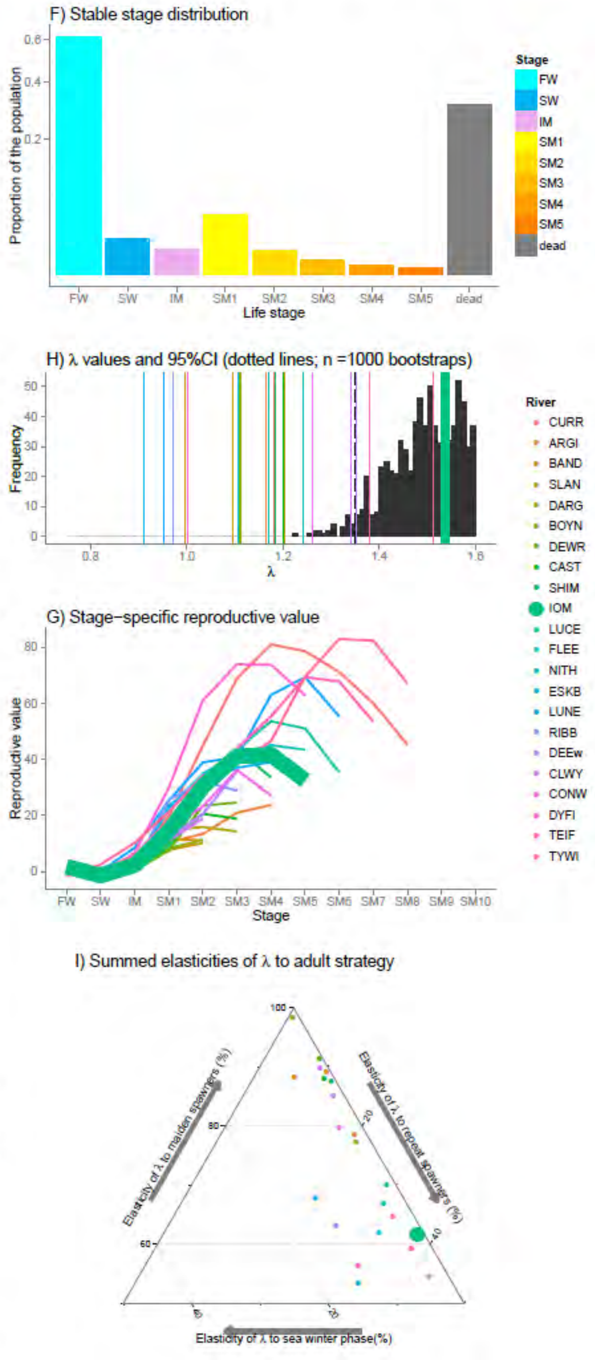
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.066	0	0	0.393	0.033	0.005	0.005	0
SW	0.002	0	0	0	0	0	0	0
IM	0.002	0	0	0	0	0	0	0
SM1	0.432	0.002	0.002	0	0	0	0	0
SM2	0	0	0	0.043	0	0	0	0
SM3	0	0	0	0	0.01	0	0	0
SM4	0	0	0	0	0	0.005	0	0
dead	0	0	0	0	0	0	0	0

River of Isle of Man (combined):

Summary statistics of population dynamics analysis of sea trout from the River IOM (n=59)





B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	0.151	0	0	14.362	25.703	34.476	41.056	49.015	0
SW	0.035	0	0	0	0	0	0	0	0
IM	0.018	0.004	0	0	0	0	0	0	0
SM1	0.096	0.046	0.05	0	0	0	0	0	0
SM2	0	0	0	0.237	0	0	0	0	0
SM3	0	0	0	0	0.571	0	0	0	0
SM4	0	0	0	0	0	0.625	0	0	0
SM5	0	0	0	0	0	0	0.8	0	0
dead	0.7	0.95	0.95	0.763	0.429	0.375	0.2	1	0

C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	1.179	0	0	0	0	0	0	0	0
SW	0.042	1	0	0	0	0	0	0	0
IM	0.021	0.004	1	0	0	0	0	0	0
SM1	0.116	0.047	0.05	1	0	0	0	0	0
SM2	0.027	0.011	0.012	0.237	1	0	0	0	0
SM3	0.016	0.006	0.007	0.136	0.571	1	0	0	0
SM4	0.01	0.004	0.004	0.085	0.357	0.625	1	0	0
SM5	0.008	0.003	0.003	0.068	0.286	0.5	0.8	1	0
dead	1	1	1	1	1	1	1	1	1

D) Sensitivities of λ to perturbations of the transition matrix

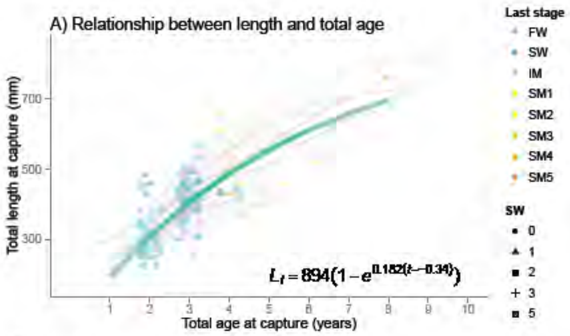
Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	0.406	0.009	0.005	0.026	0.004	0.001	0.001	0	0.208
SW	0.175	0.004	0.002	0.011	0.002	0.001	0	0	0.09
IM	0.188	0.004	0.002	0.012	0.002	0.001	0	0	0.096
SM1	5.781	0.133	0.067	0.386	0.057	0.021	0.009	0.004	2.962
SM2	12.846	0.295	0.148	0.814	0.126	0.047	0.019	0.01	6.583
SM3	16.273	0.374	0.188	1.032	0.159	0.059	0.024	0.013	8.34
SM4	17.601	0.404	0.203	1.116	0.172	0.064	0.026	0.014	9.02
SM5	12.96	0.298	0.149	0.822	0.127	0.047	0.019	0.01	6.642
dead	0	0	0	0	0	0	0	0	0

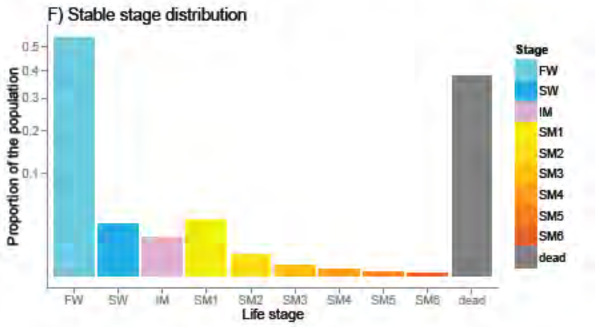
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	0.04	0	0	0.241	0.067	0.033	0.016	0.01	0
SW	0.004	0	0	0	0	0	0	0	0
IM	0.002	0	0	0	0	0	0	0	0
SM1	0.36	0.004	0.002	0	0	0	0	0	0
SM2	0	0	0	0.126	0	0	0	0	0
SM3	0	0	0	0	0.059	0	0	0	0
SM4	0	0	0	0	0	0.026	0	0	0
SM5	0	0	0	0	0	0	0.01	0	0
dead	0	0	0	0	0	0	0	0	0

River Luce:

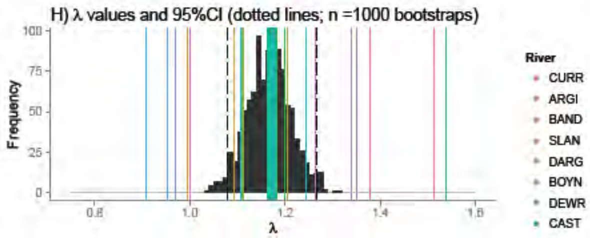
Summary statistics of population dynamics analysis of sea trout from the River LUCE (n=204)





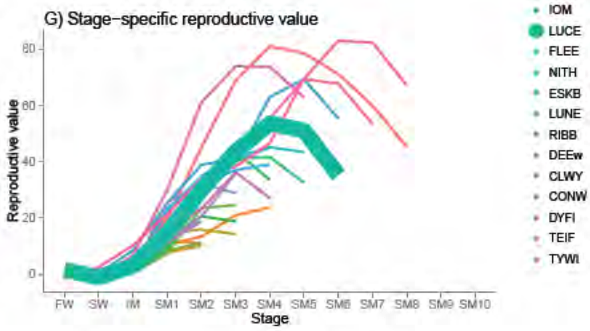
B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	dead
FW	0.153	0	0	13.265	21.648	29.712	36.528	45.525	40.15	0
SW	0.054	0.003	0	0	0	0	0	0	0	0
IM	0.031	0.003	0.001	0	0	0	0	0	0	0
SM1	0.062	0.045	0.049	0	0	0	0	0	0	0
SM2	0	0	0	0.162	0	0	0	0	0	0
SM3	0	0	0	0	0.333	0	0	0	0	0
SM4	0	0	0	0	0	0.364	0	0	0	0
SM5	0	0	0	0	0	0	0.5	0	0	0
SM6	0	0	0	0	0	0	0	0.5	0	0
dead	0.7	0.95	0.95	0.838	0.667	0.636	0.5	0.5	1	0



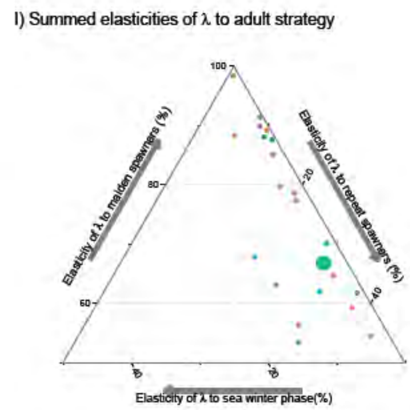
C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	dead
FW	1.18	0	0	0	0	0	0	0	0	0
SW	0.064	1.003	0	0	0	0	0	0	0	0
IM	0.037	0.003	1.001	0	0	0	0	0	0	0
SM1	0.078	0.045	0.049	1	0	0	0	0	0	0
SM2	0.013	0.007	0.008	0.162	1	0	0	0	0	0
SM3	0.004	0.002	0.003	0.054	0.333	1	0	0	0	0
SM4	0.002	0.001	0.001	0.02	0.121	0.364	1	0	0	0
SM5	0.001	0	0	0.01	0.061	0.182	0.5	1	0	0
SM6	0	0	0	0.005	0.03	0.091	0.25	0.5	1	0
dead	1	1	1	1	1	1	1	1	1	1



D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	dead
FW	0.435	0.02	0.012	0.024	0.003	0.001	0	0	0	0.306
SW	0.26	0.012	0.007	0.015	0.002	0.001	0	0	0	0.183
IM	0.283	0.013	0.008	0.016	0.002	0.001	0	0	0	0.199
SM1	6.755	0.313	0.18	0.378	0.052	0.015	0.005	0.002	0.001	4.75
SM2	13.252	0.615	0.353	0.742	0.102	0.029	0.009	0.004	0.002	9.318
SM3	18.324	0.85	0.489	1.026	0.142	0.04	0.013	0.005	0.002	12.885
SM4	23.492	1.09	0.626	1.315	0.182	0.052	0.016	0.007	0.003	16.519
SM5	23.264	1.079	0.62	1.302	0.18	0.051	0.016	0.007	0.003	16.358
SM6	14.905	0.692	0.397	0.834	0.115	0.033	0.01	0.004	0.002	10.481
dead	0	0	0	0	0	0	0	0	0	0

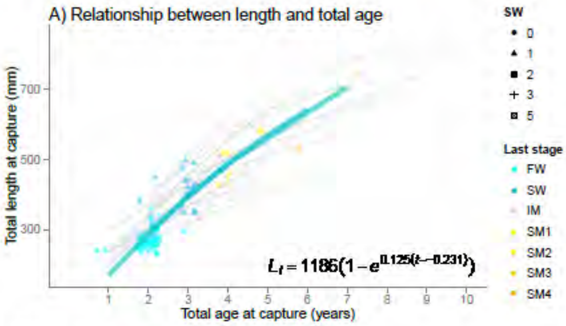


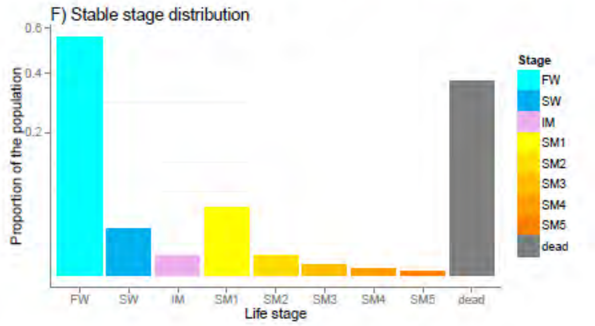
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	dead
FW	0.057	0	0	0.278	0.062	0.024	0.009	0.005	0.002	0
SW	0.012	0	0	0	0	0	0	0	0	0
IM	0.008	0	0	0	0	0	0	0	0	0
SM1	0.359	0.012	0.008	0	0	0	0	0	0	0
SM2	0	0	0	0.102	0	0	0	0	0	0
SM3	0	0	0	0	0.04	0	0	0	0	0
SM4	0	0	0	0	0	0.016	0	0	0	0
SM5	0	0	0	0	0	0	0.007	0	0	0
SM6	0	0	0	0	0	0	0	0.002	0	0
dead	0	0	0	0	0	0	0	0	0	0

River Fleet:

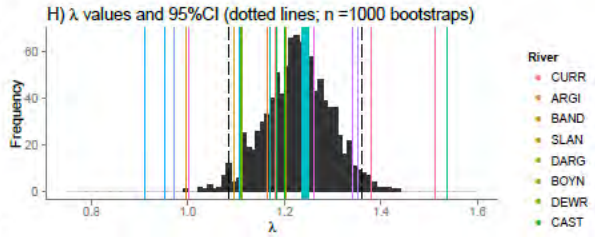
Summary statistics of population dynamics analysis of sea trout from the River FLEE (n=95)





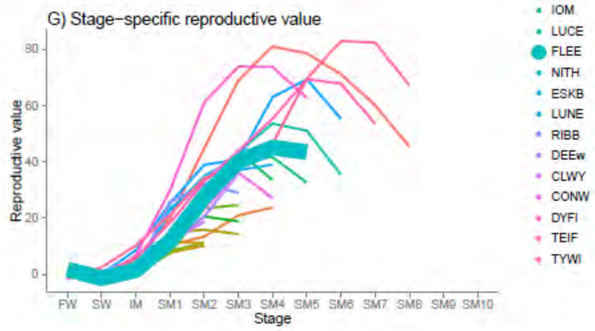
B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	0.147	0	0	10.247	21.405	26.108	35.39	53.59	0
SW	0.047	0.002	0	0	0	0	0	0	0
IM	0.008	0.005	0	0	0	0	0	0	0
SM1	0.098	0.043	0.05	0	0	0	0	0	0
SM2	0	0	0	0.116	0	0	0	0	0
SM3	0	0	0	0	0.364	0	0	0	0
SM4	0	0	0	0	0	0.5	0	0	0
SM5	0	0	0	0	0	0	0.5	0	0
dead	0.7	0.95	0.95	0.884	0.636	0.5	0.5	1	0



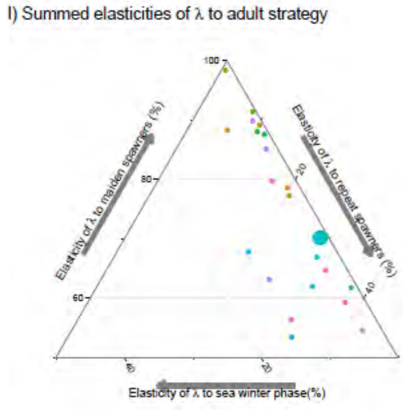
C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	1.172	0	0	0	0	0	0	0	0
SW	0.055	1.002	0	0	0	0	0	0	0
IM	0.01	0.005	1	0	0	0	0	0	0
SM1	0.118	0.044	0.05	1	0	0	0	0	0
SM2	0.014	0.005	0.006	0.116	1	0	0	0	0
SM3	0.005	0.002	0.002	0.042	0.364	1	0	0	0
SM4	0.002	0.001	0.001	0.021	0.182	0.5	1	0	0
SM5	0.001	0	0.001	0.011	0.091	0.25	0.5	1	0
dead	1	1	1	1	1	1	1	1	1



D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	0.443	0.017	0.003	0.036	0.003	0.001	0	0	0.292
SW	0.17	0.006	0.001	0.014	0.001	0	0	0	0.112
IM	0.195	0.007	0.001	0.016	0.001	0	0	0	0.128
SM1	4.837	0.182	0.032	0.391	0.036	0.011	0.004	0.002	3.192
SM2	12.735	0.48	0.085	1.028	0.096	0.028	0.011	0.005	8.404
SM3	17.463	0.658	0.116	1.41	0.131	0.038	0.015	0.006	11.523
SM4	20.289	0.765	0.135	1.638	0.153	0.045	0.018	0.007	13.388
SM5	19.092	0.719	0.127	1.541	0.144	0.042	0.017	0.007	12.599
dead	0	0	0	0	0	0	0	0	0

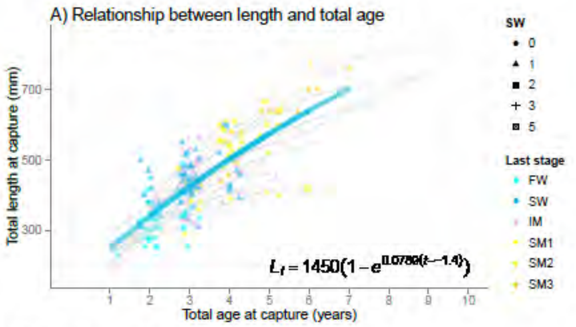


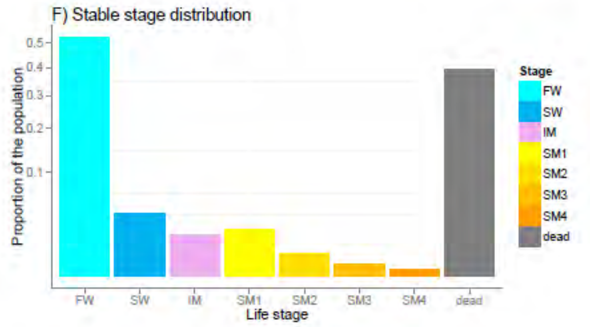
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	0.052	0	0	0.295	0.057	0.02	0.011	0.007	0
SW	0.006	0	0	0	0	0	0	0	0
IM	0.001	0	0	0	0	0	0	0	0
SM1	0.383	0.006	0.001	0	0	0	0	0	0
SM2	0	0	0	0.098	0	0	0	0	0
SM3	0	0	0	0	0.038	0	0	0	0
SM4	0	0	0	0	0	0.018	0	0	0
SM5	0	0	0	0	0	0	0.007	0	0
dead	0	0	0	0	0	0	0	0	0

River Nith:

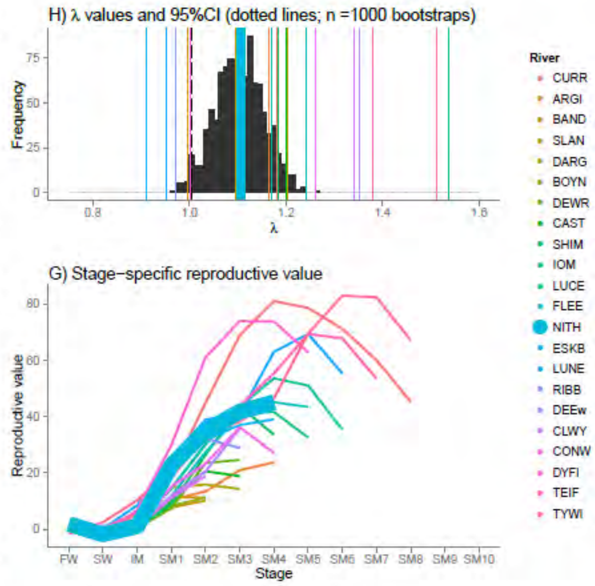
Summary statistics of population dynamics analysis of sea trout from the River NITH (n=204)





B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.152	0	0	16.236	24.895	32.207	49.942	0
SW	0.077	0.002	0	0	0	0	0	0
IM	0.033	0.005	0.002	0	0	0	0	0
SM1	0.038	0.043	0.048	0	0	0	0	0
SM2	0	0	0	0.25	0	0	0	0
SM3	0	0	0	0	0.333	0	0	0
SM4	0	0	0	0	0	0.294	0	0
dead	0.7	0.95	0.95	0.75	0.667	0.706	1	0

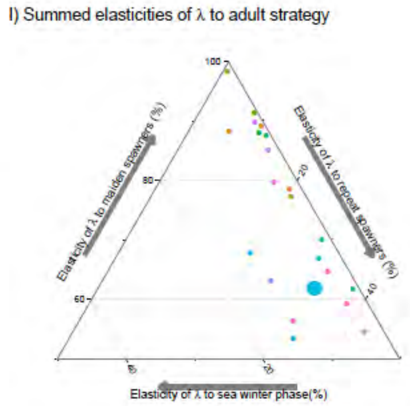


C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	1.179	0	0	0	0	0	0	0
SW	0.091	1.002	0	0	0	0	0	0
IM	0.04	0.005	1.002	0	0	0	0	0
SM1	0.05	0.044	0.048	1	0	0	0	0
SM2	0.013	0.011	0.012	0.25	1	0	0	0
SM3	0.004	0.004	0.004	0.083	0.333	1	0	0
SM4	0.001	0.001	0.001	0.025	0.098	0.294	1	0
dead	1	1	1	1	1	1	1	1

D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.418	0.029	0.013	0.016	0.004	0.001	0	0.314
SW	0.371	0.026	0.011	0.014	0.003	0.001	0	0.279
IM	0.412	0.029	0.013	0.016	0.004	0.001	0	0.31
SM1	9.426	0.658	0.288	0.36	0.081	0.025	0.007	7.094
SM2	14.577	1.017	0.445	0.557	0.126	0.038	0.01	10.97
SM3	17.176	1.198	0.525	0.656	0.148	0.045	0.012	12.926
SM4	18.857	1.316	0.576	0.721	0.163	0.049	0.013	14.192
dead	0	0	0	0	0	0	0	0

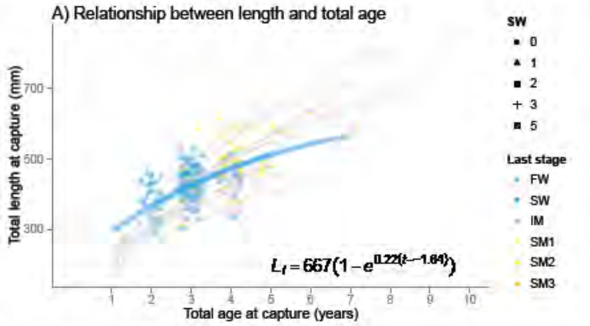


E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.057	0	0	0.234	0.081	0.032	0.013	0
SW	0.026	0	0	0	0	0	0	0
IM	0.012	0	0	0	0	0	0	0
SM1	0.322	0.026	0.013	0	0	0	0	0
SM2	0	0	0	0.126	0	0	0	0
SM3	0	0	0	0	0.045	0	0	0
SM4	0	0	0	0	0	0.013	0	0
dead	0	0	0	0	0	0	0	0

River Border Esk:

Summary statistics of population dynamics analysis of sea trout from the River ESKB (n=378)



B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.15	0	0	16.629	22.423	25.727	35.455	0
SW	0.106	0.001	0	0	0	0	0	0
IM	0.018	0.004	0.004	0	0	0	0	0
SM1	0.026	0.045	0.046	0	0	0	0	0
SM2	0	0	0	0.148	0	0	0	0
SM3	0	0	0	0	0.179	0	0	0
SM4	0	0	0	0	0	0.2	0	0
dead	0.7	0.95	0.95	0.852	0.821	0.8	1	0

C) Fundamental matrix

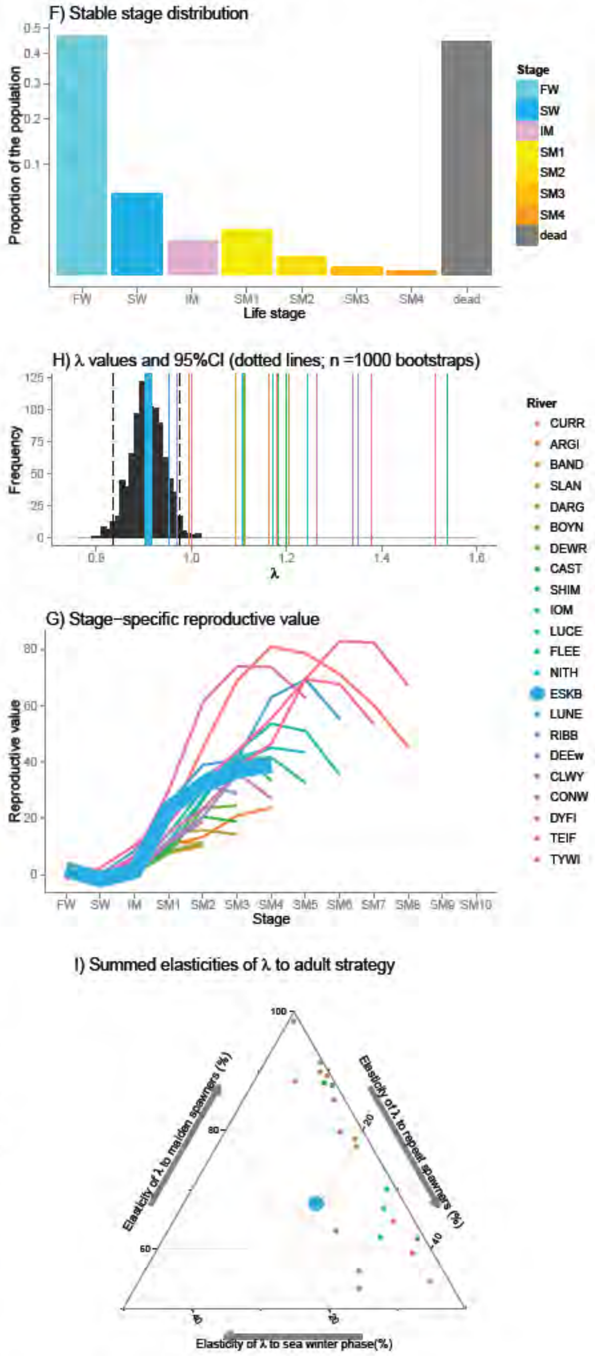
Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	1.178	0	0	0	0	0	0	0
SW	0.124	1.001	0	0	0	0	0	0
IM	0.022	0.004	1.004	0	0	0	0	0
SM1	0.037	0.045	0.046	1	0	0	0	0
SM2	0.006	0.007	0.007	0.148	1	0	0	0
SM3	0.001	0.001	0.001	0.026	0.179	1	0	0
SM4	0	0	0	0.005	0.036	0.2	1	0
dead	1	1	1	1	1	1	1	1

D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.448	0.052	0.009	0.016	0.003	0.001	0	0.427
SW	0.521	0.061	0.011	0.019	0.003	0.001	0	0.496
IM	0.534	0.062	0.011	0.019	0.003	0.001	0	0.508
SM1	10.525	1.224	0.217	0.374	0.061	0.012	0.003	10.027
SM2	14.297	1.662	0.295	0.508	0.083	0.016	0.004	13.619
SM3	16.524	1.921	0.341	0.588	0.096	0.019	0.004	15.741
SM4	17.475	2.032	0.361	0.621	0.101	0.02	0.004	16.647
dead	0	0	0	0	0	0	0	0

E) Elasticities of λ to perturbations of the transition matrix

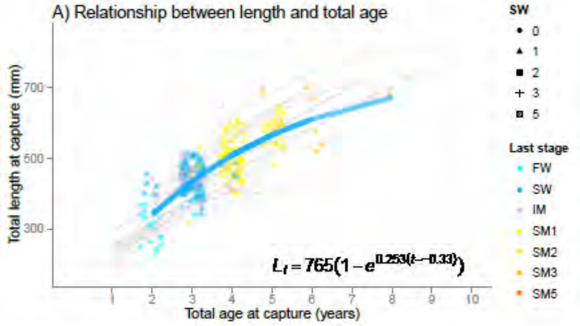
Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.074	0	0	0.291	0.084	0.014	0.004	0
SW	0.06	0	0	0	0	0	0	0
IM	0.011	0	0	0	0	0	0	0
SM1	0.303	0.06	0.011	0	0	0	0	0
SM2	0	0	0	0.083	0	0	0	0
SM3	0	0	0	0	0.019	0	0	0
SM4	0	0	0	0	0	0.004	0	0
dead	0	0	0	0	0	0	0	0



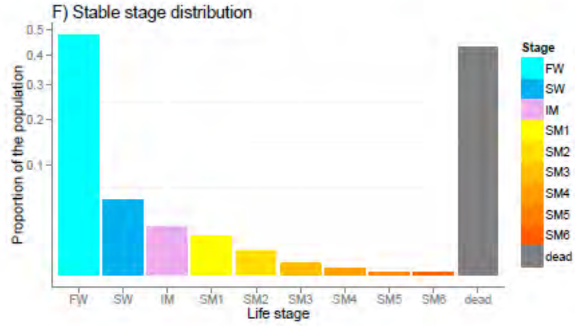
River Lune:

Summary statistics of population dynamics analysis of sea trout from the River LUNE (n=318)

A) Relationship between length and total age



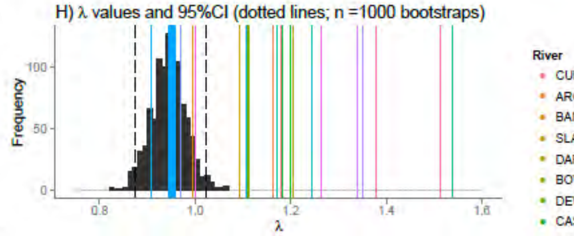
F) Stable stage distribution



B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	dead
FW	0.15	0	0	17.413	24.077	28.983	34.371	41.19	44.86	0
SW	0.094	0.002	0	0	0	0	0	0	0	0
IM	0.038	0.002	0.002	0	0	0	0	0	0	0
SM1	0.018	0.046	0.048	0	0	0	0	0	0	0
SM2	0	0	0	0.371	0	0	0	0	0	0
SM3	0	0	0	0	0.22	0	0	0	0	0
SM4	0	0	0	0	0	0.269	0	0	0	0
SM5	0	0	0	0	0	0	0.143	0	0	0
SM6	0	0	0	0	0	0	0	1	0	0
dead	0.7	0.95	0.95	0.629	0.78	0.731	0.857	0	1	0

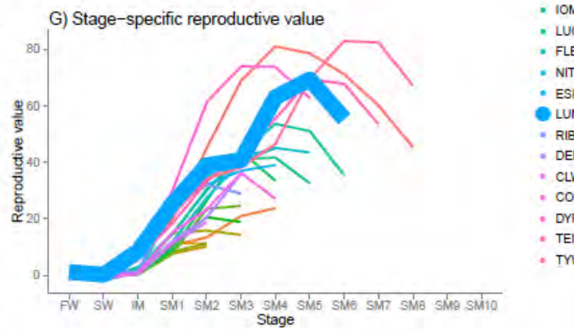
H) λ values and 95%CI (dotted lines; n =1000 bootstraps)



C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	dead
FW	1.176	0	0	0	0	0	0	0	0	0
SW	0.111	1.002	0	0	0	0	0	0	0	0
IM	0.045	0.002	1.002	0	0	0	0	0	0	0
SM1	0.029	0.046	0.048	1	0	0	0	0	0	0
SM2	0.011	0.017	0.018	0.371	1	0	0	0	0	0
SM3	0.002	0.004	0.004	0.082	0.22	1	0	0	0	0
SM4	0.001	0.001	0.001	0.022	0.059	0.269	1	0	0	0
SM5	0	0	0	0.003	0.008	0.038	0.143	1	0	0
SM6	0	0	0	0.003	0.008	0.038	0.143	1	1	0
dead	1	1	1	1	1	1	1	1	1	1

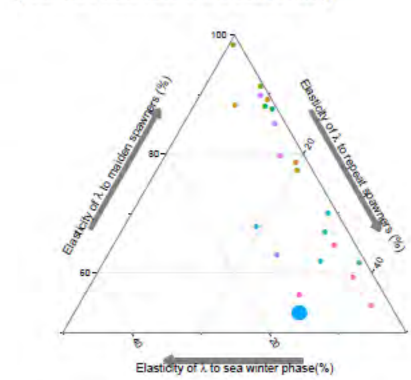
G) Stage-specific reproductive value



D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	dead
FW	0.388	0.038	0.016	0.01	0.004	0.001	0	0	0	0.35
SW	0.605	0.06	0.024	0.016	0.006	0.001	0	0	0	0.546
IM	0.636	0.063	0.025	0.017	0.006	0.002	0	0	0	0.574
SM1	12.481	1.236	0.499	0.327	0.127	0.029	0.008	0.001	0.001	11.266
SM2	13.815	1.368	0.553	0.362	0.141	0.033	0.009	0.001	0.001	12.469
SM3	17.298	1.713	0.692	0.453	0.177	0.041	0.012	0.002	0.002	15.614
SM4	19.406	1.921	0.777	0.508	0.198	0.046	0.013	0.002	0.002	17.516
SM5	35.987	3.563	1.44	0.942	0.367	0.085	0.024	0.004	0.004	32.483
SM6	18.276	1.809	0.731	0.478	0.187	0.043	0.012	0.002	0.002	16.496
dead	0	0	0	0	0	0	0	0	0	0

I) Summed elasticities of λ to adult strategy

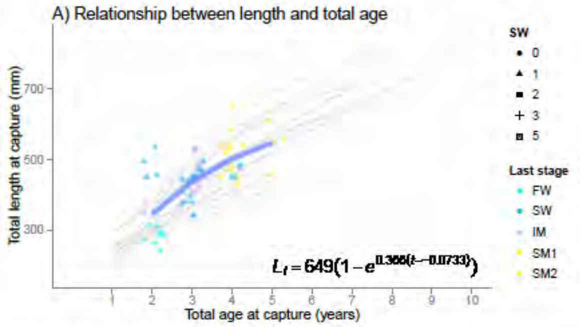


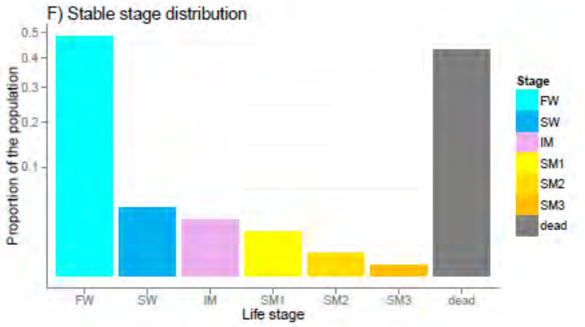
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	dead
FW	0.061	0	0	0.186	0.1	0.028	0.009	0.002	0.002	0
SW	0.06	0	0	0	0	0	0	0	0	0
IM	0.025	0	0	0	0	0	0	0	0	0
SM1	0.242	0.06	0.025	0	0	0	0	0	0	0
SM2	0	0	0	0.141	0	0	0	0	0	0
SM3	0	0	0	0	0.041	0	0	0	0	0
SM4	0	0	0	0	0	0.013	0	0	0	0
SM5	0	0	0	0	0	0	0.004	0	0	0
SM6	0	0	0	0	0	0	0	0.002	0	0
dead	0	0	0	0	0	0	0	0	0	0

River Ribble:

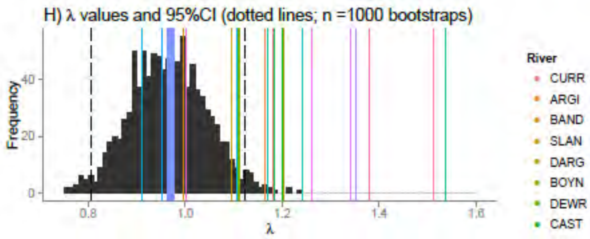
Summary statistics of population dynamics analysis of sea trout from the River RIBB (n=72)





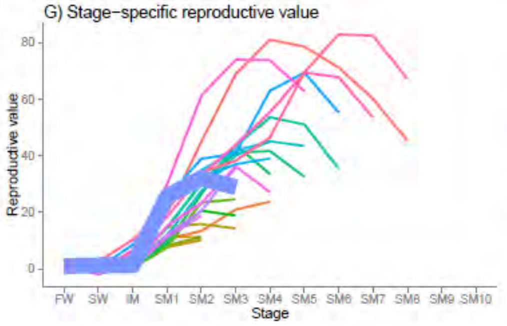
B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.143	0	0	16.79	24.702	27.942	0
SW	0.078	0.004	0	0	0	0	0
IM	0.052	0.001	0.002	0	0	0	0
SM1	0.026	0.045	0.048	0	0	0	0
SM2	0	0	0	0.25	0	0	0
SM3	0	0	0	0	0.222	0	0
dead	0.7	0.95	0.95	0.75	0.778	1	0



C) Fundamental matrix

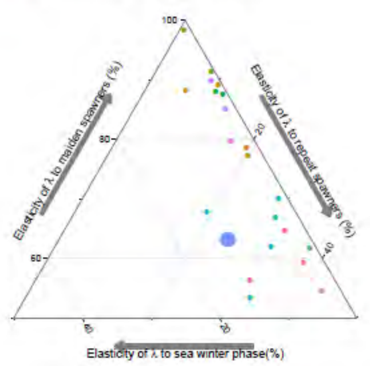
Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	1.166	0	0	0	0	0	0
SW	0.092	1.004	0	0	0	0	0
IM	0.061	0.001	1.002	0	0	0	0
SM1	0.038	0.045	0.048	1	0	0	0
SM2	0.009	0.011	0.012	0.25	1	0	0
SM3	0.002	0.003	0.003	0.056	0.222	1	0
dead	1	1	1	1	1	1	1



D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.426	0.034	0.023	0.014	0.004	0.001	0.378
SW	0.506	0.041	0.027	0.017	0.004	0.001	0.45
IM	0.541	0.044	0.029	0.018	0.005	0.001	0.48
SM1	10.887	0.882	0.588	0.363	0.093	0.021	9.674
SM2	13.651	1.106	0.737	0.455	0.117	0.027	12.129
SM3	12.263	0.993	0.662	0.409	0.105	0.024	10.897
dead	0	0	0	0	0	0	0

I) Summed elasticities of λ to adult strategy



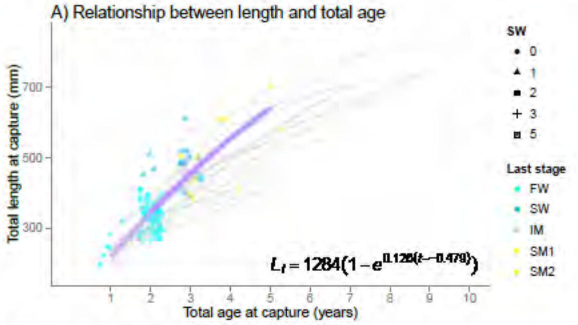
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.063	0	0	0.246	0.093	0.024	0
SW	0.041	0	0	0	0	0	0
IM	0.029	0	0	0	0	0	0
SM1	0.293	0.041	0.029	0	0	0	0
SM2	0	0	0	0.117	0	0	0
SM3	0	0	0	0	0.024	0	0
dead	0	0	0	0	0	0	0

River Dee (Wales):

Summary statistics of population dynamics analysis of sea trout from the River DEEw (n=117)

A) Relationship between length and total age



B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.145	0	0	13.786	24.941	48.4	0
SW	0.029	0	0	0	0	0	0
IM	0.027	0.002	0	0	0	0	0
SM1	0.1	0.048	0.05	0	0	0	0
SM2	0	0	0	0.111	0	0	0
SM3	0	0	0	0	0.077	0	0
dead	0.7	0.95	0.95	0.889	0.923	1	0

C) Fundamental matrix

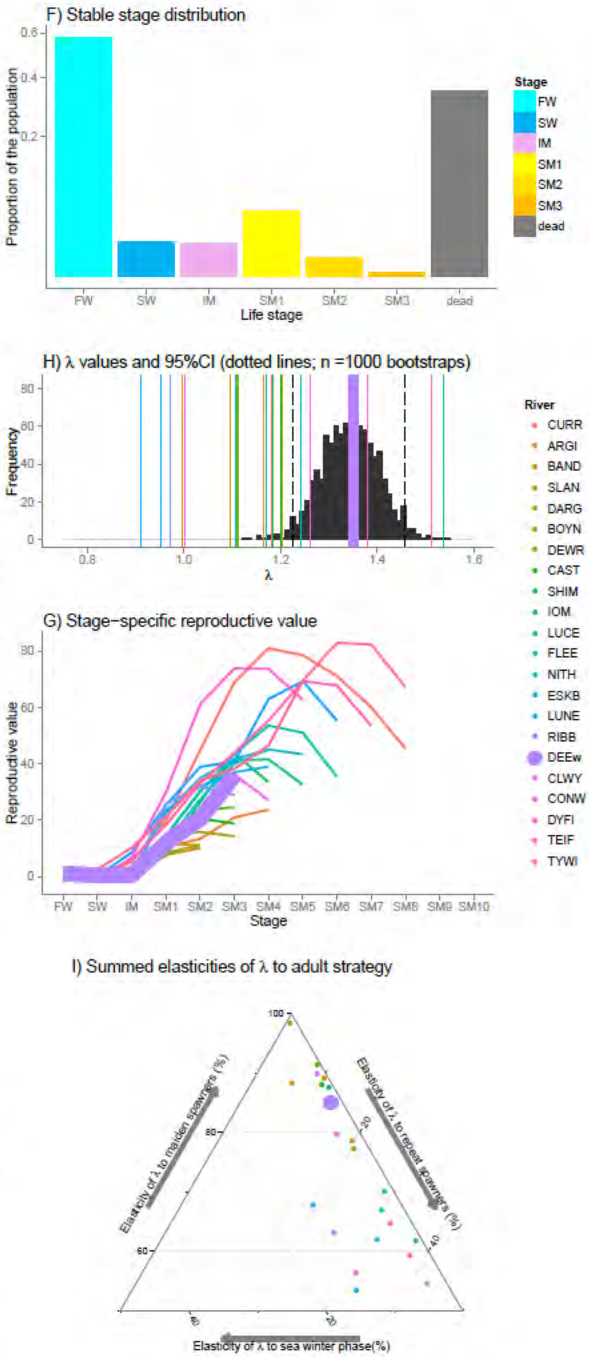
Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	1.169	0	0	0	0	0	0
SW	0.034	1	0	0	0	0	0
IM	0.031	0.002	1	0	0	0	0
SM1	0.12	0.048	0.05	1	0	0	0
SM2	0.013	0.005	0.006	0.111	1	0	0
SM3	0.001	0	0	0.009	0.077	1	0
dead	1	1	1	1	1	1	1

D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.488	0.011	0.01	0.037	0.003	0	0.293
SW	0.205	0.004	0.004	0.015	0.001	0	0.123
IM	0.214	0.005	0.004	0.016	0.001	0	0.129
SM1	5.797	0.125	0.114	0.436	0.036	0.002	3.483
SM2	9.995	0.216	0.197	0.751	0.062	0.004	6.005
SM3	17.468	0.377	0.344	1.313	0.108	0.006	10.494
dead	0	0	0	0	0	0	0

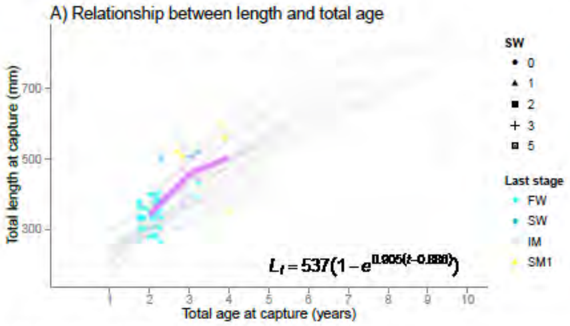
E) Elasticities of λ to perturbations of the transition matrix

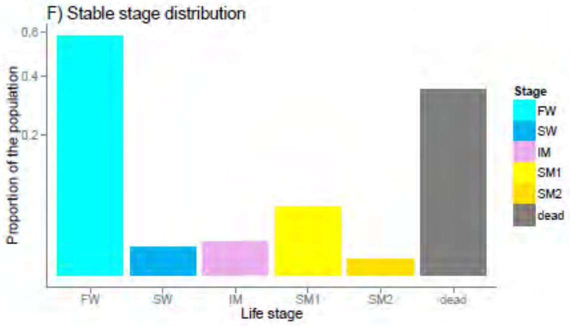
Stage	FW	SW	IM	SM1	SM2	SM3	dead
FW	0.052	0	0	0.374	0.056	0.006	0
SW	0.004	0	0	0	0	0	0
IM	0.004	0	0	0	0	0	0
SM1	0.427	0.004	0.004	0	0	0	0
SM2	0	0	0	0.062	0	0	0
SM3	0	0	0	0	0.006	0	0
dead	0	0	0	0	0	0	0



River Clwyd:

Summary statistics of population dynamics analysis of sea trout from the River CLWY (n=64)





B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	0.15	0	0	13.438	25.114	0
SW	0.019	0	0	0	0	0
IM	0.026	0.006	0	0	0	0
SM1	0.105	0.044	0.05	0	0	0
SM2	0	0	0	0.078	0	0
dead	0.7	0.95	0.95	0.922	1	0

C) Fundamental matrix

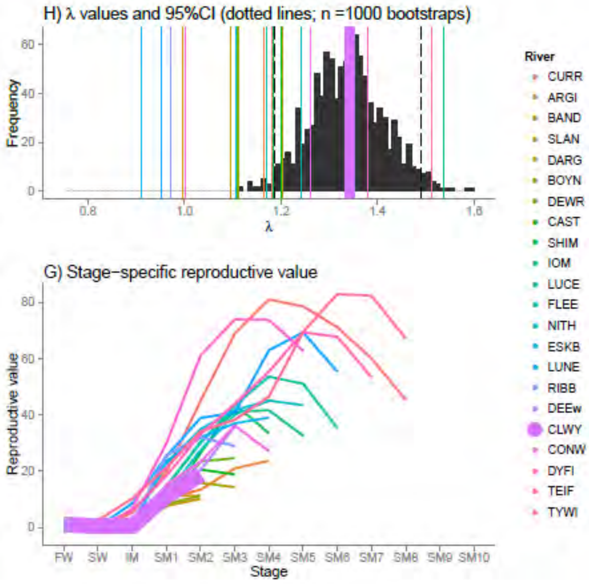
Stage	FW	SW	IM	SM1	SM2	dead
FW	1.176	0	0	0	0	0
SW	0.022	1	0	0	0	0
IM	0.03	0.006	1	0	0	0
SM1	0.127	0.044	0.05	1	0	0
SM2	0.01	0.003	0.004	0.078	1	0
dead	1	1	1	1	1	1

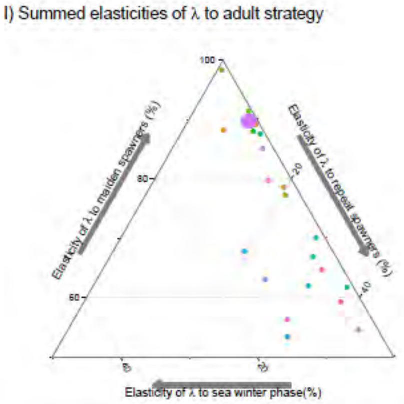
D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	dead
FW	0.503	0.007	0.01	0.04	0.002	0.304
SW	0.184	0.003	0.004	0.015	0.001	0.111
IM	0.209	0.003	0.004	0.017	0.001	0.126
SM1	5.592	0.078	0.108	0.447	0.026	3.379
SM2	9.424	0.132	0.182	0.753	0.044	5.695
dead	0	0	0	0	0	0

E) Elasticities of λ to perturbations of the transition matrix

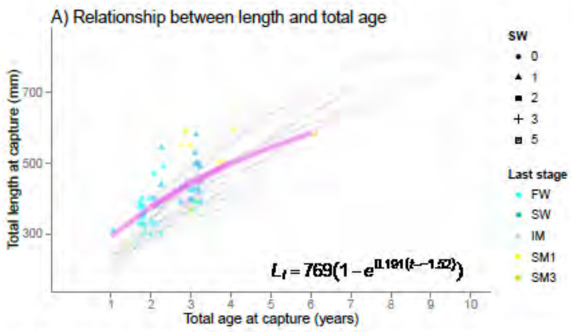
Stage	FW	SW	IM	SM1	SM2	dead
FW	0.056	0	0	0.403	0.044	0
SW	0.003	0	0	0	0	0
IM	0.004	0	0	0	0	0
SM1	0.44	0.003	0.004	0	0	0
SM2	0	0	0	0.044	0	0
dead	0	0	0	0	0	0

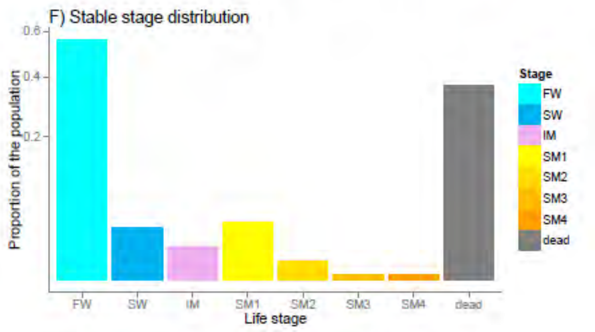




River Conwy:

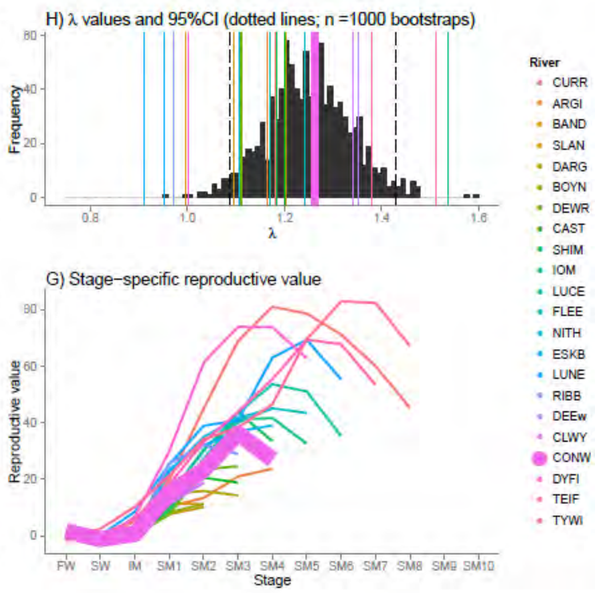
Summary statistics of population dynamics analysis of sea trout from the River CONW (n=64)





B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.144	0	0	15.809	24.626	27.84	32.11	0
SW	0.061	0	0	0	0	0	0	0
IM	0.024	0.002	0	0	0	0	0	0
SM1	0.071	0.048	0.05	0	0	0	0	0
SM2	0	0	0	0.141	0	0	0	0
SM3	0	0	0	0	0.111	0	0	0
SM4	0	0	0	0	0	1	0	0
dead	0.7	0.95	0.95	0.859	0.889	0	1	0

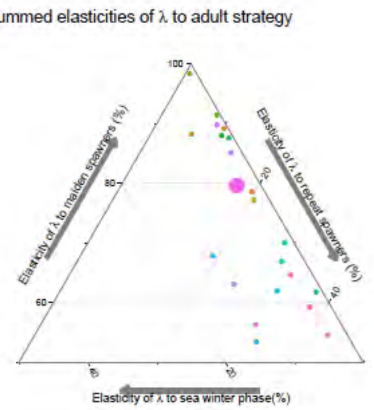


C) Fundamental matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	1.168	0	0	0	0	0	0	0
SW	0.071	1	0	0	0	0	0	0
IM	0.029	0.002	1	0	0	0	0	0
SM1	0.087	0.048	0.05	1	0	0	0	0
SM2	0.012	0.007	0.007	0.141	1	0	0	0
SM3	0.001	0.001	0.001	0.016	0.111	1	0	0
SM4	0.001	0.001	0.001	0.016	0.111	1	1	0
dead	1	1	1	1	1	1	1	1

D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.473	0.023	0.009	0.028	0.003	0	0	0.308
SW	0.272	0.013	0.005	0.016	0.002	0	0	0.177
IM	0.283	0.014	0.005	0.017	0.002	0	0	0.184
SM1	7.151	0.345	0.139	0.419	0.047	0.004	0.003	4.651
SM2	10.991	0.531	0.213	0.644	0.072	0.006	0.005	7.148
SM3	19.974	0.965	0.387	1.171	0.13	0.011	0.009	12.99
SM4	12.038	0.581	0.234	0.706	0.079	0.007	0.005	7.829
dead	0	0	0	0	0	0	0	0

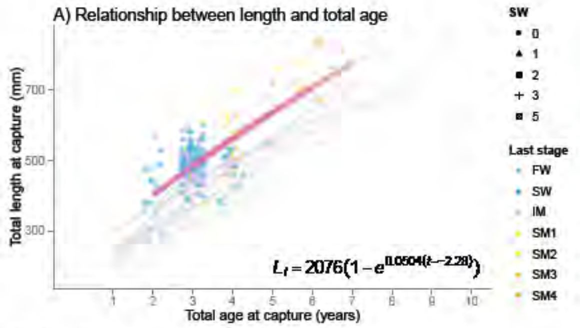


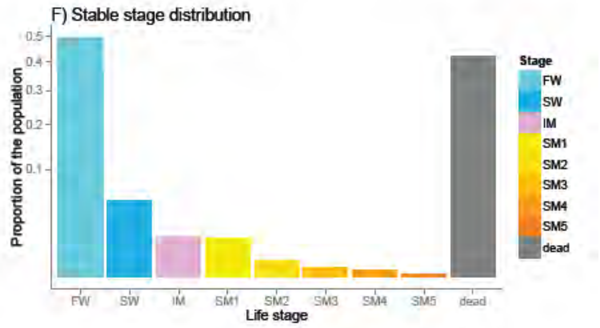
E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	dead
FW	0.054	0	0	0.348	0.06	0.006	0.005	0
SW	0.013	0	0	0	0	0	0	0
IM	0.005	0	0	0	0	0	0	0
SM1	0.401	0.013	0.005	0	0	0	0	0
SM2	0	0	0	0.072	0	0	0	0
SM3	0	0	0	0	0.011	0	0	0
SM4	0	0	0	0	0	0.005	0	0
dead	0	0	0	0	0	0	0	0

River Dyfi:

Summary statistics of population dynamics analysis of sea trout from the River DYFI (n=236)





B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	0.149	0	0	22.106	30.21	44.901	57.769	65.31	0
SW	0.102	0.004	0	0	0	0	0	0	0
IM	0.028	0.003	0.001	0	0	0	0	0	0
SM1	0.02	0.042	0.049	0	0	0	0	0	0
SM2	0	0	0	0.178	0	0	0	0	0
SM3	0	0	0	0	0.357	0	0	0	0
SM4	0	0	0	0	0	0.533	0	0	0
SM5	0	0	0	0	0	0	0.125	0	0
dead	0.7	0.95	0.95	0.822	0.643	0.467	0.875	1	0

C) Fundamental matrix

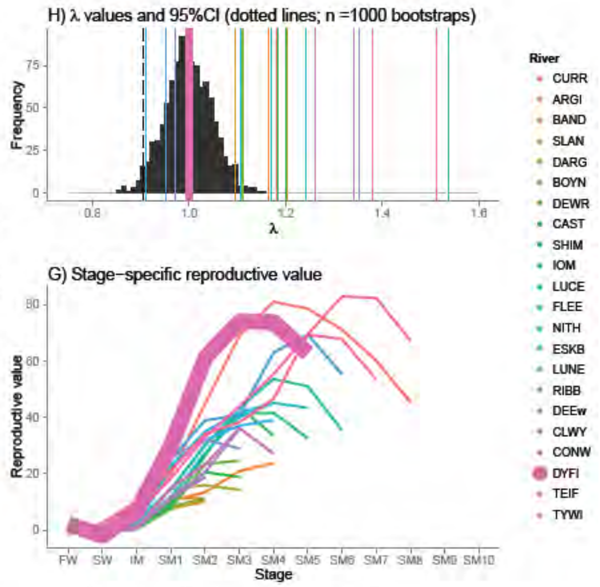
Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	[illegible]	0	0	0	0	0	0	0	0
SW	0.121	1.004	0	0	0	0	0	0	0
IM	0.033	0.003	1.001	0	0	0	0	0	0
SM1	0.031	0.043	0.049	1	0	0	0	0	0
SM2	0.005	0.008	0.009	0.178	1	0	0	0	0
SM3	0.002	0.003	0.003	0.064	0.357	1	0	0	0
SM4	0.001	0.001	0.002	0.034	0.19	0.533	1	0	0
SM5	0	0	0	0.004	0.024	0.067	0.125	1	0
dead	1	1	1	1	1	1	1	1	1

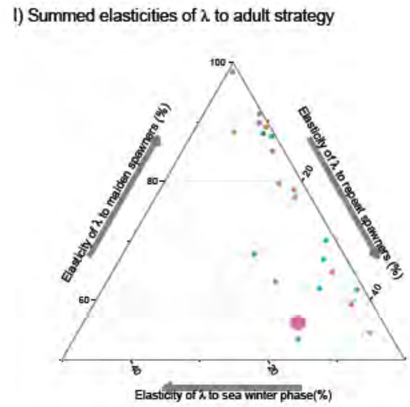
D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	0.398	0.041	0.011	0.01	0.002	0.001	0	0	0.339
SW	0.553	0.057	0.016	0.014	0.003	0.001	0	0	0.47
IM	0.637	0.065	0.018	0.017	0.003	0.001	0.001	0	0.542
SM1	12.966	1.329	0.369	0.339	0.08	0.022	0.011	0.001	11.022
SM2	23.407	2.399	0.666	0.612	0.109	0.039	0.021	0.003	19.897
SM3	31.874	3.267	0.907	0.833	0.148	0.053	0.028	0.004	27.094
SM4	26.253	2.691	0.747	0.686	0.122	0.044	0.023	0.003	22.317
SM5	26.007	2.666	0.74	0.68	0.121	0.043	0.023	0.003	22.108
dead	0	0	0	0	0	0	0	0	0

E) Elasticities of λ to perturbations of the transition matrix

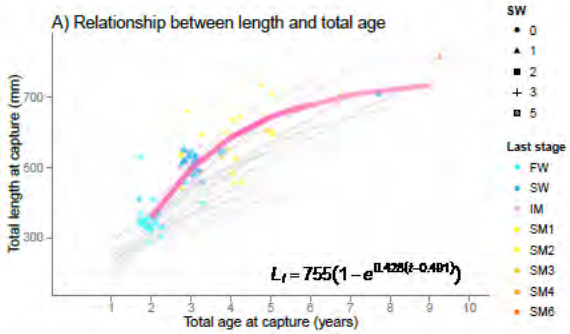
Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	dead
FW	0.059	0	0	0.23	0.056	0.03	0.02	0.003	0
SW	0.056	0	0	0	0	0	0	0	0
IM	0.018	0	0	0	0	0	0	0	0
SM1	0.265	0.058	0.018	0	0	0	0	0	0
SM2	0	0	0	0.109	0	0	0	0	0
SM3	0	0	0	0	0.053	0	0	0	0
SM4	0	0	0	0	0	0.023	0	0	0
SM5	0	0	0	0	0	0	0.003	0	0
dead	0	0	0	0	0	0	0	0	0

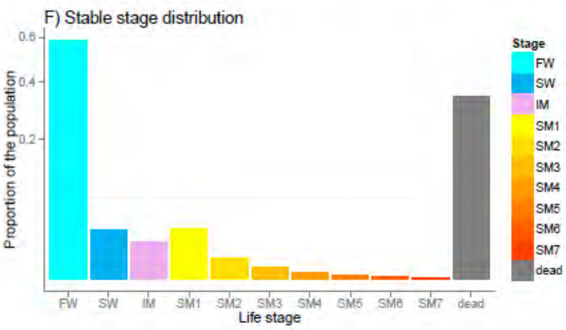




River Teifi:

Summary statistics of population dynamics analysis of sea trout from the River TEIF (n=102)





B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	dead
FW	0.149	0	0	19.277	29.001	37.293	44.763	52.1	63.68	65.65	0
SW	0.059	0.007	0	0	0	0	0	0	0	0	0
IM	0.034	0	0.002	0	0	0	0	0	0	0	0
SM1	0.058	0.043	0.048	0	0	0	0	0	0	0	0
SM2	0	0	0	0.255	0	0	0	0	0	0	0
SM3	0	0	0	0	0.423	0	0	0	0	0	0
SM4	0	0	0	0	0	0.364	0	0	0	0	0
SM5	0	0	0	0	0	0	0.5	0	0	0	0
SM6	0	0	0	0	0	0	0	0.5	0	0	0
SM7	0	0	0	0	0	0	0	0	1	0	0
dead	0.7	0.95	0.95	0.745	0.577	0.636	0.5	0.5	0	1	0

C) Fundamental matrix

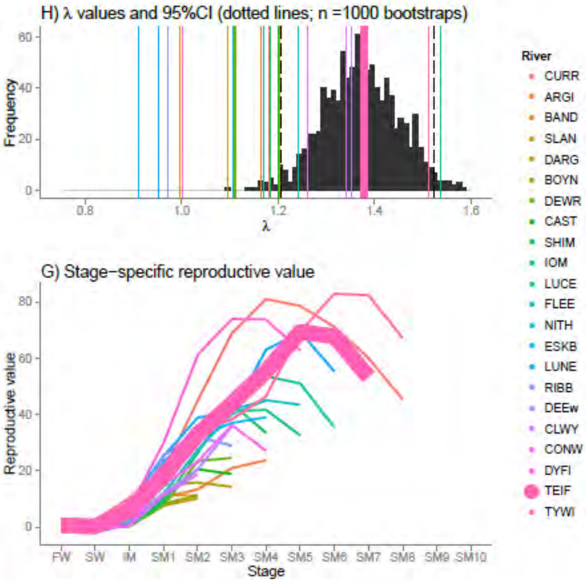
Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	dead
FW	1.175	0	0	0	0	0	0	0	0	0	0
SW	0.07	1.007	0	0	0	0	0	0	0	0	0
IM	0.04	0	1.002	0	0	0	0	0	0	0	0
SM1	0.073	0.044	0.048	1	0	0	0	0	0	0	0
SM2	0.019	0.011	0.012	0.255	1	0	0	0	0	0	0
SM3	0.008	0.005	0.005	0.108	0.423	1	0	0	0	0	0
SM4	0.003	0.002	0.002	0.039	0.154	0.364	1	0	0	0	0
SM5	0.001	0.001	0.001	0.02	0.077	0.182	0.5	1	0	0	0
SM6	0.001	0	0	0.01	0.038	0.091	0.25	0.5	1	0	0
SM7	0.001	0	0	0.01	0.038	0.091	0.25	0.5	1	1	0
dead	1	1	1	1	1	1	1	1	1	1	1

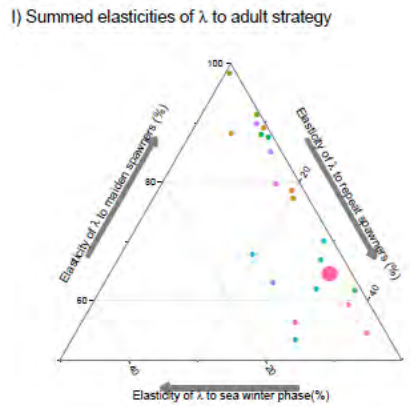
D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	dead
FW	0.42	0.018	0.01	0.018	0.003	0.001	0	0	0	0	0.245
SW	0.27	0.012	0.007	0.012	0.002	0.001	0	0	0	0	0.157
IM	0.296	0.013	0.007	0.013	0.002	0.001	0	0	0	0	0.173
SM1	8.506	0.366	0.21	0.374	0.069	0.021	0.006	0.002	0.001	0.001	4.96
SM2	14.249	0.614	0.352	0.627	0.116	0.036	0.009	0.003	0.001	0.001	8.31
SM3	17.649	0.76	0.436	0.777	0.144	0.044	0.012	0.004	0.002	0.001	10.292
SM4	23.848	1.027	0.589	1.05	0.194	0.06	0.016	0.006	0.002	0.001	13.907
SM5	28.164	1.213	0.695	1.24	0.229	0.07	0.019	0.007	0.002	0.002	16.424
SM6	33.9	1.46	0.837	1.492	0.276	0.085	0.022	0.008	0.003	0.002	19.769
SM7	19.996	0.861	0.494	0.88	0.163	0.05	0.013	0.005	0.002	0.001	11.661
dead	0	0	0	0	0	0	0	0	0	0	0

E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	dead
FW	0.045	0	0	0.258	0.072	0.028	0.009	0.004	0.002	0.001	0
SW	0.012	0	0	0	0	0	0	0	0	0	0
IM	0.007	0	0	0	0	0	0	0	0	0	0
SM1	0.356	0.012	0.007	0	0	0	0	0	0	0	0
SM2	0	0	0	0.116	0	0	0	0	0	0	0
SM3	0	0	0	0	0.044	0	0	0	0	0	0
SM4	0	0	0	0	0	0.016	0	0	0	0	0
SM5	0	0	0	0	0	0	0.007	0	0	0	0
SM6	0	0	0	0	0	0	0	0.003	0	0	0
SM7	0	0	0	0	0	0	0	0	0.001	0	0
dead	0	0	0	0	0	0	0	0	0	0	0

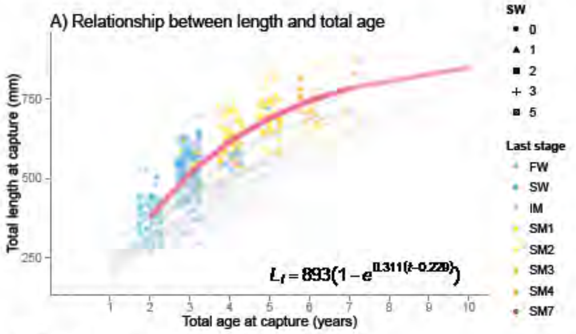




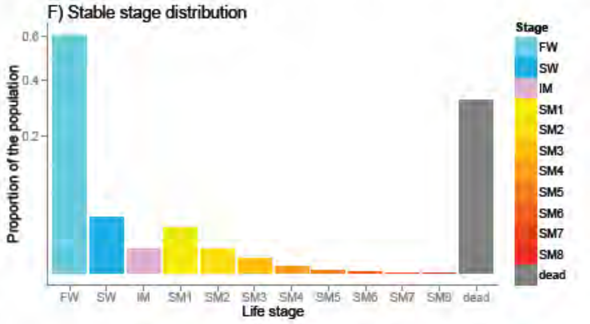
River Tywi:

Summary statistics of population dynamics analysis of sea trout from the River TYWI (n=356)

A) Relationship between length and total age



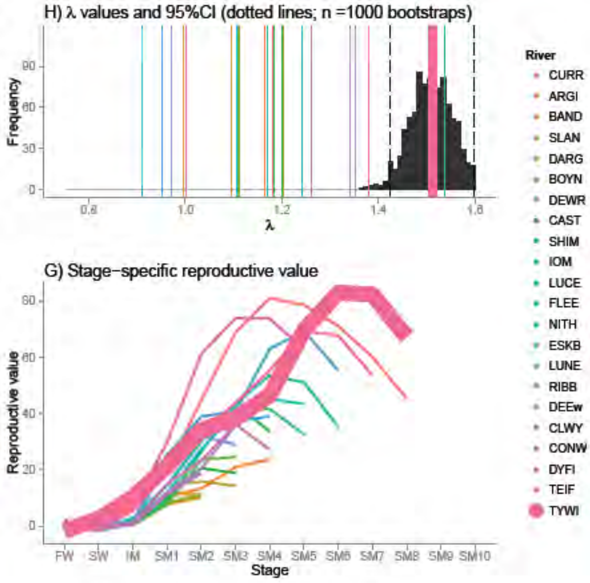
F) Stable stage distribution



B) Transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	dead
FW	0.151	0	0	21.945	34.091	44.488	53.118	62.199	78.05	82.4	85.67	0
SW	0.082	0.003	0	0	0	0	0	0	0	0	0	0
IM	0.015	0.003	0	0	0	0	0	0	0	0	0	0
SM1	0.052	0.044	0.05	0	0	0	0	0	0	0	0	0
SM2	0	0	0	0.413	0	0	0	0	0	0	0	0
SM3	0	0	0	0	0.578	0	0	0	0	0	0	0
SM4	0	0	0	0	0	0.353	0	0	0	0	0	0
SM5	0	0	0	0	0	0	0.267	0	0	0	0	0
SM6	0	0	0	0	0	0	0	0.125	0	0	0	0
SM7	0	0	0	0	0	0	0	0	1	0	0	0
SM8	0	0	0	0	0	0	0	0	0	1	0	0
dead	0.7	0.95	0.95	0.587	0.422	0.647	0.733	0.875	0	0	1	0

H) λ values and 95%CI (dotted lines; n =1000 bootstraps)



C) Fundamental matrix

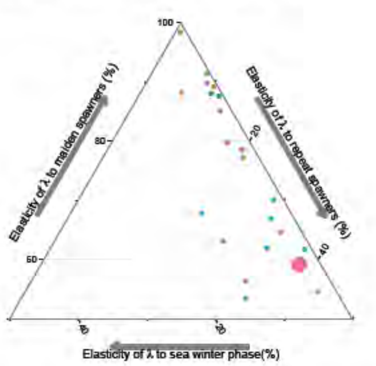
Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	dead
FW	1.176	0	0	0	0	0	0	0	0	0	0	0
SW	0.097	1.003	0	0	0	0	0	0	0	0	0	0
IM	0.018	0.003	1	0	0	0	0	0	0	0	0	0
SM1	0.066	0.045	0.05	1	0	0	0	0	0	0	0	0
SM2	0.027	0.018	0.021	0.413	1	0	0	0	0	0	0	0
SM3	0.016	0.011	0.012	0.239	0.578	1	0	0	0	0	0	0
SM4	0.006	0.004	0.004	0.084	0.204	0.353	1	0	0	0	0	0
SM5	0.001	0.001	0.001	0.022	0.054	0.094	0.267	1	0	0	0	0
SM6	0	0	0	0.003	0.007	0.012	0.033	0.125	1	0	0	0
SM7	0	0	0	0.003	0.007	0.012	0.033	0.125	1	1	0	0
SM8	0	0	0	0.003	0.007	0.012	0.033	0.125	1	1	1	0
dead	1	1	1	1	1	1	1	1	1	1	1	1

G) Stage−specific reproductive value

D) Sensitivities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	dead
FW	0.397	0.022	0.004	0.014	0.004	0.002	0	0	0	0	0	0.207
SW	0.289	0.016	0.003	0.01	0.003	0.001	0	0	0	0	0	0.151
IM	0.325	0.018	0.003	0.012	0.003	0.001	0	0	0	0	0	0.17
SM1	9.94	0.535	0.099	0.357	0.097	0.037	0.009	0.002	0	0	0	5.14
SM2	14.959	0.814	0.151	0.543	0.148	0.057	0.013	0.002	0	0	0	7.815
SM3	15.741	0.857	0.159	0.571	0.156	0.06	0.014	0.002	0	0	0	8.223
SM4	17.456	0.95	0.176	0.633	0.173	0.066	0.015	0.003	0	0	0	9.119
SM5	19.997	1.088	0.201	0.726	0.198	0.076	0.018	0.003	0	0	0	10.446
SM6	44.583	2.426	0.449	1.618	0.442	0.169	0.039	0.007	0.001	0	0	23.29
SM7	36.466	1.984	0.367	1.323	0.361	0.138	0.032	0.006	0	0	0	19.05
SM8	22.467	1.223	0.226	0.815	0.223	0.085	0.02	0.004	0	0	0	11.737
dead	0	0	0	0	0	0	0	0	0	0	0	0

I) Summed elasticities of λ to adult strategy



E) Elasticities of λ to perturbations of the transition matrix

Stage	FW	SW	IM	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	dead
FW	0.04	0	0	0.209	0.089	0.044	0.012	0.003	0	0	0	0
SW	0.016	0	0	0	0	0	0	0	0	0	0	0
IM	0.003	0	0	0	0	0	0	0	0	0	0	0
SM1	0.338	0.016	0.003	0	0	0	0	0	0	0	0	0
SM2	0	0	0	0.148	0	0	0	0	0	0	0	0
SM3	0	0	0	0	0.06	0	0	0	0	0	0	0
SM4	0	0	0	0	0	0.015	0	0	0	0	0	0
SM5	0	0	0	0	0	0	0.003	0	0	0	0	0
SM6	0	0	0	0	0	0	0	0.001	0	0	0	0
SM7	0	0	0	0	0	0	0	0	0	0	0	0
SM8	0	0	0	0	0	0	0	0	0	0	0	0
dead	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 8.1 Summary of management issues on which CSTP can comment or advise			
Category	Management Issue	Scientific Problem	Examples of CSTP Advice
1. Risks to sea trout	– 1.1 Climate change in freshwater and at sea	– How will climate (sea temperatures) and prey / predator abundance affect the life history optimisation and tactics? – Proximate factors are changes in growth, fecundity and maturation. – Main problem lies in understanding how survival/growth/fecundity/maturation (essentially survival/fertility) interact to optimise population fitness.	– Brief overview of climate changes in Irish Sea and freshwater – Comment on range of freshwater trout growth patterns and variance across CSTP geographical range and typical response to water temperature changes. – Comment on range/variance of smolt age, smolt sizes, fecundity and post-smolt marine growth. – Spawning frequency – Model effect on marine (1st year) growth. – Qualitative predictions of change based on life history theory in migratory salmonids. – Diet of sea trout will be described and impacts on those trophic levels may be possible, depending on how advanced those study areas are
	– 1.2 Over-exploitation in mixed stocks at sea or in estuaries	– What is the extent of mixed stocks; where do sea tout go, when and are they vulnerable to exploitation (include angling at sea ?) ?	– Genetic and microchemistry analysis to show extent of net exchange of adult sea trout between Irish sea regions. – Comment on seasonal timing is constrained by sample quality, but may be able to note the size/age distribution (hence vulnerability) of migrant groups.
	– 1.3.Over-exploitation generally	– At what rate are sea trout exploited in the principle net and rod fisheries (and illegal fisheries) and what risk does this pose to population growth rate and resilience and to fishing quality and values?	– General statement possible based on relative size of net and rod catches and the (currently) limited distribution of net fisheries. Quantification of exploitation rate (U) only feasible in two cases (Dee and Lune?) where quantitative estimates of runs are feasible. BUT simulation of fitness (e.g. Ro and λ) to a range of Us is possible using simple size-structures life table projection models.
	– 1.4 Impacts from marine renewable energy development	– Where do sea trout go, when and for how long (cannot comment on the individual response to e.g. noise, turbine, EMF etc, nor to the population effects of any response)? – Are their predators or prey species affected in ways that might affect sea trout?	– See 1.2, plus full EIA depends upon the response of individual and populations which is not part of CSTP (nor is it subject to adequate research elsewhere, to our knowledge).
	– 1.5 Impacts from freshwater factors	NB these are RIVER specific questions: – Is the observed sea trout production that which is expected from accessible catchment of given size? (A) migration impacts: from barriers & flows, (B) carrying capacity impacts: from habitat, pollutions, productivity changes) – Does probability of anadromy vary predictably around catchments and why?	– General statement (based on empirical models) about what different rivers should produce. – Comment on the relative contribution of different sized catchments to total Irish Sea stock production. – Identification of rivers with unusually low or high production and suggestion as to why they are so (linked with discussion in 1.1, through life history optimisation by anadromy).

2. How to manage the risk factors	– 2.1 Climate	– How to regulate environmental response to climate change (adaptation strategies)? (FW and marine)	– Follow emerging guidance from EA and elsewhere. E.g. tree canopy management; creative use of flow regime where feasible (HMWBs), planning controls on changing land use and agriculture, recognise importance of 1st order streams, marine planning controls,
	– 2.2 Marine mixed stocks	– How vulnerable are minor or low fitness stocks (e.g. most small coastal streams) to mixed stock exploitation – Is there need for routine cross-border assessment and management of potential mixed stocks	– May be able to advise on potential marine protection areas. – Simulate effects of changing U on survival, NB the size-selective exploitation of nets and rod fisheries and their consequential unequal effects; – Simulate the relative benefits (as annual egg production, lifetime fitness) of alternative season, mesh sizes, size limits or quotas.
	– 2.3 Exploitation	– How would stocks respond (in terms of fitness) to alternative catch regulation strategies (e.g. as quotas, size or season controls)	– Simulate effects of changing U, NB the selective effects of nets and rod fisheries; – Using case studies (*Tywi + Irish river or Nith?): Simulate the relative benefits (as annual egg production or lifetime fitness, or population R) of alternative season, net sizes, size limits or quotas.
	– 2.4 Marine renewables development		– See 2.2. Mitigation methods outside CSTP remit
	– 2.5 Freshwater factors	– Combines all the ecological and ecosystem science relating to freshwater trout production and, specifically, how does anadromy adjust to the various pressures. – Can we distinguish between rivers/ sub-catchments with natural low capacity to produce anadromous trout from those where environmental degradation is limiting?	– Unlikely to offer river specific advice, because of its local nature. – But may be able to comment on the inherent potential of different rivers to produce sea trout, and thereby to manage expectations and strategic catchment plans. – May be able to rank the rivers on basis of production shortfalls and, given adequate knowledge through existing catchment plans, to identify where priority management actions are appropriate. – Recommend precautionary principle to apply where data limited
3. How to Monitor & Assess sea trout	– 3.1 What should be the indicators of sea trout stocks? Are biological reference points (BRPs) feasible?	– Should the anadromous contingent be distinguished from non-migratory and, if necessary, how can that be done practicably. – How stable are the spatial distributions of anadromous trout? – What are the potential indicator and how sensitive & responsive are the potential indicators, given variance in the ness	– Estimate and comment on the relative contribution to total egg deposition from migratory and non-migratory contingents around the CSTP study rivers.
	– 3.2 What should be the indicators of sea trout fisheries?	– Do current catch and effort data offer useful data on net and rod fishery performance and can they be used also as stock indices? If not, what enhancements might be needed?	– Describe and comment on availability, reliability, biases, statistical variability of existing catch and CPUE data, including regional differences – Recommendation on catch and effort recording, noting the need to make inclusive and to involve the fishermen.

			– More counters? – Establish index system(s)
	– 3.3 What is the value of scale reading?	– How acceptable are seasonal distributions of scale samples from angler and management surveys for stock assessment purposes? – How does the between-reader performance of scale reading affect errors and values of the resulting age and growth data? – Do we understand enough about the physiological process of scale formation within and between populations to offer reliable interpretations of scale circuli and check patterns?	– Describe and comment on the variability seen in CSTP, limitations of scale reading, and also the benefits if the data can be made acceptable – Recommend alternative methods for sampling, reading and analysis – Recommend research to enhance the interpretation of scale patterns.
	– 3.4 What is the appropriate scale of MonAss? What the benefits from cross-border work?	– Does the current level of cross-border integration hamper the assessment and management of stocks and fisheries? – If so, how might it be enhanced?	– Review and comment on the pros and cons for enhanced cross-border monitoring and assessment.