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# Report of the Workshop on Sea Trout 2 (WKTRUTTA2)

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International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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## Executive summary

The second Workshop on Sea Trout (WKTRUTTA2) met at the ICES Headquarters, Copenhagen, Denmark, 2–5 February 2016, under the chairmanship of Ted Potter, UK, and Johan Höjesjö, Sweden. The meeting was attended by 22 participants from seven countries. The principal aims of the Workshop were to review different approaches for modelling sea trout (anadromous *Salmo trutta*) populations and assessing the status of stocks. The group was also asked to provide a review of currently used monitoring methods, an initiation of the work to develop Biological Reference Points (BRPs) or alternative methods to assess the status of sea trout populations, and recommendations for how this work could be taken forward.

The Workshop considered the management requirements for modelling sea trout populations and the application of BRPs. These fell into two groups, the first relating to assessing stock abundance and diversity against reference levels and the second to investigating the impacts of natural and anthropogenic factors, including fisheries, on stocks.

Sea trout frequently coexist with salmon and are caught in the same fisheries in coastal waters, estuaries and rivers, but they have often taken second place in management, and in some countries little attention has been paid to the monitoring and assessment of sea trout stocks and fisheries. As a result, the quality of catch and fishing effort statistics is very variable. Juvenile monitoring is conducted in all countries, in many cases related to the EU Water Framework Directive, although sampling programmes are not always well structured, systematic or consistent over time. Some countries have developed extensive networks of counters, usually targeted at monitoring salmon, and in some cases these also provide good data on runs of sea trout. The Workshop compiled a summary of monitored/index stocks for which detailed data are obtained, but there are few such stocks and the aims of the programmes and the lengths of the resulting time series vary considerably.

The Workshop assembled a preliminary table of sea trout rivers to support an eventual map. Stocks were graded on the proportion that was thought to be anadromous using a five-point scale, based on expert opinion, informed where possible by data on sea trout and salmon rod catches and/or samples taken by trapping or electrofishing. The Workshop recommended that the development of these databases should be completed by a follow-on expert group (see below).

The Workshop discussed anadromy versus residency in trout and whether models of sea trout populations need to take account of the contribution of resident fish (section 4 below). Considering that up to half of the variability in the migratory life-history tactic may be related to environmental conditions, it is likely that the contribution of resident fish to recruitment could change through time. It was therefore concluded that models for sea trout should ideally attempt to include the resident population where facultative anadromy occurs. Nevertheless, this may be difficult due to lack of data, and the fact that resident fish make only a small contribution to egg deposition in many rivers suggests that for these stocks it is reasonable to develop population models of sea trout on their own.

The Workshop considered a number of approaches for modelling sea trout populations and developing BRPs. Stock-Recruit (SR) relationships were examined for index rivers (section 7), but there are relatively few such systems and it is unlikely that they provide a sufficient basis for transferring BRPs to data-poor systems because of the great complexity and variability in trout life history strategies. SR relationships have also been developed based on catch records (section 8). The Workshop concluded that the methods that currently showed greatest promise for widespread application to assess the status of stocks were the Trout Habitat Score (section 6) and catch-based pseudo-stock-recruitment relationships (section 8.5), and the group recommended that a Working Group should be established to take forward work on these topics.

# 1 Introduction

## 1.1 Background

Sea trout are the anadromous migratory form of the brown trout (*Salmo trutta*) which go to sea to feed and mature as adults prior to returning to spawn, usually in their natal rivers. Extensive overviews of sea trout fisheries and biology have been prepared for ICES by the Study Group on Anadromous Trout (SGAT); (ICES, 1994) and the Workshop on Sea Trout (WKTRUTTA); (ICES, 2013). In addition, two international symposia on sea trout, held in Cardiff, UK in 2004 (Harris, 2006) and in Dundalk, Ireland in 2015 (Harris, in prep) have made proposals for future management and research priorities. This Workshop builds on the scene-setting work of WKTRUTTA (ICES, 2013), focusing specifically on the development of models to help address key management questions and in particular to develop Biological Reference Points (BRPs) for use in the management of fisheries and the provision of regulatory advice on other anthropogenic impacts.

Stock declines, for example in areas where marine mixed stock fisheries prevail (e.g. the Baltic) and where there is salmon farming, have raised concerns about our lack of knowledge of the complex and variable life cycle of this species. Sea trout have historically taken second place to Atlantic salmon in national fishery assessment programmes and management priorities. As a result relatively few sea trout stocks have been studied for sufficient time to allow the development of population models. Initiating such studies will be very expensive and it will take many years to provide results useful for modelling. There is therefore a need to consider alternative modelling approaches, for example based on catch data or juvenile surveys.

## 1.2 Terms of Reference and deliverables

The full SCICOM resolution for the Workshop (WKTRUTTA2) is shown at Annex 1, and the principal Terms of Reference for the meeting were to:

a ) Review the pros and cons of different approaches for modelling sea trout (anadromous *Salmo trutta*) populations taking account of parameterization, data collection and management application;

b ) Consider whether, and if so how, to take account of resident as well as migratory trout in population models;

c ) Review methods currently used and develop new approaches for assessing the status of trout stocks.

In addition, the expected deliverables from the Workshop included a review of currently used monitoring methods, an initiation of the work to develop BRPs or alternative methods to assess the status of sea trout populations, and recommendations for how this work could be taken forward. The aim was that the final report and recommendations would guide both individual countries in making progress on sea trout assessment and management, and also steer ICES on the best next steps for Sea trout science, assessment and advice.

The meeting was attended by 22 scientists from seven European countries with sea trout stocks (Annex 2). Twenty-one presentations were received (Annex 3) on national and local monitoring programme, modelling exercises and development of BRPs and alternative indices. A glossary of sea trout terms in included at Annex 4.

# 2 Key Management Questions

The Workshop recognised the need to have a clear idea of the management questions that were to be addressed with population models, and emphasised the need for good communications between scientists and managers. As a basis for framing their discussions, the Workshop outlined the key management questions that would be assisted by the use of population models and biological reference points as follows:

## 2.1 Measures of stock abundance

As a basis for any evaluation or forecast of the effects of anthropogenic or environmental factors on stocks, it is essential to be able to assess historic, current and future stock levels.

## 2.2 Measures of sustainable stock size

In order to manage any resource it is important to have measures or indices of the desired/required abundance or status of that resource. For fish stocks such indices take the form of Biological Reference Points (BRPs) which may define various stock states, including stock levels to be exceeded with a high probability (Conservation Limits (CL) or stock levels to aim at (Management Targets (MT)). Management Objectives (MO) may also be defined on the basis of such BRPs; for example, the aim of management might be to have a greater than 75% probability of exceeding the CL in any year.

For species such as trout, with more complex and variable population structures, it may also be desirable to have more detailed reference points relating to the diversity of life histories.

## 2.3 Measures of stock diversity

The brown trout is a highly complex species exhibiting a wide range of life history strategies, of which the anadromous sea trout form is just one. These strategies vary from local (in-river) to wide (international) geographic scales. The principal areas of variation relate to:

- Nature of migrations (e.g. within-river, river to lake, river to estuary, river to sea);
- Extent of marine migrations;
- Proportion of males and females that exhibit different migratory habits;
- Age at first return to fresh water and/or first maturation;
- Age structure (e.g. average and/or first return;
- Growth rates in fresh water and the sea.

It is generally hypothesised that the different life history strategies have arisen because they confer fitness benefits to the fish from particular populations (or sub-populations), although the extent to which they express polymorphisms is not clear.

Maintaining stock diversity is an essential part of management, but stock diversity may be particularly difficult to evaluate or manage without a clear understanding of the fitness benefits conferred by specific life history strategies in different rivers.

## 2.4 Impacts of fisheries

One of the most common management questions relates to the regulation of exploitation by net and rod fisheries. Whether fisheries are controlled by effort or catch restriction may determine the type of modelling required.

## 2.5 Impacts of other anthropogenic factors

Other anthropogenic activities which may influence sea trout populations include those impacting habitat quality, such as factors affecting discharge, water quality and habitat connectivity. There are also needs to forecast the effects of developments in rivers, estuaries and coastal areas, such as renewable energy schemes (e.g. tidal power generation) and port developments.

## 2.6 Impacts of environmental factors

It is important to be able to distinguish between anthropogenic factors and natural environmental variation. In addition, climate change is expected to have significant effects on both freshwater and marine environments, particularly through changes in temperatures and patterns of precipitation. Very little quantitative information exists on how an increased temperature might affect the population size and life history of sea trout. On the Swedish west coast, size and abundances of different year classes of anadromous brown trout were examined using electrofishing data for the last 30 years. The results suggest that regional increased temperature affected both smolt and parr sizes positively causing a significant change in mean smolt age and size derived by a larger number of fish migrating at a younger age (Aldve´n *et al.* in prep).

# 3 National monitoring and assessment programmes for sea trout

## 3.1 Organisation of data collection

The aims of investigations currently underway into sea trout stocks and fisheries that were presented during the meeting ranged from assessing aspects of sea trout biology, assessing the status of populations, and annual monitoring of populations and catches. Unlike salmon, sea trout are not included in conservation legislations and so often there is less concern about monitoring stocks. As a consequence, there is relatively little consistency in the datasets currently being collected in different countries.

### 3.1.1 Juvenile Monitoring

Electrofishing is widely employed to survey juvenile salmonid populations, although the extent and frequency of these surveys varies significantly. In most countries electrofishing surveys of juveniles have been focused on salmon and, while there is considerable overlap, the two species can have very different distributions at the extremities of habitat types (for example sea trout use of very small tributaries or coastal streams). The intensity of monitoring parr densities varies between countries as does the duration and frequency of routine collections of densities. The extent of the monitoring varies from covering all rivers, almost all rivers, principal rivers, rivers with salmon, to just a sample of rivers, and this is reflected in the number of sites. In general habitat data are collected from the electric fishing sites or in a few cases from the entire river system.

### 3.1.2 Counters and traps

Fixed, automated fish counters are in place on a number of salmonid rivers in Europe, and several countries have developed quite extensive counter networks. In Ireland, for example, 27 permanent fish counters are operated (see Section 2.1. "Ireland" for further details), and in France 23 sites (traps with video) provide upstream migration counts for sea trout on 19 rivers (see Section 3.2). While these sites tend to have been established to monitor salmon populations they are also capable of providing information on sea trout movements and good quality sea trout counts are often produced, especially where the specifications of the counter are set to include smaller fish than 'standard salmon' counters.

Traps have been employed on only a very small number of rivers to develop long-term population data sets. In Ireland, Northern Ireland, Norway (video counters and Wolf-traps), Wales (Upstream) and France a small number of permanent fish trap facilities are maintained, for which all upstream and downstream movements of salmon, sea trout and, in a few cases, eels may be recorded. In some locations video recorders have been used to monitor migrations, but data series are not consistent.

### 3.1.3 Catch and effort statistics

The legal requirements and procedures for reporting sea trout catches and fishing effort vary widely among jurisdictions, and there are frequently different reporting requirements in marine and river fisheries, and recreational and commercial fisheries. Very few jurisdictions collect detailed information on fishing effort for sea trout. Sea trout have tended to take second place to salmon in fishery management, and in a number of countries, sea trout fisheries have been considered to be of little importance relative to salmon and so catch records have been of little interest. In some jurisdictions, there are no requirements to either provide or maintain sea trout catch records (see Section 3.2), and in others, catches are only recorded for fish over a certain size, usually set to allow catches of Atlantic salmon and sea trout to be separated. Furthermore, owing to the differences in reporting requirements among organisations, the quality of the data also vary significantly. However, attitudes do appear to be changing, and there is a growing interest in gathering and accessing sea trout fisheries data in the form of both catch and effort levels.

### 3.1.4 Tagging and telemetry

**External (non-telemetry) tags or marks** typically contain a unique identification code, with which tagged individuals can be identified on recapture and are usually attached below the dorsal fin on sea trout to minimize the impact or influence of the tag on natural behaviour and maximize tag retention. Tagging and marking have been widely used to study the migratory behaviour, distribution and population dynamics of sea trout, and data from such studies can be very helpful in population modelling. Extensive Carlin tagging programmes have been carried out in Finland and Sweden, with wild and reared sea trout (Carlin, 1969; Degerman *et al.* 2012). There is some concern, however, about the utility of these data in recent years because of a likely decline in tag reporting rates in the Baltic (ICES, 2014). The quality of the tagging database maintained by Swedish hydropower companies has also come into question (E. Degerman SLU, pers. comm.). Visible Implant tags (http://www.nmt.us/products/via/via.shtml) have been used on sea trout on the Welsh Dee for a number of years to provide returning stock estimates by mark-recapture (Davidson *et al.*, 1996).

**Passive Integrated Transponder** (PIT) tags are small, individually coded tags that are injected into the body musculature or internal body cavity and are detected with a hand-held electronic tag reader, portable or fixed antennas (Nelson *et al.*, 2013). These tags overcome some of the problems of selective tag reporting and allow identification of tagged fish as they pass through detector arrays without catching them. PIT tagging is believed to be a very effective tool as long as tag detection is good at the arrays. An example of the use of PIT tags is provided by work on the River Oir, a small coastal stream in France, where between approximately 600 and 3000 trout parr (both resident and migrant), smolts and adults caught at a trap have been PIT tagged (tags were implanted in the abdominal cavity) each year since 1993. Recaptures take place in a downstream trap (smolts and parr), an upstream trap (parr, resident adults and anadromous adults) and during electrofishing sessions (parr, resident adults and anadromous adults). PIT tags are also detected by two fixed autonomous antennas, one by the trap which helps improve assessment of the trap's efficiency, another at the entrance of a main spawning brook. The antennae records provide information on the survival of the detected individuals, but the condition of these individuals is unknown. PIT tag retention is assumed to be very high, except when tagging mature females, when PIT tags may not have enough time to be embedded inside abdominal tissues and are often expelled with eggs at spawning. In the future, PIT tag monitoring will continue on the Oir, and a large scale PIT tag monitoring programme is planned for the Bresle River, starting in 2016.

**Acoustic and radio telemetry** are also used in some areas to provide information on migration routes and timings in relation to both natural and anthropogenic factors. Telemetry can provide very detailed information on fish movements but may be constrained by cost.

## 3.2 National monitoring programmes

The Workshop received presentations on monitoring and sampling programmes being undertaken in different countries to assess sea trout stocks and fisheries. These programmes vary widely, and there is little standardisation. Some studies are aimed at hypothesis testing, with correspondingly focused data collection activities, others are routine and ongoing as part of regional or national monitoring programmes targeting catchment-wide ecology, where sea trout may comprise only part of the monitoring activities. Others activities are fishery focused, regional or national, although infrequently with sea trout as the target species as often they are considered as being of secondary importance to Atlantic salmon.

Details presented during the meeting pertaining to data collection activities are summarised below by country:

### 3.2.1 France

In France, sea trout stocks are not assessed at the national level, and sea trout management can be considered to be a by-product of salmon management. Sea trout catch records are only collected for recreational freshwater fisheries, and catch reporting is voluntary. The catch statistics thus provide a very incomplete picture of the fishing activity; for example, in 2014 only 350 sea trout were reported compared to 1365 salmon, for which catch reports have been compulsory since 1987. Collection of data on fishing effort is almost unknown, with only 22 logbooks collected from 3996 registered "salmonid fishermen" by ONEMA in 2014 (Sauvadet, 2015).

Upstream migration counts are available for 23 sites (traps with videos) on 19 rivers. The species identification on the video records can, however, be problematic in rivers where both sea trout and salmon are present. Most operators use observed fish length as the only discriminating factor, which may induce some bias in population composition data. Moreover, the detection rate is unknown at most sites, thus preventing reliable abundance assessment.

There are two monitored sea trout stocks in France, in the Rivers Bresle and Oir. The River Bresle in northern France is 70 km long with a wetted area of 746 $km^2$. Upstream and downstream migration of Atlantic salmon, trout and eel have been monitored for 32 years with a few data gaps. Between 2013 and 2015, a Bayesian model was implemented to estimate trap efficiency and test the hypothesis that salmon and sea trout behave the same way in relation to the traps and hence the species can be combined to increase the sample size. Based on Petersen's mark-recapture model, the model includes the effects of stream flow, which influences trapping efficiency. The model was also applied to downstream migrating sea trout smolts, although not to test the hypothesis of interspecies variability. Average sea trout length for the Bresle stock is 55 cm and weight, 2.35 kg. The population is dominated by 1+ fish (72%). Estimated egg to smolt survival (fecundity) is 0.2% (1.24% for salmon) and marine survival (trap return rates) 20.5% (4.9% for salmon). Investigations of the population structure within the river are underway. During discussions comparisons with other sea trout monitoring programmes suggested that the estimated survival rates are generally good.

The River Oir, a small coastal stream in Lower Normandy, is another index river for sea trout. Initially designed to monitor the Atlantic salmon population, field protocols have been extended to all the migratory fish species, including sea trout, which represents only a few percent of the juveniles produced in the river. Detailed trout population monitoring involves partial trapping of downstream migrating smolts and parr (since 1985) and upstream migrating anadromous adults (since 1983), and redd counts. Downstream trap efficiency estimation is based on capture-mark-recapture experiments on salmon smolts. Upstream trap efficiency is estimated through specific electrofishing recapture sessions targeting anadromous salmon and trout. Unfortunately, upstream trapping efficiency has decreased significantly since 2008 following modification of the guiding device. Juvenile monitoring on the Oir includes PIT-tagging of juveniles (since 1994) and standardised electrofishing surveys to assess juvenile density (resident and anadromous forms are combined) in spring and autumn (abundance estimates are available from 1988 and from over 11 designated sites since 2006).

A detailed habitat survey was conducted on the river Oir, which led to the development of a habitat model (Baglinière *et al.* 2005) used to predict salmon parr and smolt production on adjacent river systems. Habitat characteristics are transformed into a surface of productive riverbed for salmon, with ratios of parr or smolt per production unit derived from key index rivers.

### 3.2.2 Germany

Commercial sea trout catches in the Baltic Sea are reported annually. In 2015, a total of 232 German vessels reported sea trout catches, with ~ 70% being less than 8 m in length. There is known to be a highly developed recreational sea and shore-based sea trout fishery along the Baltic coastline but no catch data are regularly collected. A bus route intercept & telephone survey was conducted 2013/2014 & 2014/2015 respectively to estimate catch and effort in the recreational sea trout fishery. Commercial and recreational sea trout catches in the North Sea are negligible, however, there is some commercial and recreational fishery targeting sea trout in the rivers and estuaries flowing into the North Sea but no structured and region-wide catch statistics are collected.

Two electrofishing surveys for 0+ and 1+ parr stages based on the Trout Habitat Score (THS) method have been established to evaluate the recruitment and stocking success in about 30 rivers in the Baltic Sea catchment area. However, historical monitoring programs did not cover the entire catchment and only recently a harmonisation of the data collection has been initiated. In the North Sea catchment area, some electrofishing surveys are also conducted but these surveys are conducted by different actors (e.g. angling clubs, federal state agencies) and no regional coordination exists. A project-based smolt-trapping campaign has been initiated in 2016 to monitor smolt production from one river flowing into the Baltic Sea (SD 22).

A monitoring program using video cameras is established in three rivers flowing into the Baltic Sea to monitor adult spawners since 2009. Different projects investigating numbers and quality of spawning redds have been performed or are still ongoing covering rivers flowing into the North Sea, Kiel Kanal and Baltic Sea. However, quality of the data varies as different actors are involved and data collection efforts are uncoordinated.

### 3.2.3 Ireland

Catch statistics are routinely collected for all sea trout over 40 cm in length. Catch is detailed by date and river, with length and weight recorded. This is part of the national Wild Salmon and Sea Trout Tagging Scheme, for which salmon are the target monitoring species.

Some 27 fish counters are operated by the state body, Inland Fisheries Ireland (IFI), primarily using Logie resistivity and Vaki infra-red counters. They provide upstream and downstream count data, with logie counters verified with video footage. As for catch data, the focus has primarily been on assessing migrations of Atlantic salmon, but good quality sea trout counts are produced.

Permanent or seasonal, trapping stations are located on four rivers in Ireland, the Burrishoole, Erriff, Invermore, and Owengowla catchments (Annex 3).

The sea trout population in the River Burrishoole has been monitored at a trapping facility for the past 45 years, including stock structure, upstream and downstream movements, marine survival and relationships between stock and recruitment. Resident trout are also included in stream monitoring. Silvered and unsilvered migrating trout are counted in the upstream traps, with unsilvered fish believed to migrate only as far as the brackish lake or estuary, and not progressing further to the sea, before returning. Details of the stock are given in Chapter 7.3 of this report. There has been a downward trend in the Burrishoole sea trout stock and rod catch since the late 1970s, but the stock collapsed in the late 1980s/early 1990s, with a dramatic reduction in marine survival for all age classes in 1988 & 1989, and a subsequent reduction in smolt recruitment. In 1975, the sea trout run was 3348 but this fell to a mean of 163 migrating trout in the 2000s and has been down to less than 100. Sea-lice are considered to be the primary cause of the stock collapse in the 1990s, but it is acknowledged that other factors may have been at play and have affected stock since, including afforestation and deforestation, catchment erosion, flooding and agricultural changes in land use. The stock is dominated by sea age 0+ fish. Results to date support the view that resident trout have not compensated for the collapse in the spawning stock.

Beverton-Holt relationships were found to be most robust in SR estimations, giving recruitment estimates of 3000 to 4000 smolts prior to the collapse in 1989, which equates to approximately 6 smolts per hectare. This compares well with smolt outputs from a number of "low smolt production" Connemara catchments while another group of catchments produce considerably more smolts per hectare (range 16.9-49.5 per ha) and it is thought that this striation may be habitat based. Preliminary genetic analysis in Burrishoole has suggested distinct sub-stock structuring in the trout stock within the catchment and the role of lakes in smolt production still needs to be fully investigated. Data for the other catchments where annual trapping is undertaken has been published, for the Invermore and Owengowla (Gargan *et al.* 2006s) and the Erriff (Gargan *et al.* 2016). All these catchments were affected by the collapse in marine survival in the late 1980s with varying impacts on smolt production.

### 3.2.4 Netherlands

Many organisations in the Netherlands are involved in monitoring the ecological status of rivers. Historically three reference rivers have been maintained, however this has now been reduced to two. Returning adult sea trout are monitored through Wolf traps in index rivers, with data collected on size and age. PIT tagging is also used and every 1 to 5 years, rotary screw traps are employed.

There is generally little data on the sea trout populations. In-stream 0+ and parr densities in late summer are estimated by electrofishing. Electrofishing data are generally of good quality, but on most rivers there is no systematic sampling programme, although these are being developed. Redd counts are conducted and are thought to be reliable where repeated standardised surveys are conducted on the same rivers under uniform water flows.

Most commercial fisheries for sea trout operate in coastal waters. There are some limitations on fishing seasons, with stricter coastal regulations due in the coming year. Catches in registered fisheries are monitored, but the quality of the official catch statistics is not known. PIT tag data of returning spawning adults may include some inaccuracies.

Under the research project "CHASES" (Studying how land-use change and other human activities may alter life history strategies in salmonids and community ecosystem services (2016-2019)), differences between resident and migratory trout are being investigated and the following sampling is being undertaken:

- All brown trout in a small river monitored using PIT tags;
- Molecular techniques to define males/females;
- Growth rates by seasonal electrofishing;
- Age by scale reading; and
- Visual counts of spawning in spring.

The data from this work should start to become available in 2016/17.

### 3.2.5 Norway

There has been a recent government decision to increase monitoring programmes to obtain more information on sea trout and salmon, with a particular focus to determine the effects of aquaculture on stocks. An updated overview of Norwegian Sea trout catch statistics is given in Anon (2015).

Sea trout populations and recruitment are being estimated using Carlin Tags (Jensen *et al.* 2012) and PIT tags. About 2500 pre-smolts are PIT tagged in each river, above and below water antennas, which have detection ranges of up to 90 cm, and being used to record movements. Hand held scanners are used to check catches. Migration times from smolts are being estimated, and recaptures are being used to assess growth. All monitoring is in-river with no sea recaptures.

Acoustic tracking is also used in some rivers to obtain information on population migration routes and timings. 2D and 3D migration routes are detectable. About 300 smolts are marked with acoustic tags in one system (€1500 per tag) and detected with permanently positioned hydrophones in rivers and fjords on their outward migration.

Rivers where these monitoring programmes are being undertaken include the Rivers Etne (PIT/HA), Oselva (PIT/HA), Sylte/Moaelva (PIT), Vigda (PIT) and Heggaelva (PIT). With regard to assessing the remaining trout rivers in Norway; the chosen rivers are representative of the range of sea trout rivers, chosen to give information on ranges as index rivers to set up management approaches for local areas as described in Fiske *et al.* (2014). This work has been initiated and under progress.

### 3.2.6 Poland

There is no national sea trout monitoring program in Poland, but basic information about sea trout rivers is available from an inventory of rivers' ichthyofauna carried out by the Inland Fisheries Institute. The main method of monitoring is by a survey of spawning grounds and redd counting, carried out annually on four rivers and irregularly on a few others.

Spawning runs have been monitored by automatic fish counters on the Slupia River, since 2006, and on the Ina river (tributary of lower Odra River), since 2013. Densities of parr are estimated by electrofishing at one to three sites on the spawning grounds in three to four rivers annually.

Data on river catches are collected by the Inland Fisheries Institute from the Polish Angling Association and from fishery cooperatives. Reporting of river catches is only obligatory for landed fish (not for catch & release).

Commercial offshore and coastal catch statistics are based on logbooks for vessels over 10 m and on monthly reports of vessels smaller than 10 m. Fishery data from logbooks and monthly reports are held in a database run by the Fishery Monitoring Centre (FMC) of the Ministry of Maritime Economy and Inland Navigation. Since June 2013, vessels with the length over 12 m have to send their data electronically with use of an e-logbook.

More detailed sea trout monitoring has been conducted on The Łeba River in northern Poland. This river is 126.7 km long with a mean water discharge of 5 $m^3/s$ and river basin area 1767 $km^2$. The river runs to the Baltic Sea in the middle of the Polish coast. At the end of its course it passes through Lake Łebsko, the third largest lake in Poland by surface area (7 142 ha). Because of impassable obstacles, the main spawning areas are located in the middle of the basin. Currently 70 km of the Łeba river is open to fish migration.

The river basin is intensively stocked with a range of age classes: smolts (aged 1+); alevins; and since 2013 fry. Between 2010 and 2015, 34-70 thousand smolts and 210–520 thousand alevins were stocked. Fry numbers have varied from 94 000 to 170 000. Juveniles for stocking originate from native spawners, caught in the autumn each year in Lake Łebsko. A smolt adipose fin-clipping programme commenced in 2007.

A study of mass marking of sea trout alevins has been carried out since 2010. Immersion in a solution of fluorochrome - alizarin red S (ARS) was applied as a marking method. In 2013 this method was also implemented on sea trout summer fry. To distinguish fish originating from these two groups a single ARS batch marking procedure was applied to alevins and a double marking procedure to fry. So far over 1 320 000 alevins and over 430 000 fry have been marked and stocked. The aim of the work is to identify stocked fish (alevins, summer fry and smolts) from fish naturally reared in the wild.

Monitoring of sea trout spawners used for artificial spawning has been ongoing since 2007. Activities have focused on biological characteristic of fish and development and implementation of age validation method, e.g. cross-sections of dorsal fin rays.

Based on short-term observations, the Łeba river sea trout generally spend two years in freshwater followed by up to three years at sea, with relatively few fish remaining at sea for three years. This could be affected by fishing pressure in the coastal waters. The percentage of finnock is less than 0.5%. Fin-clipped fish are identified in the spawning stock, with a ratio of fin-clipped to non fin-clipped varying each year between 60 and 80%. The first adults originating from alevin stocking were caught in the autumn of 2012, following a year in freshwater and a year spent at sea. In the subsequent years following age groups were caught and identified.

Annual monitoring has included electrofishing surveys carried out on the parts of tributaries stocked in the spring, and redd counting on the inventoried spawning grounds located in the Łeba River and its tributaries. Steps towards monitoring of ulcerative dermal necrosis (UDN) and its impact on the mortality of sea trout spawners are one of the main points in the management process. Furthermore, hydrotechnical infrastructure, river regulation, environment pollution and poaching during the spawning season are currently the main issues to be addressed.

### 3.2.7 Sweden

Nationally, catch statistics for in-river fisheries in Sweden are of good quality, however the extent of non-commercial sea fishing is unknown and is believed to account for the major part of the total catch. In some regions though along the coast there is a network of sport fisherman using an app for cell phone where they report their catches which eventually can be used to monitor the stock. There is a general lack of age data (both smolt and sea ages). In some rivers smolt age is estimated from fish size (weight), with some infrequent validation. Monitoring on four of seven monitored rivers, which are predominantly salmon rivers, is state funded and so there is much data on salmon. In contrast, the three small trout streams lack long-term funding, resulting is low quality monitoring.

Sea trout (and lake trout (*Salmo trutta lacustris*)) assessments are therefore reliant on electrofishing data and habitat surveys which are more widespread. Stock assessment is based on the THS method which has been developed for application across Baltic sea trout systems to assess the status of sea trout as part of the ICES Baltic Salmon and Trout Assessment Working Group (WGBAST) (ICES, 2015a) (See Section 5.2).

The Trout Habitat Scores assessed at 232 sites in 105 streams show reliable ranges when compared to parr 0+ densities for a range of Swedish electrofishing sites (3500 sites covering a range of river types, Figure 3.2.7.1).

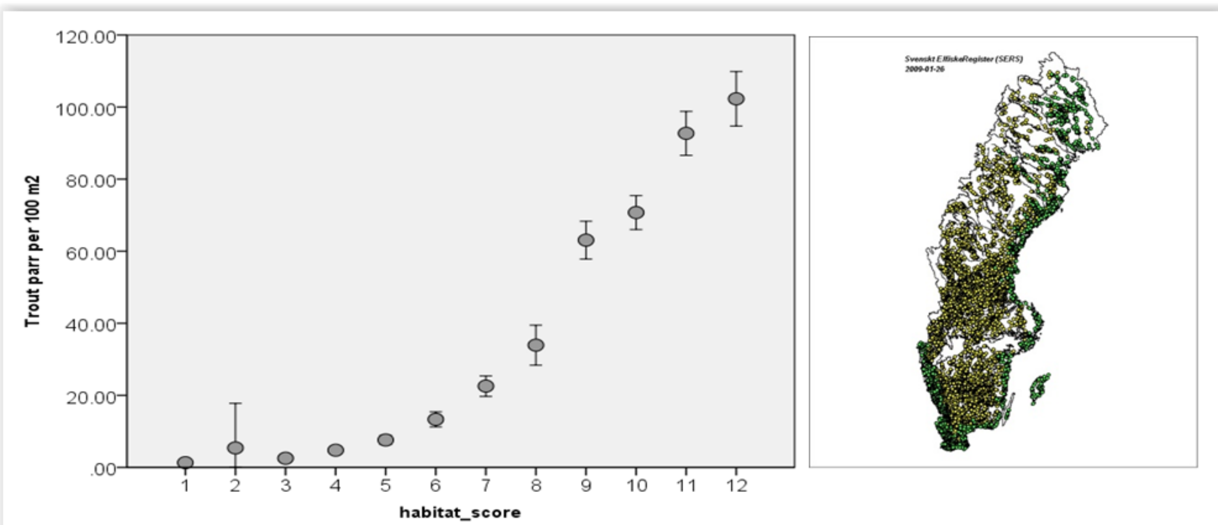



**Figure 3.2.7.1. Trout Habitat Scores with respect to trout parr (0+) densities (left) for Swedish electrofishing sites (right).**

As in Norway, acoustic tracking has been used to monitor migration routes and timings of out-migrating sea trout. On the west coast of Sweden approximately total 300 smolts has been marked with acoustic tags in 2 systems (Himleån and Byfjorden) and detected with permanently positioned hydrophones in rivers and fjords on their outward migration. The result implies that migration was triggered by both discharge and temperature and that mortality in years with low precipitation could be up to 51% (Aldve´n *et al.* 2015a, 2015b).

### 3.2.8 UK (England & Wales)

In England and Wales, there are about 70 sea trout streams, most on the west coast, for which standard net and rod fisheries monitoring has been undertaken since 1994, giving records of catches, landings and effort (number of fishing days).

In the absence of a stock-based reference point for sea trout, equivalent for example to the Conservation Limits used in salmon management, the Environment Agency and Natural Resources Wales apply a fishery-based assessment to the principal sea trout rivers in England and Wales (Miran Aprahamian, *pers com*). The purpose of this assessment is to provide an early warning about potential problems and so prompt further investigation into the status of stocks and the need for management action.

The approach utilises the time-series of angling catch per unit effort (CPUE) data – expressed as catch per day - collected via a national licence return since 1994. The assessment is undertaken annually on each river and includes:

- comparison of the most recent 3-year mean CPUE value to the 50th and 80th percentile values calculated from the previous 10-years of data ('reference period'); and
- an examination of the most recent 10-year trend in CPUE values.

An example of the assessment for the River Teifi sea trout fishery is shown in Figure 3.2.8.1.

Risk categories are assigned according to the matrix below:

| Status | Category | Score |
|---|---|---|
| Trend in CPUE significantly up or stable & current stock >80% of reference period. | Not at risk | 4 |
| Trend in CPUE stable & current stock between 50 and 80% of reference period | Probably not at risk | 3 |
| Trend in CPUE stable & current stock < 50% of reference period. | Probably at risk | 2 |
| Trend in CPUE significantly down & current stock < 50% of reference period | At risk | 1 |

This approach has been implemented over a number of years and provides a standardised objective method for reviewing the current stock status in comparison to past stock status. However, while it is effectively similar to the current UK approach to salmon stock monitoring, it is recognised that there is room for improvement as there is potential for trends and changes within the ten-year baseline to be missed. The shifting 10-year reference period built into this approach will not necessarily reflect a biological optimum e.g. carrying capacity, and could, for example, in a prolonged period of low stock levels/poor fishery performance result in a favourable assessment of stocks well below carrying capacity. Further discussion on this method is provided in Section 3.4.

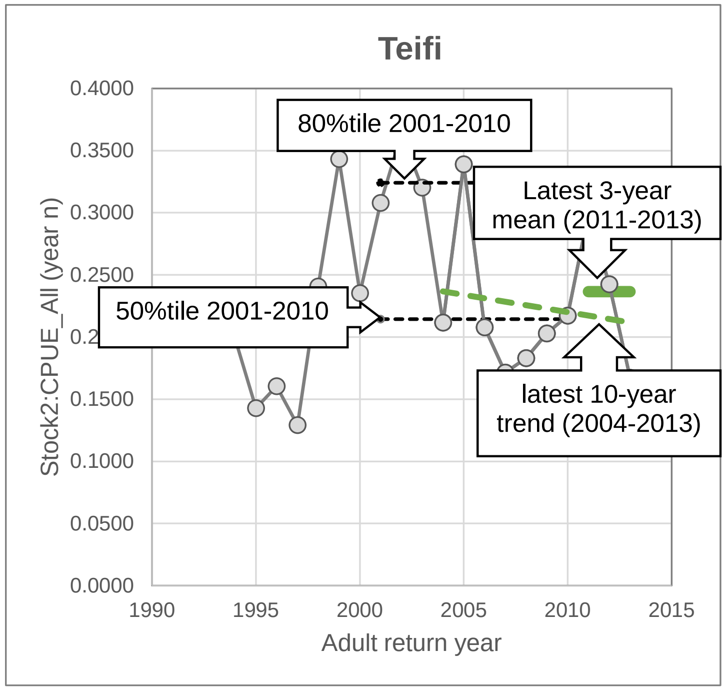



**Figure 3.2.8.1. Angling CPUE assessment of River Teifi (UK(Wales)) sea trout fishery status.**

### 3.2.9 UK (Northern Ireland)

Atlantic salmon and trout are both classed as 'salmon' in Northern Ireland legislation. As a result, owing to a closure of salmon fisheries, there is now no permissible catch of sea trout. Sea trout monitoring in Northern Ireland is often a by-product of ongoing statutory Atlantic salmon assessment work. Estimates of larger migratory trout are available in several rivers from automated fish counters. Information on sea trout catches from commercial and recreational fisheries have also been collected through logbook and carcass tagging schemes.

This main dataset collected in the region includes extensive semi-quantitative electric fishing surveys detailing the relative abundance of 0+ age class trout in several coastal rivers. Some supplementary information from opportunistic quantitative electric fishing surveys are also available.

The primary monitoring river in the country, the river Bush, has a small run of whitling and over the past 10 years sea trout have become more of a focus.

It is recognised that monitoring studies are expensive and take time to develop, and so the use of indicator stocks is being considered as an alternative. For this purpose, the Shimna river has been investigated, and a relatively simple model developed to describe the stock population dynamics (Figure 3.2.9.1). A fish counter is operated on the river, and the rod fishery gives a good return, although most fishing takes place in tidal waters, which may mean that fish from other systems are also included in the catches. Five-minute standardised electrofishing has been undertaken for 14 years covering of 25 sites enabling development of a fry index for the river and some acoustic tagging has been undertaken. A Ricker curve gives best fit for the SR relationship for river Shimna stock ($r^2$ of 0.70); (see Section 5.3.4).

Investigations have been undertaken to determine whether the approach works for other stocks. For the River Main it seems to work well (Ricker curve, $r^2$ of 0.84), however for the River Gelndun, the approach seems less effective (Ricker curve $r^2$ of 0.30), possibly owing to the fish counter being tuned to salmon. Longer time series will reveal if the approach is robust for transfer to other rivers.

Estimates have been made of the egg deposition by resident and anadromous trout and indicate that sea trout contributed 80-90% of the eggs in the river. The Baltic Sea electrofishing THS approach was trialled on the Shimna, giving a THS using 5 variables (missing data on slope) (See Section 5.2). Outcomes gave apparently robust agreements and may work well, and generally agreed with the current understanding of local stocks.

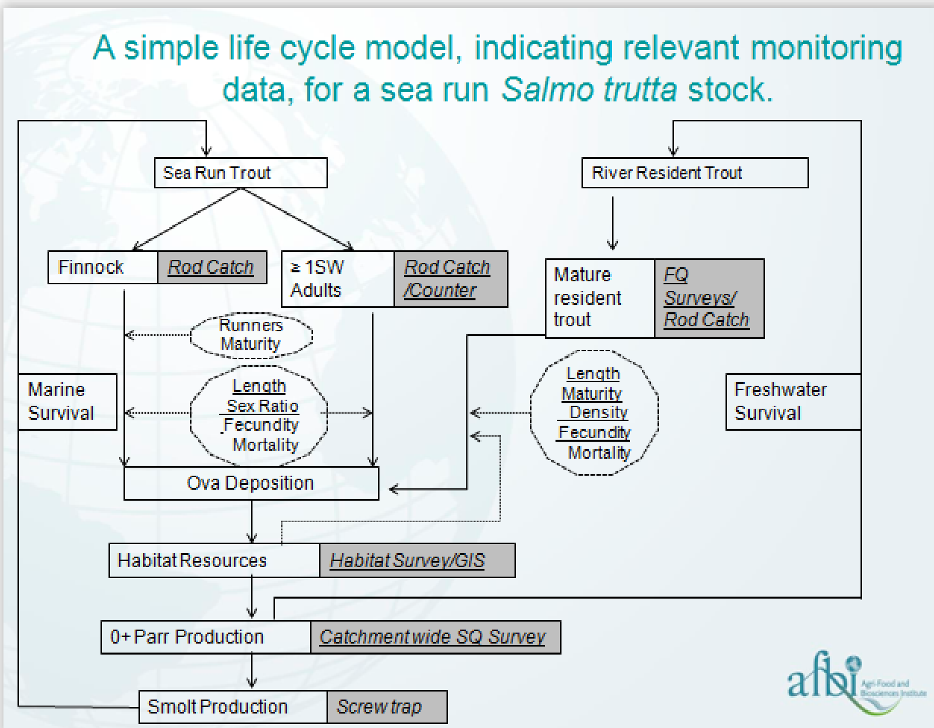



**Figure 3.2.9.1. A descriptive model of the sea trout stocks of the Shimna river.**

### 3.2.10 Scotland

Organisations in Scotland are in the early stages of determining how they may develop and provide management advice for sea trout stocks. Catch statistics are recorded, however no effort data are collected. Details of sea trout are not maintained on the rivers monitored for salmon. Counts of sea trout made by fish counters, which had been removed to estimate total salmon counts, could be reconfigured to obtain run estimates, but this may take a lot of work.

There is a considerable amount on data from electrofishing, and although sea trout are considered to be an incidental catch, the data are likely to be more easily available. What is not currently apparent is how the electrofishing data may be used in developing monitoring and assessments. In, Scotland promising attempts have been made to correlate the density of Atlantic salmon fry with habitat drivers such as distance to sea, upstream catchment area, altitude, channel width, gradient and land-use (Millar *et al.* 2015). These approaches been used to determine reference levels for juvenile abundance that have been applied in some provisional assessments in the river Dee (Malcolm *et al.* 2016). A similar approach may be possible for trout populations and very broadly resembles the method of trout habitat scores described in section 6.

## 3.3 Developing inventories of sea trout stocks

### 3.3.1 Mapping European sea trout stocks

The Workshop noted it is difficult to consider the question of why sea trout are present in some streams and not in others because there is no map or inventory of sea trout rivers in the ICES area or indeed any definition of 'a sea trout river'. The Workshop felt that to apply BRPs to rivers and to focus monitoring and research, it would be helpful to have a database of rivers that currently do, or could, hold sea trout. It is evident from studies in Norway (L'Abee-Lund *et al.*, 1989; Jonsson *et al.*, 2001), France, the UK and Ireland (Anon, 2016) that marine and freshwater habitats are likely to be at least partly responsible for determining the nature of sea trout stocks. Comprehensive information on the spatial variation in environmental factors and sea trout stock characteristics would thus be of great value for developing population models.

The Workshop agreed to assemble a preliminary table of sea trout rivers to support an eventual map. In the absence of widespread data, an expert opinion approach was suggested that graded rivers on a 5-point scale, informed where possible by (1) data on sea trout and salmon rod catches and / or (2) samples of adults taken by trapping or electrofishing. A historic set of rod catch data from the EU SALMODEL (Crozier *et al.* 2003) project was available for 192 ICES area rivers. This had been prepared to investigate the influence of sea trout on salmon in the context of setting salmon conservation limits in what were regarded then as 'salmon rivers' and so missed out many notional sea trout rivers. In the preliminary table developed by the Workshop (Annex 5), the ratio of sea trout to salmon catch (ST/SL ratio) was used to guide a judgement about the sea trout grade.

### 3.3.2 Index stocks

In a relatively small number of rivers, quite detailed information on the sea trout populations has been collected for extended periods; these are referred to as 'index' rivers. The types of monitoring activities on these rivers include purpose built trapping facilities, fish counters, routine electrofishing surveys, monitoring of catch and investigations of weights and lengths of returning spawners. The aims of these monitoring programme and the lengths of the time series vary considerably, but they are generally the best data sets available on sea trout populations. The Workshop therefore compiled a summary spreadsheet of monitored/index stocks (Annex 6) detailing the following information:

- River name, location and country, Organisation maintaining the facility/ collecting data, time series of the data;
- River wetted area and length, counter distance; river mouth latitude; stream order, presence of lakes; habitat classification and presence of a fishery

- Trap or counter facility; electrofishing surveys; tagging surveys; in river catch and method; sea catch and method;
- Estimates of weights, lengths, fecundity, run dates, smolt age composition, adult age composition, sex composition; and
- Reference point estimations: Adult (Spawning stock) estimates, smolt estimates, parr estimates, ova estimates.

To date, 34 rivers have been included in the summary (Table 3.3.1 and Annex 6), including 26 with trapping or counting facilities. For 32 rivers, juvenile electrofishing records exist and for 16 there are records of catch data. For 16 river populations, there are estimates of weights, for 19 there are estimates of length (respectively 8 and 11 by sea age) and for 6 there are fecundity estimates. Information on the timing of spawning runs has been collected on 19 rivers and for smolt runs on 16 rivers. Smolt age and sea age compositions have been assessed for 16 and 14 river populations respectively, and sex composition on 12 populations. Estimates of the size of the adult spawning stock have subsequently been made on 14 rivers, including smolt (10), parr (19) and ova (10) estimates (details are provided in Annex 6).

**Table 3.3.1. Summary of monitored sea trout rivers across Europe (See Annex 6 for further details).**

| Ref | Organisation | Country | Contact | Region | River | Time series |
|---|---|---|---|---|---|---|
| | | | | | | |
| 1 | Office National de l'Eau et des Milieux Aquatiques | France | Quentin Josset | Normandie | Bresle | 1982-2015 |
| 2 | INRA | France | Marie Nevoux (Didier Azam) | Normandie | Oir | 1984-2015 |
| 3 | Natural Resources Wales | Wales | Ian Davidson | North Wales | Dee | 1991-2015 |
| 4 | Environment Agency | England | Niall Cook | Northeast | Tyne | 2004-2015 |
| 5 | Environment Agency | England | Rob Hillman | Southwest | Tamar | 1994-2015 |
| 6 | Environment Agency | England | Rob Hurrell | Southwest | Fowey | 1995-2015 |
| 7 | Environment Agency | England | Andy Croft | Northwest | Lune | 1992-2015 |
| 8 | Environment Agency | England | Dave Spiby | Northwest | Kent | 1997-2010 |
| 9 | AFBI | N. Ireland | R. Kennedy | Antrim | Bush | 1974-2015 |
| 10 | AFBI | N. Ireland | R. Kennedy | Down | Shimna | 2003-2015 |
| 11 | Marine Institute | Ireland | Russell Poole | Mayo | Burrishoole | 1971-2015 |
| 12 | Inland Fisheries Ireland | Ireland | Paddy Gargan | Mayo | Erriff - Tawnyard | 1985-present |
| 13 | Inland Fisheries Ireland | Ireland | Paddy Gargan | Galway | Invermore | 1991-present |
| 14 | Inland Fisheries Ireland | Ireland | Paddy Gargan | Galway | Owengowla | 1991-present |
| 15 | Swedish University of agricultural Science | Sweden | Erik Degerman | Baltic | Åvaån | 1998-2015 |
| 16 | Swedish University of agricultural Science | Sweden | Erik Degerman | North Sea | Högvadsån | 1954-2015 |
| 17 | Swedish University of agricultural Science | Sweden | Stefan Palm | Baltic | Mörrumsån | 2002-2015 |
| 18 | Swedish University of agricultural Science | Sweden | Stefan Palm | Baltic | Vindelälven | 1998-2015 |
| 19 | Swedish University of agricultural Science | Sweden | Stefan Palm | Baltic | Rickleån | 2010-2015 |
| 20 | Sport fishing association | Sweden | Lars Vallin | Baltic | Själsöån | 1995-2015 |
| 21 | County of Skåne | Sweden | Anders Eklöv | North Sea | Kävlingeån | 1998-2015 |
| 22 | GEOMAR | Germany | Christoph Petereit | Schleswig-Hol | Habernisser Au | 2013-2015 |
| 23 | GEOMAR | Germany | Christoph Petereit | Schleswig-Hol | Lipping Au | 2013-2015 |
| 24 | GEOMAR | Germany | Christoph Petereit | Schleswig-Hol | Koseler Au | 2013-2015 |
| 25 | GEOMAR | Germany | Christoph Petereit | Schleswig-Hol | Aschau | 2013-2015 |
| 26 | GEOMAR | Germany | Christoph Petereit | Schleswig-Hol | Hohenfelder Mühl | 2013-2015 |
| 27 | GEOMAR | Germany | Christoph Petereit | Schleswig-Hol | Schmiedenau | 2013-2015 |
| 28 | GEOMAR | Germany | Christoph Petereit | Schleswig-Hol | Nessendofer Mühl | 2013-2015 |
| 29 | GEOMAR | Germany | Christoph Petereit | Schleswig-Hol | Farver Au | 2013-2015 |
| 30 | GEOMAR | Germany | Christoph Petereit | Schleswig-Hol | Kremper Au | 2013-2015 |
| 31 | FuU | Germany | Harry Hantke | Mecklenburg | Hellbach-System | 2011-2016 |
| 32 | FuU | Germany | Harry Hantke | Mecklenburg | Peezer Bach | 2011-2016 |
| 33 | FuU | Germany | Harry Hantke | Mecklenburg | Tarnewitzer Bach-S | 2011-2014 |
| 34 | FuU | Germany | Harry Hantke | Mecklenburg | Zarnow | 2014-2016 |

# 4 Anadromy and residency in trout

## 4.1 Background

Anadromy is one of a range of life history strategies found in *S. trutta*. Others include river residence, river migration, river-lake migration (adfluvial), lake residence and river-estuary migration (Ferguson *et al.,* 2015). The degree of migration (i.e. within freshwater or between freshwater and marine environment) is influenced by a combination of the environment (physical characteristics and productivity (e.g. nutrient/food availability)) and genetics. Migration is probably a means to increase energetic input and growth (Gross *et al.*, 1988; Elliott 1994; Ferguson *et al.* 2015). A higher proportion of anadromy is usually observed in females compared with males (e.g. Jonsson *et al.* 2001): the larger size that can be realised through anadromy is more beneficial for females, through increased egg production, whereas resident males can adopt a 'sneaking' tactic to fertilise eggs rather than competing for mates (Ferguson *et al.* 2015).

The tendency to anadromy appears to increase with latitude (Jonsson & Jonsson 2009) and anadromous fish dominate egg production in most northern European river systems.

Nonetheless, a range of stock structures in terms of resident and anadromous fish can occur over quite localised geographic scales. For example, on the north coast of France, rivers in the west of the region support primarily resident brown trout, whereas rivers in the east (upper Normandy) support a high proportion of sea trout. Sympatric resident trout are also important in many lacustrine systems, but considerable variation in contributions to egg deposition and smolt production is observed.

Anadromy will tend to confer higher fitness (greater lifetime reproductive output) when better feeding opportunities exist at sea, leading to higher growth rates and fecundity as well as larger ova with higher survival. A more stable marine environment may also offer refuge from variable conditions in the river (Ferguson *et al.* 2015). On the other hand, residency may be advantageous through a lower risk of predation and parasitism (higher survival rate) and avoiding the energetic costs of anadromous migration with its associated physiological changes. The proportion of anadromous migrants in a system is thus expected to vary according to the characteristics of the local riverine and marine environments.

The extent to which anadromy versus residency in *S. trutta* is influenced by genetics or environmental conditions is unknown and is the topic of a number of current research projects. Heritability estimates for anadromy in steelhead (hatchery) and brook charr (wild) of 0.5 to 0.6 indicate that about half of the variation in life-history can be attributed to additive genetic variation (Ferguson *et al.* 2015). Other life-history traits in sea trout appear to show relatively high levels of phenotypic plasticity (for example, the proportion of finnock (0+ sea winter fish) out of all returning sea trout varies strongly from year to year in many stocks). A genetic difference in migratory tendency between the sexes has also been found in some rivers, with females showing a higher degree of anadromy (Jonsson 1985).

Energetic status may be the most important proximate environmental influence affecting the anadromy decision. Food and energy limitation (e.g. because of high densities or fast growth in the river) have been found to be correlated with anadromy, while higher lipid stores (needed for maturation) are associated with residency (Ferguson *et al.* 2015).

The prevalence of anadromy may also be related to river size and the presence of salmon; for example, sea trout are often found in small coastal streams that don't support salmon, while salmon often dominate in larger rivers. On the basis of the observed correlation between salmon abundance and the propensity for trout anadromy in large rivers, salmon abundance was suggested as a potential predictor for proportion of migratory fish in rivers where this is unknown. Annex 5 summarises information by country about the ratio of sea trout to salmon in rivers where sea trout occur.

Using life-tables to study the trade-offs (in lifetime reproductive output) between anadromy and residency for a river such as the Tywi in Wales showed that assuming a similar (slightly lower) survival rate and a higher growth rate for migratory fish relative to residents, anadromy will tend to dominate a population if heritability is high due to larger size and higher fecundity of migratory individuals. For example, this exercise showed that if residents are slow-growing and anadromous fish comprise 20% of the spawning population, 80% of recruitment could be expected to come from migratory parents (Anon, 2016).

## 4.2 National data on anadromous *v.* resident trout

Information was presented to the Workshop on the relative abundance of resident and anadromous individuals in sea trout stock in different European countries.

### 4.2.1 France

In upper Normandy, the trout population of the Bresle River appears to be dominated by the anadromous form which represents on average 85.9% of the captures from the traps on the 1982-2015 period. However, this ratio may be biased owing to ontogenic differences between anadromous and resident trout, influencing their displacements and thus their probability of being captured. The female/male ratio observed in returning anadromous adults is about 1.20, which is consistent with that found in other rivers from Normandy (Euzenat *et al.*, 1999), while for resident trout it is 0.82 (Quéméré *et al.*, 2012). However, the sex ratio among 0+ juveniles is quite evenly balanced (1.06).

### 4.2.2 Ireland

Some Irish catchments, such as the Burrishoole, had a relatively high proportion of ova deposited by resident trout (~80% in 1985) and yet showed a remarkable decline in the S/R relationship (smolt output) following the stock collapse in 1989 (Poole *et al.*, 2006), while other lake dominated catchments, such as Owengowla and Invermore, continued to produce considerable number of smolts sometime after the 1989 stock collapse (Gargan *et al.* 2006a; Gargan *et al.* 2006b). Considerable adfluvial migrations occur in some catchments which have large lakes and access to the sea, but don't produce significant sea runs, such as Lough Neagh in Northern Ireland, and Lough Ree on the River Shannon.

### 4.2.3 Norway

Freshwater resident females were found to comprise a relatively small part of populations (mean 3·7%), although resident males were abundant in all the investigated populations (mean 48·9%), based on a study of 17 coastal streams with mean annual water discharges of ≤1 $m^3 s^{-1}$.

### 4.2.4 Sweden

In two small coastal stream in Sweden, between 17.9 and 57.0% of the males in a cohort become small resident (male parr); (Dellefors & Faremo 1988) although the proportion of individuals showing anadromy probably can vary considerably (Jonsson & Jonsson, 2006). Unpublished data based from electrofishing suggests that resident fish make up between 1% and 12% of populations with a mean of 3%.

Resident females are generally rare but there are a few studies of spawning sea trout in small streams were the proportion of resident females participating have been quantified. When comparing the sex ratio among resident individuals in six small coastal stream, resident females only represented 10 % of the resident adults (Pettersson 2002). Further, in the river Krogabäcken, south of Göteborg, the spawning population at one site consisted of only 27 fish, of which 10 (6 females and 4 males) were anadromous (judging from colour) and the resident population consisted of 15 males and 2 females. The proportion of resident females was then 4.5% of the spawning population (unpublished data).

In the River Broälven, on the west coast, spawners were sampled between 1984 and 1990. Out of a total of 211 spawners, only 3.3% were resident females. Overall, 98 fish were resident (46 %) but the female proportion only represented 7 fish (7%). In contrast the proportion of females within the anadromous spawners were 37 %. (Unpublished data).

### 4.2.5 UK (Northern Ireland) – Shimna river

The overall production of ova by the resident and migratory portion of the Shimna river was estimated using data derived from quantitative electric fishing surveys and from a resistivity fish counter in conjunction with biological data including (density, sex ratio and maturity) with published fecundity estimates for resident and anadromous trout (Crisp & Beaumont, 1995). The ova production estimates indicated that larger sea trout (>40 cm), produced the majority (~85%) of eggs deposited in the river each year.

## 4.3 Influence of marine environment in the Irish Sea on variation in life history traits

### 4.3.1 Introduction

Key post-smolt life history traits of survival, growth and maturation are important characteristics of sea trout stocks and define their population dynamics and stock structure. These were described and analysed in rivers around the Irish Sea as part of the Celtic Sea Trout Project (Anon, 2016). A brief account of this work, as given to the WKTRUTTA2 meeting, is outlined below, with the main hypothesis that the observed variations in traits are associated with spatial variation in the marine environment.

### 4.3.2 Marine environment of the Irish Sea

The marine habitat of the Irish Sea (Figure 4.3.2.1a-c) is characterised by varied bathymetry, fronts, gyres and residual currents. The coastline is strongly featured, especially on the eastern seaboard (Wales, northwest England, southwest Scotland) with large, shallow embayments and estuaries that are warmer in summer and cooler in winter than the western seaboard (Irish coast) which tends to be less featured, although there are important enclosed parts such as Strangford Lough and Dundalk Bay.

Sea bed composition appears to influence the availability of habitats of key prey species, particularly sandeel, and trawl surveys demonstrate regional variation in the distribution and abundance of sprat and sandeel which are shown to be the key diet in the sea trout of the Irish Sea.

In this preliminary study sea temperatures were estimated for the immediate coastal environment of each river. Spatial location was defined by latitude and E-W divisions between the seaboards of the Irish Sea.

### 4.3.3 Life history

Contemporary (2009–2012) data came from scale reading from samples from 23 rivers mainly around the Irish Sea, but extending to the Currane in southwest Ireland, which enters the Celtic Sea. The samples were mostly collected from the in-river angling fisheries and therefore represent multiple populations although in the following are taken as representative of putative whole river population.

The diversity of age structures is seen in Figure 4.3.2.2, with rivers ranked by proportion of n.0+. Post-smolt growth of each river population was indexed by the mean length of 2.0+ whitling sampled during the project. Tree regression showed that growth was significantly higher on the eastern side of the Irish Sea and it was significantly higher in lower latitudes on both the sides of the Irish Sea (Figure 4.3.2.3). This is inversely consistent with the sea temperature data, which also showed significant relationships with latitude and with growth.

Marine survival was significantly lower on the western side of the Irish Sea and on the eastern side was higher in more southerly locations (Figure 4.3.2.4). Similarly, the proportion of whitling was significantly lower on the western compared to eastern seaboards, but the latitude effect was less marked (Figure 4.3.2.5).

Overall, the pattern of growth and survival was quite distinctive (Figure 4.3.2.6) and in line with previous studies that have looked at parts of the Irish Sea stocks (e.g. Fahy 1978; Harris 2002). Within the major geographical groups there was further variation (Figure 4.3.2.7) that may be explained by additional factors such as better models of sea trout post-smolt distribution, local river specific effects, coastal structures, marine productivity and genetics. Assuming that these latitudinal and longitudinal variations are due to varying marine conditions, this analysis points to the potential for substantial marine influences on adult life history traits that might be expected to act on population dynamics through fitness. Further analyses of life history traits incorporating as explanatory variables better metrics of marine habitat, productivity and freshwater habitat variables are planned.

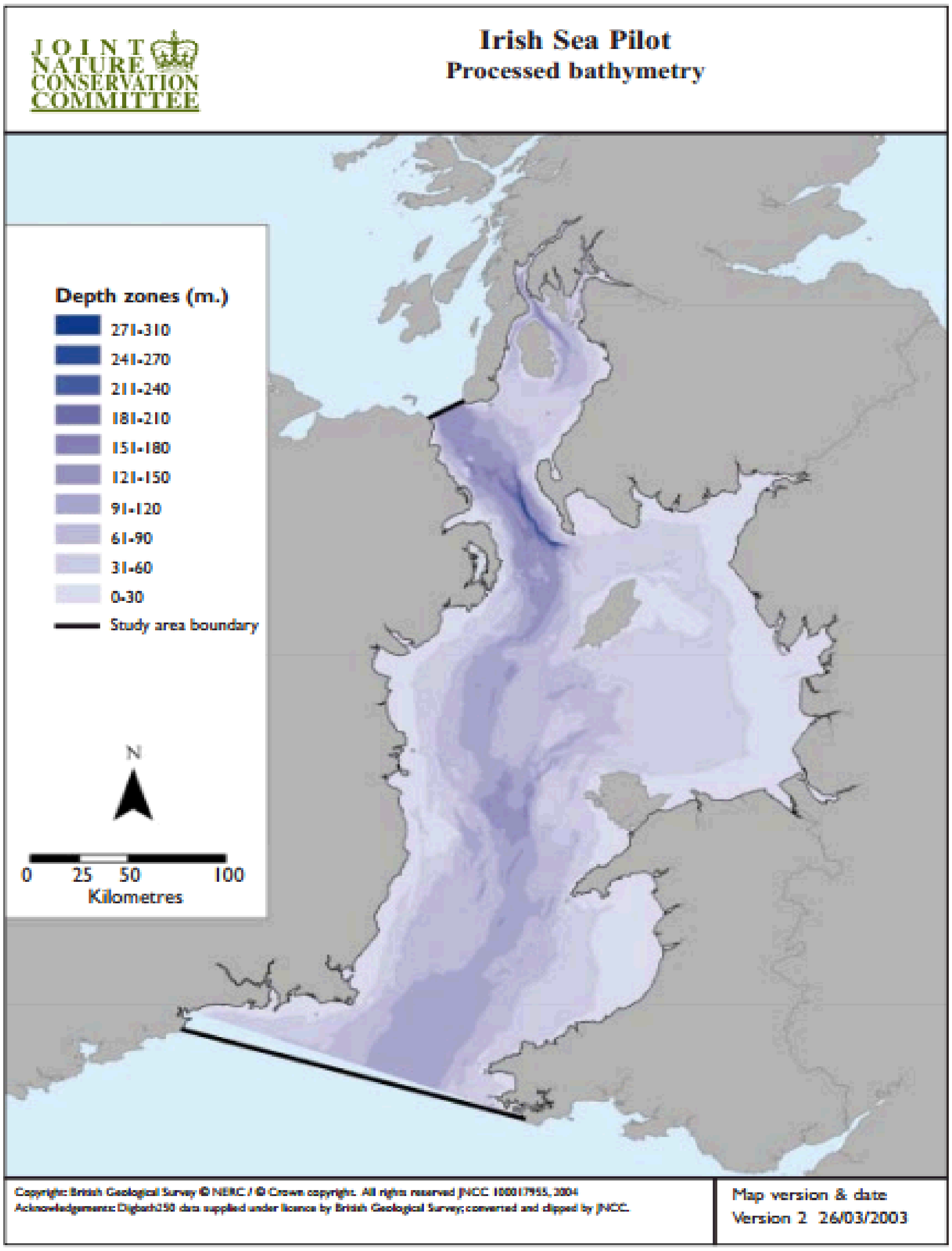



Figure 4.3.2.1a. Geographical variation in depths in the Irish Sea.

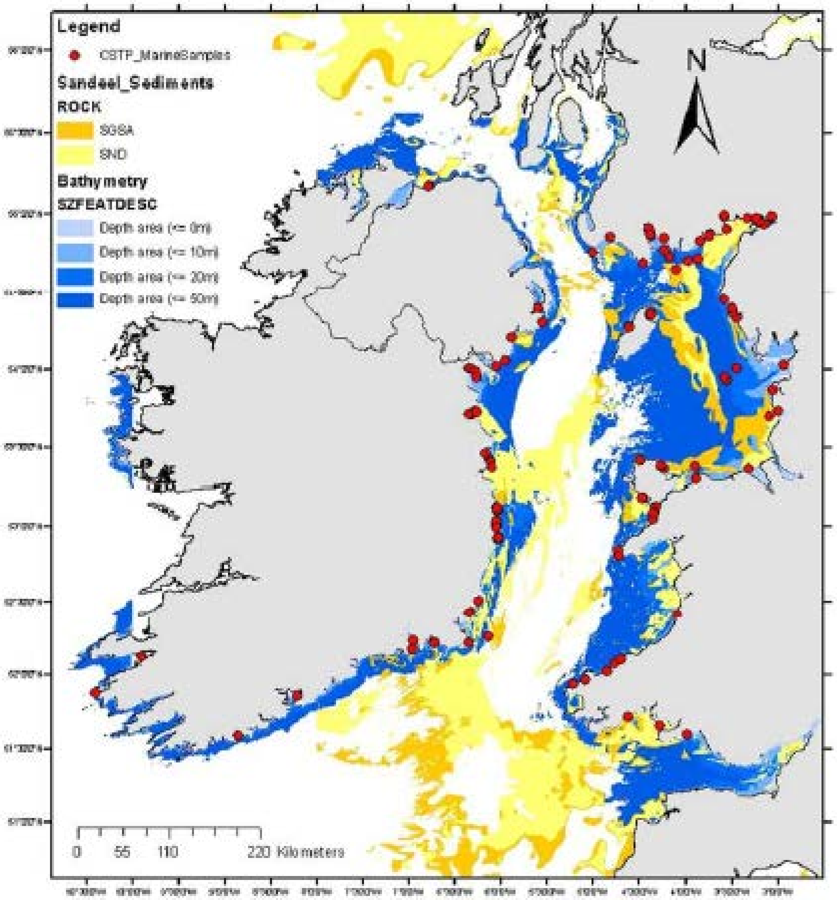



**Figure 4.3.2.1b. Geographical variation in sea bed substrate in the Irish Sea.**

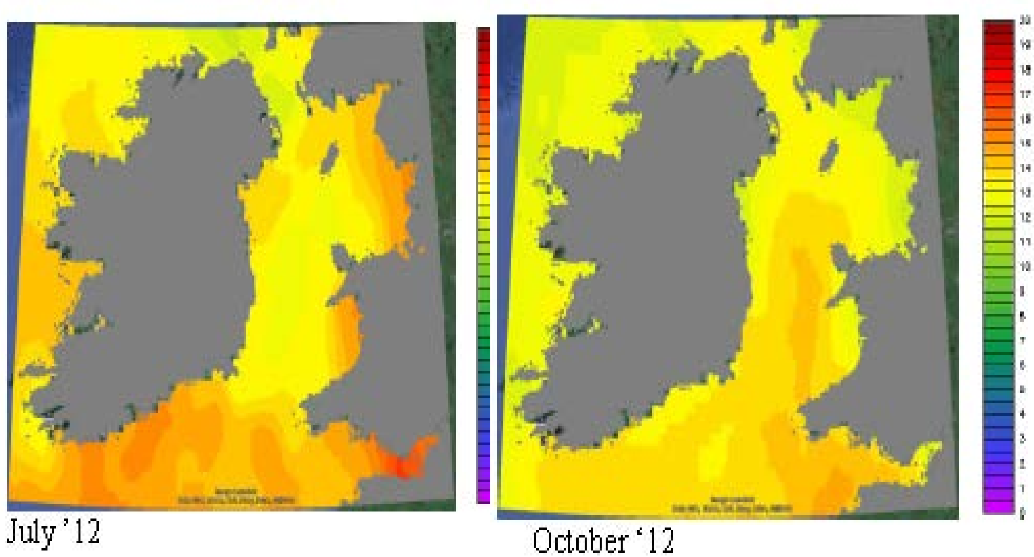



**Figure 4.3.2.1c. Geographical variation in water temperature around the Irish Sea in July and October 2012 (colour scale in degrees C).**

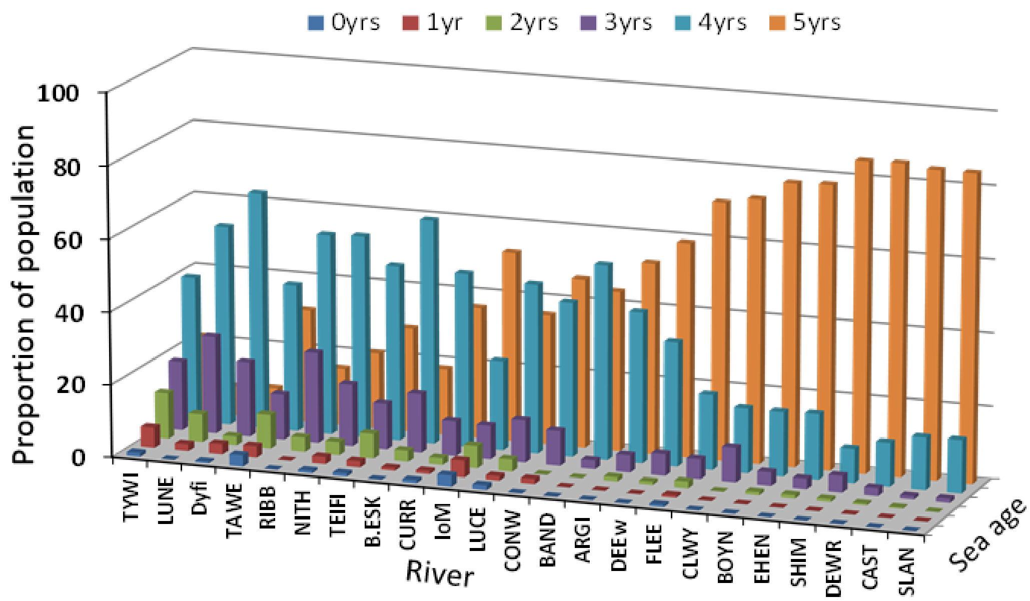



**Figure 4.3.2.2. Sea age variation in sea trout from 23 Irish Sea rivers.**

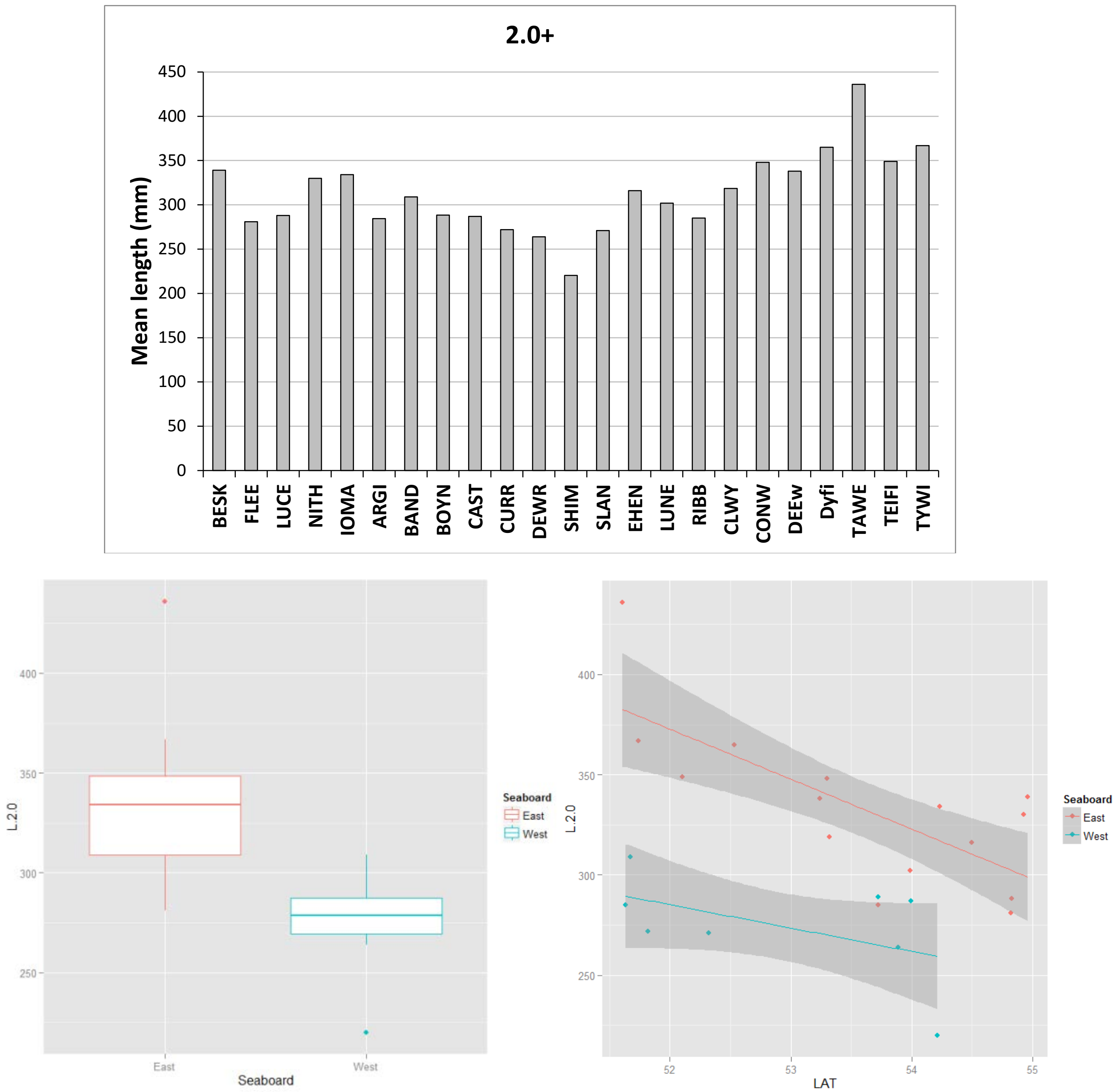



**Figure 4.3.2.3. Top: variation in fish lengths of 2.0+ (whitling). Lower left: mean fish lengths on east and west sides of the Irish Sea (referred to as 'seaboard' in axis label and legend). Lower right: effect of latitude on length on east and west sides of the Irish Sea (referred to as 'seaboard' in legend).**

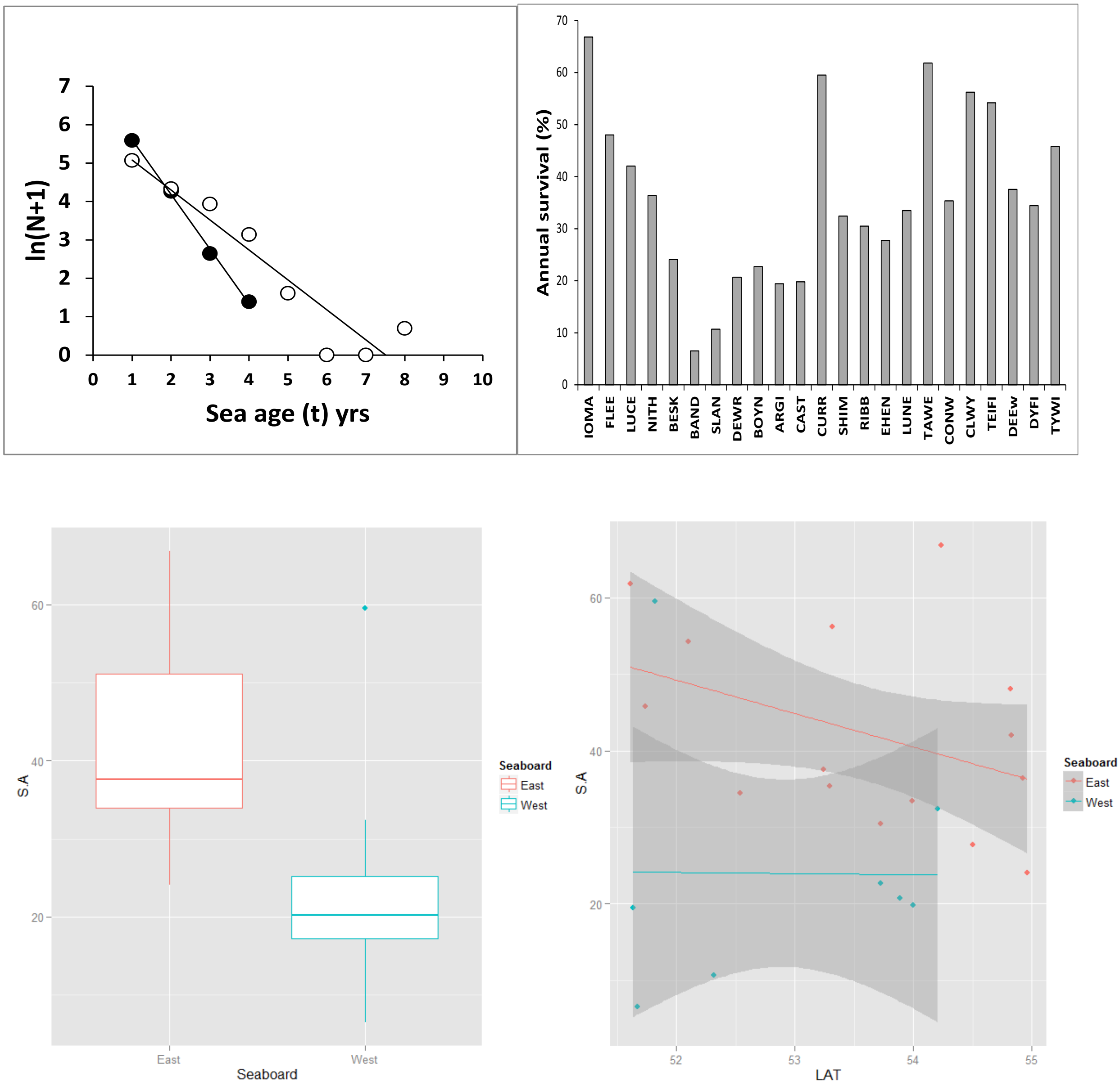



**Figure 4.3.2.4. Average marine survival (SA). Top left: Estimation method in two rivers (Border Esk (closed circles; Tywi (open cicles)), mean SA(%) estimated from abundance (N) loss rate over sea age range of population, after first marine winter (SA = 100. exp(-z), where z is regression slope). Top right: variation in SA in 23 rivers; mean values for east and west sides of the Irish Sea (referred to as 'seaboards' in axis label and legend). Lower right: effect of latitude on SA on east and west sides of the Irish Sea (referred to as 'seaboards' in legend).**

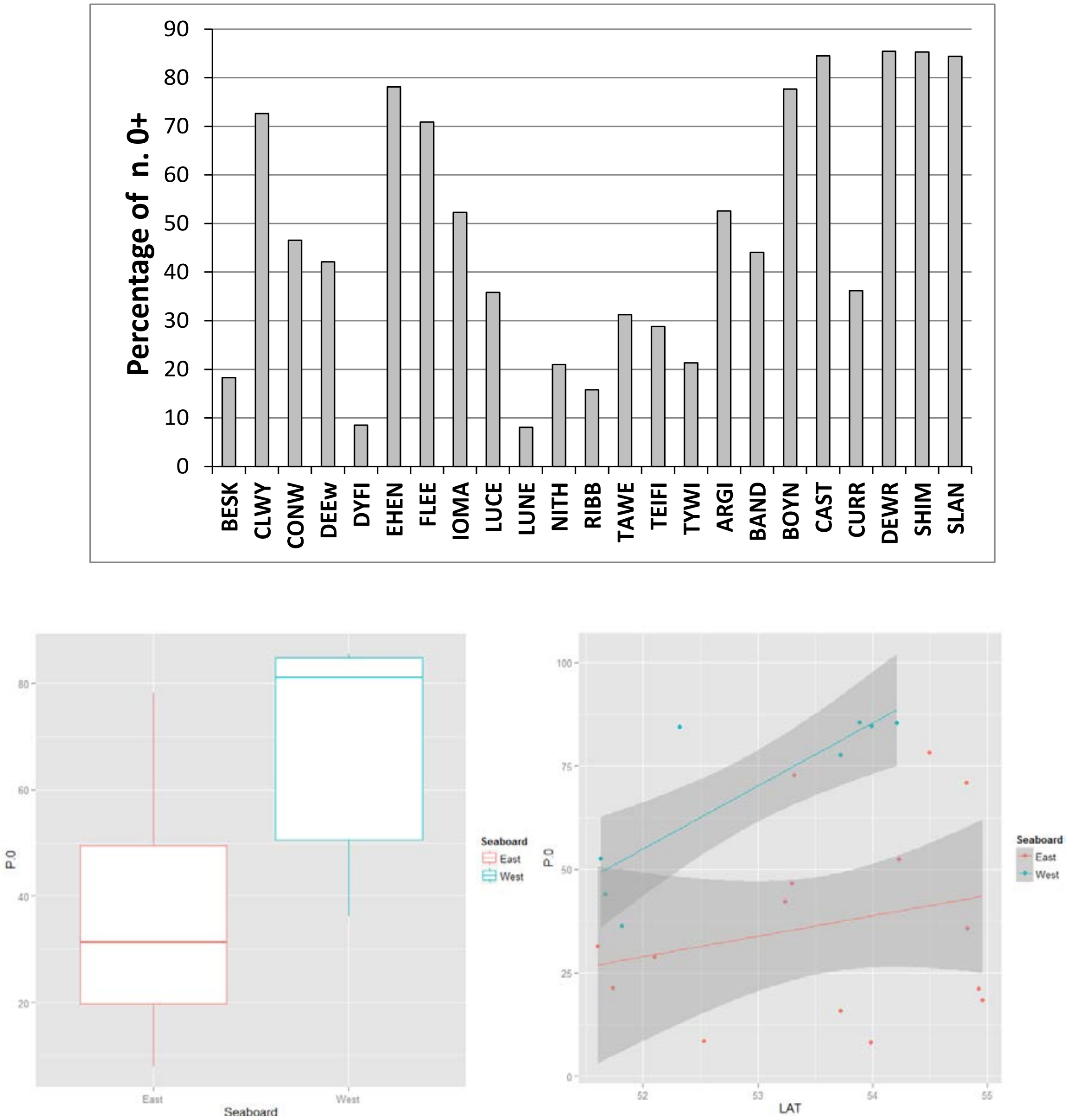



**Figure 4.3.2.5. Top: variation in percentage n.0+ in sample. Lower left: mean values for east and west sides of the Irish Sea (referred to as 'seaboards' in axis label and legend). Lower right: effect of latitude on % for east and west sides of the Irish Sea (referred to as 'seaboards' in legend).**

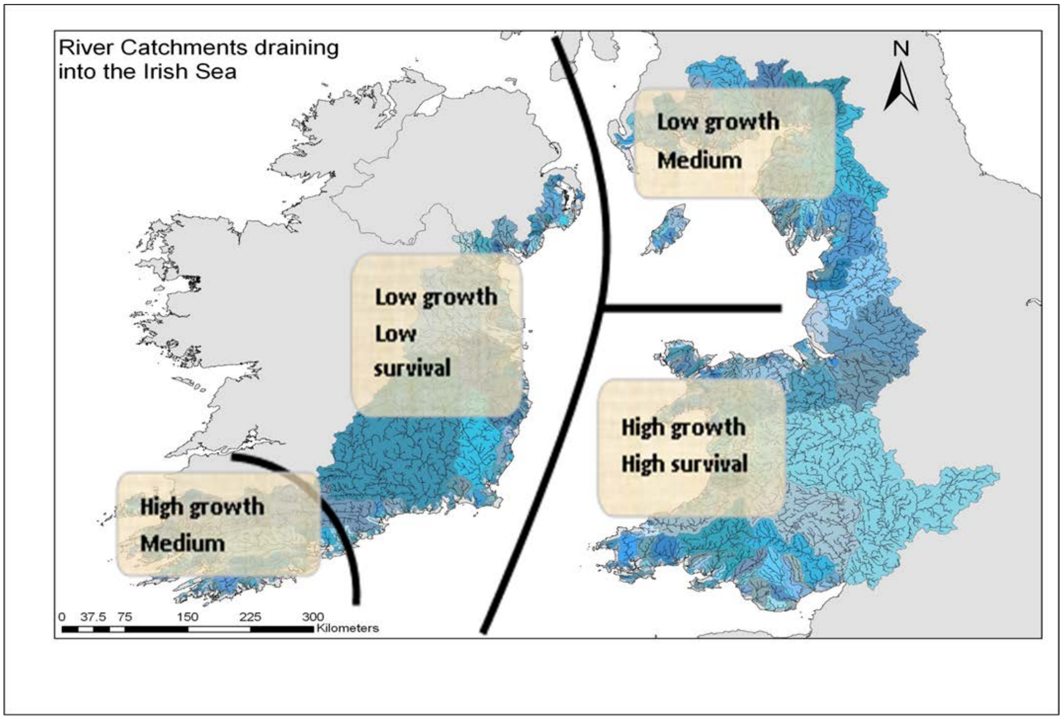



**Figure 4.3.2.6. Summary map of spatial variation in sea trout growth and survival in the Irish Sea. There is also variation within these groups.**

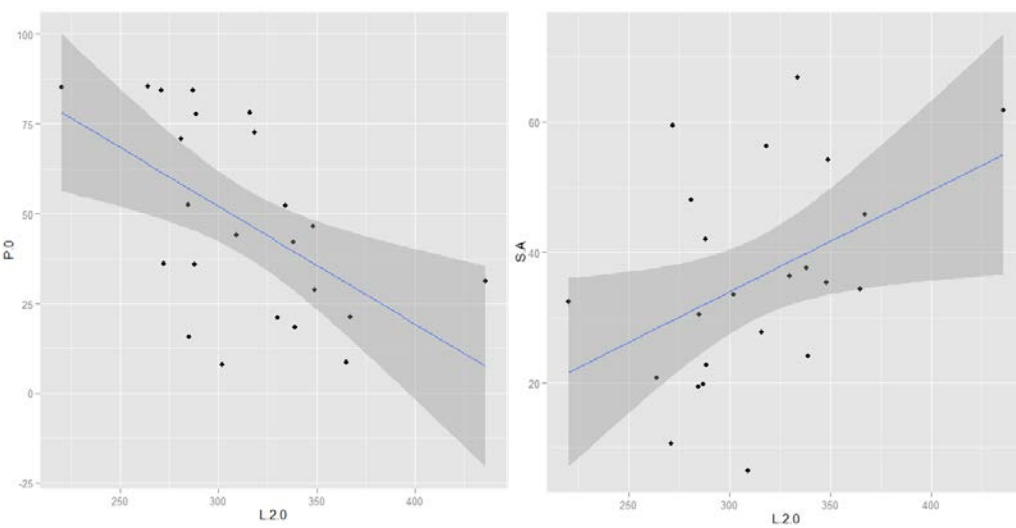



**Figure 4.3.2.7. Left: relationship between length of whitling (2.0+) and percentage of n.0+ in population. Right: length of whitling (2.0+) and mean annual survival.**

## 4.4 Discussion

The presence of freshwater resident trout, particularly females, can have a number of influences on stocks and stock assessments. Considerable production of juvenile trout from residents may make the results of juvenile stock surveys difficult to interpret. Estimating SR relationships for sea trout may also be problematic if the resident component of the population is not accounted for. Considering that up to half of the variability in migratory life-history tactic may be related to environmental conditions, it is difficult to rule out the possibility that the contribution of resident fish to recruitment could change through time e.g. in response to deteriorating conditions in the river, or a systematic decrease in marine survival rates. Under such circumstances, using the spawning contribution from anadromous fish only to predict recruitment may be problematic.

The relative contribution of anadromous and resident trout to smolt production differs between catchments, and resident trout stocks may make a significant contribution in some systems. A case-by-case approach is therefore warranted. In general, it was recommended that models for sea trout should ideally attempt to include the resident population where facultative anadromy occurs. For example, a generic modelling framework could be developed in which residency and anadromy are included within the model structure (e.g. in a probabilistic framework or using reaction norms), so that the degree of residency could be specified appropriately for the system in question. Nevertheless, this may be difficult to undertake owing to lack of data, and the fact that resident fish make only a small contribution to egg deposition in some rivers suggests that for these stocks it is probably reasonable to develop population models of sea trout on their own.

# 5 Modelling populations and setting reference points

## 5.1 Population versus Individual based models

Both population based models (PBMs) and individual based models (IBMs) may be used to describe the dynamics of fish populations. PBMs simulate populations by applying survival and growth parameters to the population as a whole, including stochastic variation where appropriate. Variation between individuals can be taken into account by applying ranges to parameters and running multiple simulations, thus providing a range of outcomes.

IBMs simulate populations as being composed of discrete individual organisms. IBMs follow each single individual through a set of key demographic, physiological or behavioural mechanisms that are explicitly described in a probabilistic framework (e.g. survival, growth, smoltification, etc.). They are bottom-up models in which population-level patterns emerge from the interactions among autonomous individuals with each other and their environment. This approach can integrate a high level of heterogeneity among individuals, thus returning a higher diversity in life history trajectories than population based models.

## 5.2 Bayesian approaches

### 5.2.1 Application of IB-SALMON to sea trout

Bayesian models permit a probabilistic approach to fisheries stock assessment in which uncertainties about unobserved quantities are formulated as probability distributions (McAllister and Kirkwood, 1998; Gelman *et al.* 2005). Today, the scientific advice for Baltic salmon is entirely based on Bayesian methods (IB-SALMON); (Kuikka *et al.* 2014; ICES

2015a). This framework can be applied both for estimation of historical stock status and for predictions of future stock development under possible alternative management actions. Under a Bayesian interpretation of probability, one can also answer the essential questions of interest, such as, “what is the probability of the stock reaching $B_{MSY}$ in the next five years?" or “what is the probability of the spawning stock falling below some precautionary reference point in the next 10 years”. Current salmon stock-assessments are based on describing the population life-history using an age-structured state-space model (Michielsens *et al.* 2006, 2008; Kuikka *et al.* 2014; ICES, 2015a).

Bayesian population dynamics models offer a flexible approach for building mechanistic models of sea trout stock and their fisheries that can utilize all and integrate all of the available biological knowledge and data in a framework that can accommodate both process and observation errors (Millar and Meyer, 2000; Buckland *et al.*, 2007). A Bayesian population dynamics model for sea trout could be built to include salient aspects of sea trout life-history. For example, the prevalence of resident and migratory components of the population by using expert knowledge to inform model structure.

A Bayesian approach allows a diverse range of data and expertise to be incorporated probabilistically into the stock assessment. This is seen as a key advantage in possible applications to sea trout where the available data are often sparse (high degree of uncertainty) and diverse. Multiple data sources can be integrated in a rigorous way: posterior distributions obtained from the analysis of one dataset can be used as prior distributions in the analysis of another dataset. In this way, the Bayesian approach serves as a formal tool for scientific learning as the information from multiple datasets accumulates sequentially (Michielsens *et al.* 2008). An overview of the Baltic salmon assessment model with the different sub-models, data or information used within the sub-models and their outputs is shown in Figure 5.2.1.1. The use of a Bayesian estimation procedure allows this type of systematic and integrative modelling approach which can utilize most of the information sources available.

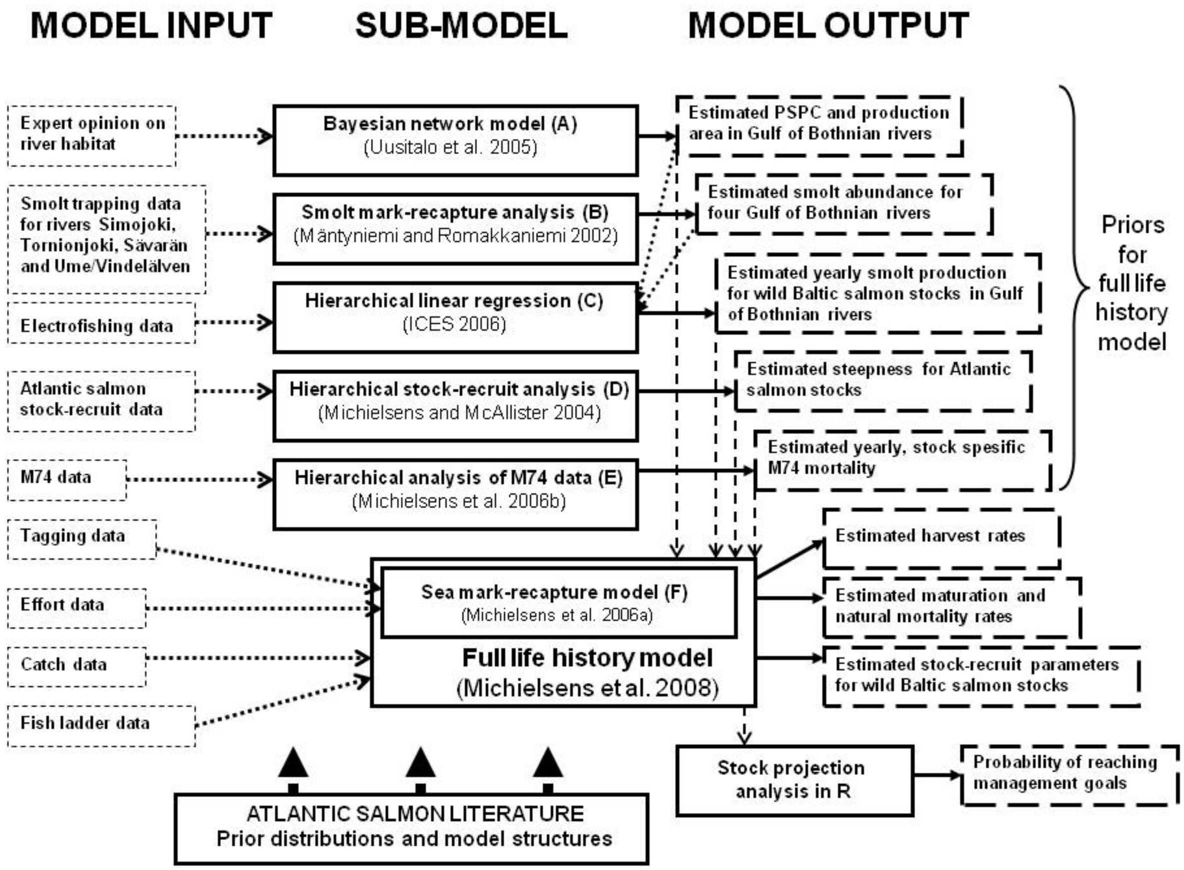



**Figure. 5.2.1.1. The structure of the Baltic salmon assessment model. The most essential blocks of the model are shown in the boxes enclosed by solid lines. The data are illustrated with thin dashed-line boxes on the left and the model outputs with thick dashed-line boxes on the right**

### 5.2.2 Account for uncertainty (risk assessment)

The precautionary approach incorporated in EU fisheries legislature demands methods that explicitly take into account all sources of uncertainty (Kuikka *et al.* 2014). The principal advantage of Bayesian models compared to traditional statistical models is perhaps that the uncertainty inherent in large and highly variable datasets as well as uncertainty about population and fishery processes can be taken into account to provide quantitative probabilistic assessments of population status. The Bayesian statistical framework facilitates incorporation of the full range of uncertainty (Punt and Hilborn, 1997) and is therefore a suitable tool for the appropriate assessment of the risk to fish stocks that is associated with different management actions (McAllister and Kirkwood, 1998).

### 5.2.3 Share information among stocks with limited data

In data-poor situations (the case for many sea trout stocks), Bayesian approaches are extremely useful, as they allow learning via synthesis of information from other conspecific or related stocks. Often, data are available from other stocks of the same species or from other related species, and these can be used to build informative prior distributions for the stock of interest with hierarchical models.

Hierarchical Bayesian models (HBM); (Gelman *et al.* 2005; Romakkaniemi 2015 and references therein) offer a natural way to model variation at multiple levels (for example, at the population and meta-population levels), and to “borrow strength” between and within the different levels of a model. In the context of sea trout, for example, a hierarchical approach could be used to learn about biological parameters or SR parameters for stocks with little or no available data (e.g. Pulkkinen and Mäntyniemi 2013)

## 5.3 Mark-recapture analyses

Mark-recapture essentially involves the marking of individual fish either with a common “mark” e.g. fin-clip or more usually, a unique mark or tag that can be used to identify the individual, such as Carlin Tags which have been used for mark-recapture studies of sea trout (Jensen *et al.* 2012). Marked individuals are then detected or recaptured on subsequent occasions. If recapture rates are sufficiently high, tag return data from a well-designed experiment are amongst the most informative data available for fisheries stock assessment (Punt *et al.* 2000; Martell and Walters 2002).

Data from a well-designed tagging study could potentially address a variety of important questions for sea trout populations. Mark-recapture analyses could be used to estimate key demographic parameters, for example rates of natural mortality, movement (which may be related to smoltification and maturation rates), recruitment to the population and growth. Providing the underlying assumptions are met (see below) mark-recapture analyses can provide a powerful method for estimating abundance (Thompson *et al.*, 1998). Where tagged fish are recaptured by fisheries, recapture data can also be useful for estimating rates of fishing mortality, providing that the tag reporting rate is known or can be estimated. In addition, tagging experiments could potentially be used to quantify the proportions of resident and migratory fish in sea trout populations.

Depending on study design, it may be possible to estimate parameters by individual characteristics of interest such as age, size or sex, or with respect to time (year, season) and/or area. The influence of environmental covariates (temperature, flow) on key demographic parameters can also be investigated. Parameter estimates from mark-recapture models can be incorporated into population dynamics models that can be used to assess the viability of the population over time, quantify the main threats to the population and evaluate the impact of different management strategies (Lettink and Armstrong 2003).

Mark-recapture models can be classified according to a number of structural features which depend on the kind of data available. Returns of conventional tags (e.g. Carlin tags) are often fishery dependent, giving rise to single recapture events when a fish is captured; in contrast, telemetry tags and PIT tags can provide data without physical recapture and can produce multiple observations for a single individual over its lifetime. Tag return models are appropriate where returns of harvested fish come from one or more fisheries over an extended period of time. They model single recapture events of tagged fish and are a means of estimating a population’s total mortality rate, and in some contexts can be used to estimate separate fishing and natural components of mortality (Brownie *et al.*, 1985; Pollock *et al.*, 1991; Hoenig *et al.*, 1998). Multiple-recapture methods allow estimation of the abundance and survival of animal populations as well as movement probabilities, based on locations and/ or states of fish at release and subsequent recapture events (Pine *et al.*, 2003).

Parameter estimation through mark-recapture modelling is contingent on a number of assumptions, outlined by Brownie *et al.* (1985). These are as follows; that the marked sample is representative of the population, there is no tag loss, survival rates are not influenced by the tagging process itself, the tag reporting rate must be known or estimated, time and location of recoveries are correctly tabulated, the fate of each tagged animal is independent of the fates of other tagged animals and all tagged animals in a stratum (e.g. age class) have the same survival and tag recovery rates. In general, mark-recapture models can be used to estimate tag recovery rates, which are composites of harvest rates and rates of tag reporting, tag shedding and tag-induced mortality. Parameter estimation can be improved where covariate data are available to estimate auxiliary parameters such as the tag reporting rate, tag-induced mortality rates and tag-shedding rates. Where available, fishing effort data can be incorporated as a covariate for fishing mortality, allowing the tag reporting rate, natural mortality rate and catchability coefficient to be estimated (Hoenig *et al.*, 1998).

Marking of juvenile trout in the Oir River, France, has been used in a multiple recapture framework to compare the life-history strategies of resident and sea trout in a population dominated by resident trout. A multi-event mark-recapture model has been developed to explicitly describe ecological processes (survival, migration, maturation) while accounting for imperfect observation processes (detection, life stage assessment using various recapture devices). Temporal fluctuations in migration probabilities out of the river were estimated in juvenile trout. This study also investigated difference in the age of maturation and survival rates of resident and anadromous trout, as well as strategy-specific responses to changes in environmental conditions and density.

Carlin Tags and PIT-tags are used for sea trout studies in several rivers in Norway (Jensen *et al.* 2012; Fiske *et al.* 2014).

Bayesian state-space mark-recapture models have been applied to tag return data from Carlin tagged reared sea trout release in the Finnish Isojoki and Lestijoki Rivers (Whitlock *et al.* 2016). The open population models were age- and life-history stage structured, tracking the movements of parr released in the river. Fleet-specific rates of fishing mortality were estimated for both recreational and commercial fisheries in the river and sea environments. This study also estimated life-history specific rates of natural mortality and rates of migration from river to sea and sea to river.

For overviews of mark-recapture models, see e.g. Seber 1982, Burnham *et al.* 1987; Lebreton *et al.* 2009.

## 5.4 Developing Biological Reference Points

ICES has established principles for setting BRPs for Atlantic salmon (*Salmo salar*) and European eel (*Anguilla anguilla*) either of which may be used as a basis for setting BRPs for sea trout. In the case of Atlantic salmon, the North Atlantic Salmon Conservation Organisation (NASCO) has agreed that CLs and MTs should be set for each river stock and that stocks should be maintained above the CL by the use of the MT (NASCO 1998). ICES and NASCO currently define the CL for salmon as the stock size that is expected to generate maximum sustainable yield in the long term (i.e. $S_{MSY}$); (ICES 2015b) as derived from an adult-to-adult SR relationship (Ricker, 1975; ICES, 1993). Thus annual estimates of the numbers of returning spawners or the egg deposition can be compared with the reference level to determine the stock status, and forecasts of stock numbers can be compared with the reference level to set fisheries regulations (ICES, 2015b). Management objectives are defined in terms of the probability that the CL is being or will be exceeded.

ICES (1998) advised that CLs for salmon should ideally be set for individual rivers based on long time-series of stock and recruitment data. The best SR relationship would be derived from data collected over a long time period using multiple traps or counters to provide information on individual populations, but in practice data is normally collected on whole river stocks. As such data can only be collected for a very small proportion of rivers, it is necessary to transport data from the 'donor' rivers, where BRPs have been established, to rivers without these data. The approaches used rely on estimating suitable habitat types by various methods and applying target egg deposition rates derived from known S-R relationships.

An alternative procedure has been adopted for eel by the EU. There is no good SR relationship and so the BRP for eel has been based upon a predetermined percentage of the pristine spawning stock biomass ($B_0$). The pristine spawning stock biomass is the stable population size that would be expected to arise if all fishing pressures and other anthropogenic impacts were removed. Some countries have applied this by using habitat based population models to estimate the pristine spawning stock biomass for each River Basin District. Estimates of the annual silver eel escapement are then compared with this figure. Unlike salmon and sea trout, there is presumed to be one single spawning stock of eel and then a dispersal of recruits to the continent where the stock is fragmented into individual sub-units during the growth phase. The adoption of the notional population size compared to the pristine state required for the EU assumes that the sum of individual sub-unit targets is the equivalent of the whole stock achieving its target.

The Workshop considered that either (or both) of these approaches could be adapted for sea trout. An approach similar to the eel model, based on juvenile trout stocks, has been developed for the Baltic and is described in Section 5.2. Applying the methodology developed for salmon would require SR relationships for index river stocks that could be transported to other rivers. However, there are few monitored stocks for which SR relationships have been developed (See Section 5.3), and in view of the great complexity and variability of the sea trout life-cycle, it may be more difficult to transport BRPs reliably. Alternative methods might therefore need to be used to develop pseudo SR relationships, for example using catch statistics (See Section 5.4). Other modelling approaches were also discussed by the Workshop that can contribute to sea trout stock management.

# 6 Juvenile based assessment – Trout Habitat Score

## 6.1 Background

Assessing trout recruitment at electric fishing survey sites requires a common classification system that describes habitat quality or 'habitat score' at specific locations. Corresponding information on expected trout abundance at each habitat grade/score is also required in order to evaluate recruitment potential. A common habitat classification system for trout parr habitat, the THS, was developed for use on sea trout rivers in the Baltic Sea region (SGBALANST, 2011).

Biological reference points (BRP) should be based on knowledge of pristine conditions or carrying capacity. All aspects of sea trout life history need to be included in an assessment, but preferably it should focus on vital life stages that have small stochastic variations and are easy to sample. The Baltic ICES Study Group SGBALANST screened available data for different regions/countries and found that all partners had good electrofishing data for fry (0+) and parr (>0+), but few data on fishing, ascending spawners, smolt production and as a consequence SR relationships (e.g. ova to smolt, spawners to fry, river catch to fry). Monitoring of sea trout in the Baltic Sea is a by-product of the intense monitoring of Baltic salmon. SGBALANST concluded that this monitoring was not sufficient to perform a sea trout assessment, mainly due to the large size of (salmon) rivers monitored and the lack of monitoring in small and southern rivers and streams.

It was therefore decided to establish a stock index using electrofishing data, recruitment status, focusing on the abundance of fry in late summer sampling, i.e. after the expected high density dependent mortality earlier in summer (cf. Elliott 1994) in streams with sufficient number of spawners. In order to estimate the amount of trout parr habitat available in different rivers, a field stream habitat survey of the whole river often needs to be performed. The group found that no joint survey system existed and that data were generally lacking outside Denmark and Sweden.

At a catchment or reach scale, trout habitat indicated using maps and Geographical Information Systems (GIS) may be correlated with population occurrence and abundance. However, the ultimate factors structuring stream fish communities in streams may be productivity and water velocity. The latter is determined by slope and friction against bottom and shores. This means that a larger volume of water (increased stream width and depth) will have a higher velocity at a comparable slope. Catchment area, average flow, wetted width and slope can be used as proxies for water velocity. Slope has been proven an important characteristic of streams and fish distribution may be predicted from it (Huet 1959, Wang *et al.* 2003, Pont *et al.* 2005). Accordingly, modelling spatial distribution of salmonid occurrence in streams using different techniques (e.g. multiple regression, logistic regression, neural networks, classification trees, hierarchical Bayesian models) together with geographic information system (GIS) tools has proven successful, but normally only presence/absence has been predicted with good precision (McCleary & Hassan 2008, Clingerman *et al.* 2007, Rahel & Nibbelink 1999, Wyatt 2003). Often catchment size, slope (gradient) and water temperature (a proxy for productivity and/or growth rate) were important characteristics in these models (op. cit., Pont *et al.* 2005). Habitat descriptions from electrofishing sites are used in the current Baltic model and GIS data are excluded.

The approach consisted of five steps, with a sixth step added during the Workshop meeting:

1 ) Harmonising environmental data from electrofishing sampling;
2 ) Creating a common data base;
3 ) Establishing a simple habitat model describing the habitat quality for fry;
4 ) Establishing reference points for expected abundance at undisturbed sites;

5 ) Constructing the index; and
6 ) Validation.

These steps are described further below.

## 6.2 Harmonising environmental data from electrofishing sampling

In 2010/2011, a between-country comparison of the parr habitat description at electrofishing sites was performed and it was concluded that available data allowed sites to be compared with regard to habitat features (wetted width, average water velocity, average depth, dominating substratum, shade and for some countries slope/gradient).

## 6.3 Creating a common data base

Data from 2002 to 2008 were compiled and habitat descriptors were harmonised. A data set from the Baltic is updated bi-annually during the work of WGBAST (Working group of Baltic salmon and sea trout) where the section on sea trout is led by Stig Pedersen, Denmark. Recruitment status has been used in 2012 and 2015 to evaluate the status of sea trout stock in the Baltic Sea area. Results have been in alignment with expert judgement, and modelled trends in recruitment status have followed expected patterns. The database consists of 2700 fishing occasions.

## 6.4 Establishing a simple model describing the habitat quality for fry

Using data from Sweden, a habitat index was constructed as a simple additive model. Through the literature review (ICES 2011), earlier work in Poland (Piotr Debowski), a recent evaluation of Swedish data (Degerman & Sers 2010) and expert judgement of the SGBALANST group, the suitability of each of the six environmental factors for trout parr was determined. The suitability ranged from 0 to 2, with 2 indicating the highest habitat quality. Smaller streams, with a slope of 0.5–3% and a bottom substrate dominated by gravel and small stones (approx. 20–200 mm) had high macrohabitat quality (Table 6.4.1). For substrate, a bottom dominated by fine particles (<0.2 mm) was considered a bad habitat (habitat score=0), whereas sand (0.2-2 mm) or coarse stones and boulders (>200 mm) was given a habitat score of 1. Water velocity is normally only estimated in the field. Suggested classes are slow/still (<0.2 m/s), moderate (0.2–0.7 m/s) and fast (>0.7 m/s). No account of stream size, length or presence/ absence of lakes is made in calculating the THS.

The THS is simply all the individual scores of the six descriptors summed for each site, as follows:

$$THS = width + slope + velocity + depth + substrate + shade$$

The score may range from 0 to 12.

The suggested trout macrohabitat score was tested on southern (from the county of Uppsala to Bohuslän) Swedish coastal streams with a catchment area below 1000 km$^2$. In total, the trout macrohabitat score (THS) could be calculated at 13164 fishing occasions. The abundance of trout parr (all ages) followed the score (Figure 6.4.1, ANOVA $F_{11,8229}=468$, $p<0,001$). Salmon parr occurrence decreased with THS (Figure 6.4.2).

The THS was also tested on data from Danish streams. Data included were from 2008-10 (a few sites have data back to 2005) and also streams outside the ICES area of the Baltic were included. Whenever there was doubt about habitat quality class this was estimated conservatively - e.g. substrate is in many cases given with equal percentage cover for more groups (two or more groups co-dominate) and in those cases the lower value was chosen. Data on stream gradient was not available so this descriptor was omitted. Thereby the maximum value was 10. Danish data showed that THS is a good indicator of habitat value for sea trout. Some countries were doubtful about how to calculate slope, but the Danish data (ICES 2011) indicate that this variable can be omitted and THS calculated using only five descriptors.

To lessen variation, it was decided to use a habitat score of four classes. The classes, if slope is included or omitted, from the results in Figure 6.4.1 are shown in Table 6.4.2.

**Table 6.4.1. Suggested habitat scores for the six common field descriptors of habitat quality.**

| | Habitat score | | |
|---|---|---|---|
| | 0 | 1 | 2 |
| Wetted width of stream (m) | >10 | 6-10 | <6 |
| Slope (%) of section | <0.2 & >8 | 0.2-0.5 & 3-8 | >0.5-<3 |
| Water velocity class | Slow/still | Fast | Moderate |
| Average/dominating depth (m) | >0.5 | 0.3-0.5 | <0.3 |
| Dominating substratum | Fine | Large stones, boulders or sand | Gravel-Stone |
| Shade (%) | <10% | 10-20 | >20 |

**Table 6.4.2. Habitat classes (0-3) of THS groups to reduce variation.**

| Habitat Class | THS – including slope | THS omitting Slope |
|---|---|---|
| 0 | <6 | <5 |
| 1 | 6–8 | 5–6 |
| 2 | 9–10 | 7–8 |
| 3 | 11–12 | 9–10 |

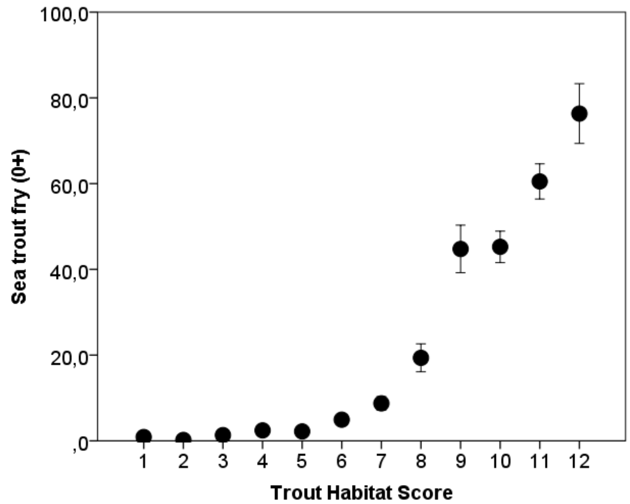



**Figure 6.4.1. Average abundance of sea trout fry (±95% confidence interval) for each trout habitat score class (n=13164 fishing occasions in coastal streams from southern Sweden).**

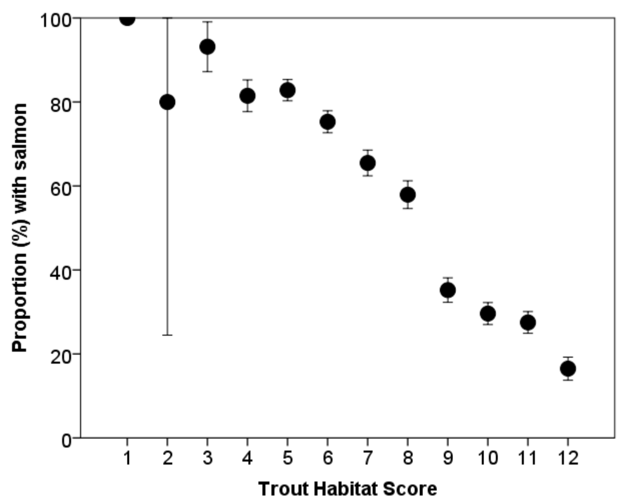



**Figure 6.4.2. Average occurrence (%) of Atlantic salmon parr at investigated sites (±95% confidence interval) for each sea trout macro-habitat score class (n=13,164 fishing occasions in coastal streams from southern Sweden).**

## 6.5 Establishing reference points for expected abundance at undisturbed sites

In the previous work of SGBALANST (ICES 2009), a simple model was constructed from recruitment data. Densities of sea trout parr depend on climate and river size (op. cit.). As data on climate and flow characteristics were not available for all sites, longitude and latitude were used as proxies. The size of the river was indicated by the wetted width at the sampling sites.

In order to find a maximum density of fry in undisturbed sites, only rivers with good water quality and good habitat as reported by the members of SGBALANST were selected for modelling. Only data from the period 2000–2008 were used as this period was available from all members that had electrofishing data. Further, only stable populations were used, i.e. those with a CV (Coefficient of variation) below 50% (calculated from $\log_{10}$-transformed river averages of trout parr abundance different years). This was done to eliminate rivers with large fluctuations, e.g. some rivers in the Gulf of Finland that had limited ascent of spawners in the autumn of 2002 due to low water flow. Data from ICES subdivision 31 (Bothnian Bay) was not used as it was the opinion of the Finnish and Swedish delegates that these stocks were extremely small, well below carrying capacity, owing to fishing mortality in the sea. A few rivers with stocking of parr were included as it was suggested that the stocking levels did not exceed carrying capacity.

The final model to predict maximum fry densities was:

Log10 (0+ density) = 0.963 - (0.906*logwidth) + (0.045*airtemp) - (0.037*longitude) + (0.027*latitude) + (THS*0.033); ($r^2$=0.5, Anova; $F_{2,254}$=51.8, p<0,001).

## 6.6 Constructing the index

The observed abundance for each river and year was divided by the predicted abundance and expressed as percentage, defined as the 'recruitment status'.

*Recruitment status = (Observed $\log_{10}$-density/ Maximum $\log_{10}$-density)*100*

Rivers with abundance as predicted would then get a recruitment status of 100%, and rivers with a lower abundance than predicted would have lower percentages. Recruitment status of 100% does not mean that a true maximum production of recruits is present; it is an index of what was the best production in rivers with good habitat and expected low fishing pressure during 2000–2008. Preferably this model should be updated using more data from a larger region, e.g. including Great Britain, Ireland, France and Norway and adding Germany who could not produce data at the time.

Recruitment status is then used to summaries recruitment estimates by river, region, nation and sub-divisions of the Blatic Sea over the preceding year and 5 year period (for example Figure 6.6.1). It is now applied to assess sea trout stocks in the nine countries surrounding the Baltic Sea as a simple, transparent model where limited and variable data exists on sea trout stocks.

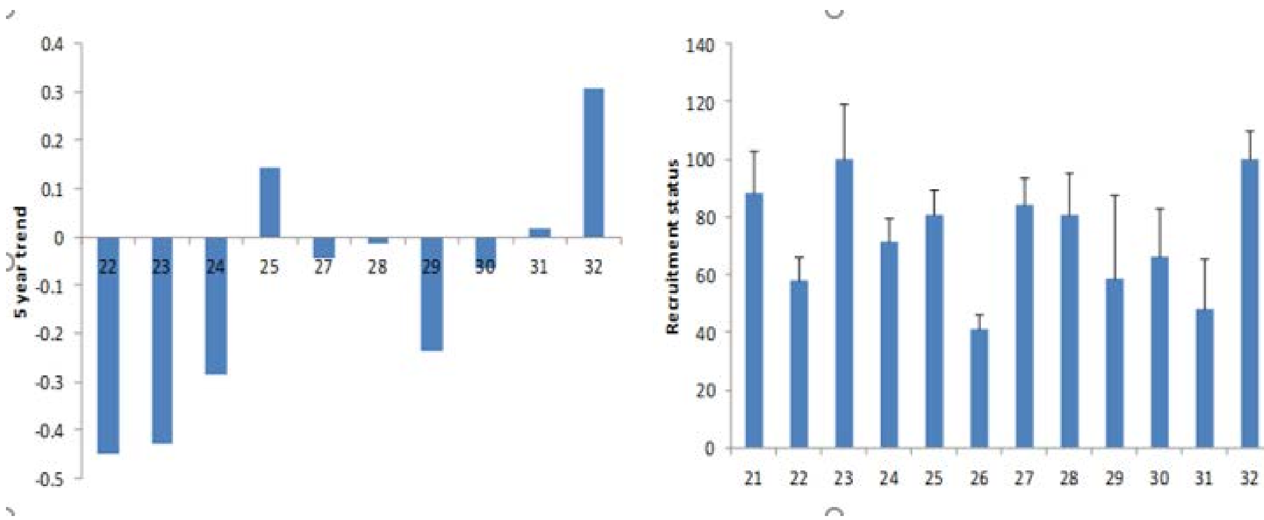



**Figure 6.6.1. Recruitment status (left) and five year trend (right) of ICES subdivisions of the Baltic Sea (Figure 6.6.2).**

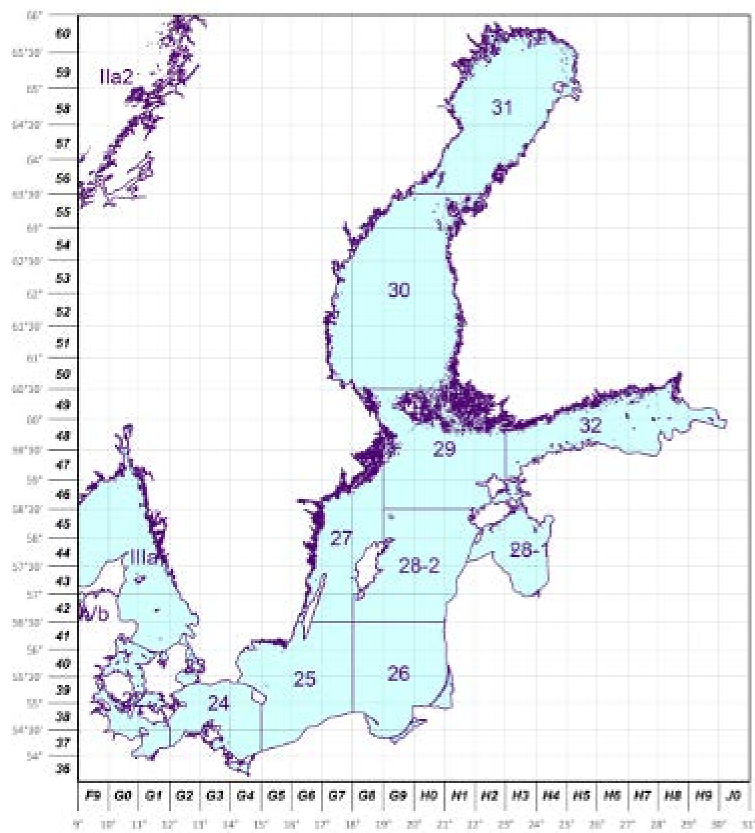



**Figure 6.6.2. ICES subdivisions of the Baltic Sea.**

## 6.7 Validation

The THS system was tested against local quantitative electric fishing data for rivers in UK (Northern Ireland) for which habitat information was available.

Data were compiled on 266 electric fishing occasions conducted through-out Northern Ireland from 1969–2010 by various agencies. For the Northern Irish data set the abundance of 0+ age class trout parr positively tracked the THS (Figure 6.7.1); (ANOVA $F_{264}$=4.1, p<0.001) and suggested that THS was a good indicator of potential habitat value for 0+ trout parr in Northern Ireland. This case study indicates that the development of a THS with suitable reference points may be more widely applicable across the range of sea trout.

Similar relationships have been found in French rivers, where more stream details are now being included in the model.

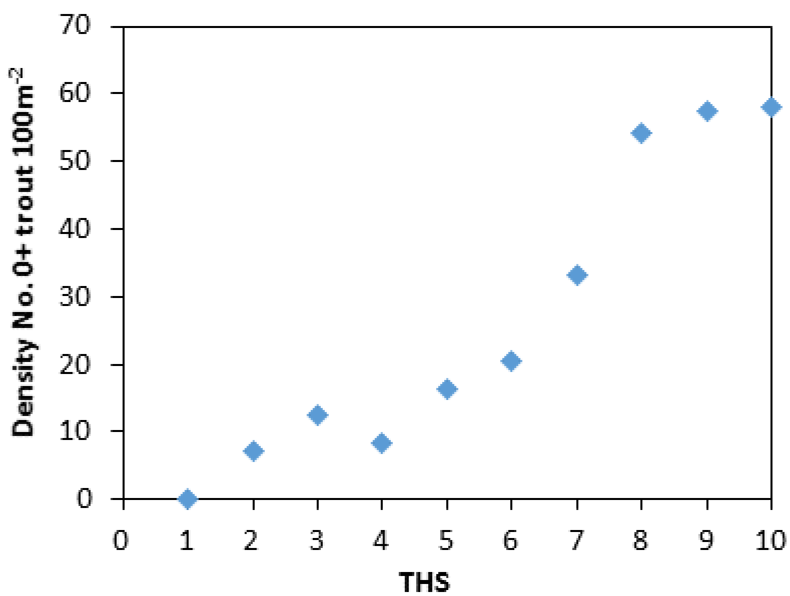



**Figure 6.7.1. Mean abundance of 0+ trout parr (+/-1 S.E) for THS values determined from quantitative electric fishing sites in the DCAL area of Northern Ireland (n=266).**

## 6.8 Conclusion

Although promising, the approach still needs further development and the Workshop noted the following areas that deserved attention:

a) A common database also including rivers outside the Baltic Sea region should be gathered in order to facilitate further work.

b) The THS-system should be tested with more sophisticated methods (e.g. GAM) to account for collinearity of descriptors and weighing them according to importance. Further the interaction of two or more variables may be accounted for, e.g. depth and velocity.

c) The model of maximum production should include a wider range of regions and be established from a more strict protocol to describe pristine (or close to) conditions.

d) The effect of smolt age, and thus the effect of the proportion of >0+ parr competing with fry, should be tested.

e) The effect of resident trout on the juvenile parr stock and smolt production needs to be addressed.

f) And most important, using SR-models from Index Rivers to establish true BRPs using recruitment status should be established. As suggested this may be done by applying the model to data from the British Isles where SR-models are already present. Or just comparing recruitment status with adult abundance (catches).

g) Although not promising so far, an effort should be made to go from site descriptors to catchment descriptors, thus enabling transportation of future BRP's from Index Rivers to other rivers, irrespective of characteristics of single sites. Is there a correlation between THS and catchment descriptors?

# 7 Stock–recruitment relationships for index stocks

## 7.1 Background

Long-term time series of data on both stock (i.e. numbers of spawners or egg deposition) and recruits (i.e. numbers of smolts, or adult returns or spawners in the next generation) have been collected for only a handful of European sea trout stocks but these provide the best sources of data for investigating population dynamics and developing BRPs.

Where SR relationships can be established, for example using standard Ricker or Beverton & Holt curves, a range of different BRPs can be derived (e.g. $S_{max}$, $S_{MSY}$, etc). For Atlantic salmon, NASCO (1998) agreed that stocks should be managed by means of Conservation Limits (CL) and Management Targets (MT); the CL is set at $S_{MSY}$ and the management objective to ensure that there is a low probability of stocks falling below this level. The MT is set as the point to aim at in order to achieve the management objective.

The Workshop considered that a similar approach could be applied for sea trout if CLs (and MTs) could be established for monitored stocks, similar principles could be applied.

Details of 10 sea trout index river systems are discussed below.

## 7.2 France – River Bresle case study

The Bresle is a 70 km long chalky river, located in upper Normandy, in the North of France. The river has populations of both salmon and sea trout, the latter being largely predominant with a ratio of 11-1 in the adult run. These populations have been monitored since 1982, using trapping facilities located in EU and Beauchamps tributaries, respectively 3 and 12 km from the estuary. Adults are controlled in EU, during their migration towards the spawning grounds and surviving fish are recaptured as kelts in the secondary adult trap in the Beauchamps. Most of the spawners (74%) return after 1 sea winter at an average fork-length of 55.1cm, but multi-spawners are common and account on average for 15% of the annual run. Smolts are double-trapped, first when migrating toward the sea in Beauchamps and secondly in a smaller trap in the EU. Fish size averages 19.7cm, and most individuals migrate after 1 river winter (82%). The traps attractiveness and efficiency is highly dependent on hydraulic conditions. Floods can severely alter trapping capacity, and are responsible for gaps in the data series in 2001 and 2002. Estimated average efficiency of the upstream and downstream traps is respectively 62.7% (min= 30.9%; max= 84.2%) and 51.0 % (min= 40.5%; max= 60.5%). Efficiency is estimated from mark-recapture surveys; all the adults captured are marked by pelvic fin clip, and smolts by opercula punching.

A Bayesian approach, based on Petersen's mark-recapture model, is used to derive estimates of the runs from the controlled fish. This method makes the model more realistic, by taking into account the flow-dependent efficiency of the traps. For adult fish, it is assumed that salmon and sea trout show the same behavioural response to the traps, and thus the same capture/recapture probabilities, therefore allowing the captures of the two species to be merged to increase sample size. For smolts, sea trout and salmon are assumed to respond differently to the trap, and are modelled separately. This approach to estimating annual runs represents a non-biased estimation method for low samples. As a hierarchical model, it can estimate runs when data is missing (Delmotte *et al.*, 2010).

Further analysis of model outputs is pending and currently the only SR model available on the Bresle data is the one presented in Euzenat *et al.* (2007). Stock and recruitment inputs originated from trap and catch data. Ricker and Beverton & Holt models were tested and despite a rather weak SR relationship, the Ricker model was considered to provide the best fit. This model estimated the spawning stock maximizing the recruitment at 955 fish, which based on the average fecundity of Bresle trout, was equivalent to 2.4 million eggs, giving a maximum smolt production of approximately 7000 individuals, or 2.6 smolts 100 $m^{-2}$.

It is considered that BRPs may support improved management of sea trout stocks in Normandy. This will require an update of the current models with more recent data and stock estimates from the Bayesian modelling approach.

## 7.3 Ireland – River Burrishoole case study

**Catchment Description:** The Burrishoole is a relatively small (100 $km^2$) upland catchment situated on the west coast of Ireland (53° 56' N, 9° 35' W). It experiences a temperate, oceanic climate with mild winters and relatively cool summers; maximum summer air temperatures rarely exceed 20°C, while minimum winter temperatures are usually between 2°C and 4°C. The base geology on the west side of Burrishoole is predominantly quartzite and schist, leading to acidic runoff, with poor buffering capacity. On the east side of the catchment, the geology is more complex as quartzite and schist are interspersed with veins of volcanic rock, dolomite and wacke, leading to higher buffering capacity and aquatic production. The catchment soil consists of poorly drained gleys, peaty podsols and blanket peats and the main land-uses are commercial forestry and extensive sheep grazing. Feeagh and Bunaveela, the two largest freshwater lakes in the catchment, are both relatively deep (mean depth >12 m), oligotrophic (TP <10 ug $l^{-1}$), coloured (c. 80 mg $l^{-1}$ PtCo) due to high levels of dissolved organic carbon (DOC), and have low alkalinity (<20 mg$l^{-1}$ $CaCO_3$) and pH (c. 6.7) and the catchment is drained by some 45 km of streams.

The wetted area of the catchment is comprised of 450 ha of lake and 24.7 ha of fluvial habitat.

Partial upstream and downstream fish trapping facilities have been in operation in Burrishoole since 1958, and full trapping facilities were put in place in 1970. The traps, at the freshwater outflow tidal limit, enable a complete census of migrating fish in to (adult salmon and sea trout) and out of (salmon and trout smolts, juvenile trout and silver eel) the catchment.

**Stock Dynamics:** Data are available to describe the characteristics of the Burrishoole sea trout population since 1970 (Poole *et al.* 1996, 2006). Up to 24 age classes (5 sea age years) of migrating trout have been described in the mid-1980s, but a severe sea trout population collapse was evident between 1988 and 1990 (Gargan, *et al.,* 2006b). The annual number of returning finnock and older sea trout reached a maximum of 3348 in 1975, declined through the 1980s, and more rapidly in 1987 and 1988, followed by a collapse in all sea ages in 1989 to an annual migratory sea trout stock of usually of less than 300 fish. Prior to 1990, relatively few unsilvered fish were included in the upstream "sea trout" count (Piggins *pers obs*). Each year since 1990, between 40 and 168 unsilvered trout have been recorded migrating upstream. The majority (59-93%) of these fish fall into the 0+ "sea-age" class. Methods for compiling the stock and recruitment database were fully described in Poole *et al.* (2006).

**Rod Catch:** Between 1971 and 1988, the Lough Feeagh rod catch ranged from 41 to 453 fish per annum. Between 1980 and 1986 the mean CPUE with effort normalised to eight-hour rod-days, between June & September) for L. Furnace (tidal) was 0.84 and for L. Feeagh was 0.56. There was a marked reduction in CPUE in both lakes between 1985 and 1990, and it has since remained low and the fishery was closed since 1997. These data indicate that the collapse in the sea trout catch between 1988 and 1990 was not related to lower angling effort, which actually increased throughout the late 1980s and the 1990s.

**Upstream stocks:** Spawning escapement is calculated as the total upstream count of migrating trout (silvered and unsilvered) less the rod catch in L. Feeagh. The proportion of the stock entering L. Feeagh that was subsequently captured by angling has varied between 4% and 19% over the period 1971 to 1996 (mean: 10.5%), with a high of 32% in 1993.

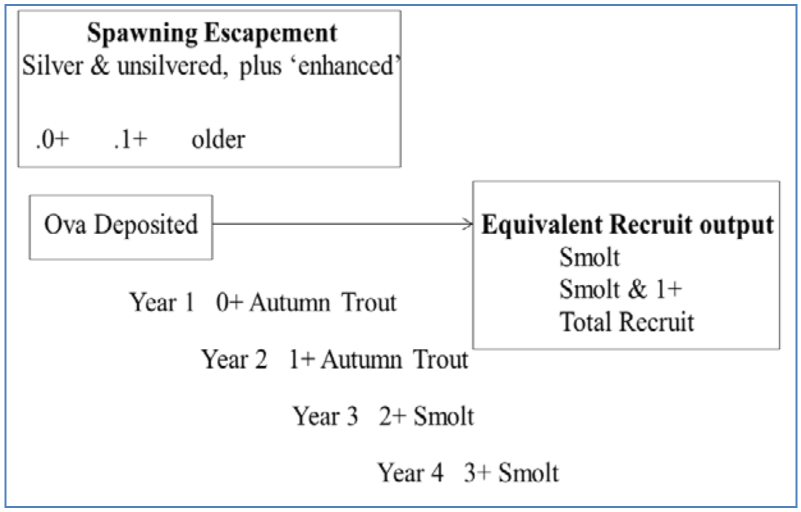
**Downstream stocks:** There was considerable variation in the annual number of smolts counted downstream between 1970 and 1990, from a maximum of 6710 in 1981 to a minimum of 530 in 2001. Before 1991, there was no significant trend in annual smolt numbers, but since 1991 there has been a significant reduction in smolt output. The age composition of the smolt run was similar in 1958–1960 and 1980–1984 and averaged 68% 2+, and 32% 3+ years old. Throughout the 1990s, the relative proportions of 2 to 3 year old smolts changed, possibly related to differing levels of spawning effort.

There was a downward trend in numbers of unsilvered juvenile trout migrating in autumn over the entire study period. This contrasts with smolt abundance, which has shown a decline only since 1991. The age composition of the autumn trout ranged from 0+ to 3+ years, the percentage of 0+ trout varied from 16.1 to 60.9% in the period 1982-2014. It is not known if the 0+ age fish are true migrants or if they are displaced downstream as a result of population pressure or, possibly, floods. Whilst 0+ trout are not old enough to become sea trout smolts in the following spring, tagging studies show that the remainder, predominantly 1+ age fish, could contribute to the overall recruitment of smolts in the following year and ultimately to the sea trout stock.

**Marine Survival Rates:** The percentage of smolts that return as finnock in the same year ranged from 11.4% to 32.4% over the period 1971 to 1987 with a mean of 21%. In 1988, this return rate fell to 8.5% and in 1989 to 1.5%. This was followed by finnock return rates fluctuating around a mean of 7.8% until 1999, when it rose to 16.7% – the highest rate since 1986. Returns of older sea-run fish followed the same pattern with a total stock collapse in 1989/1990. The return of smolt as finnock in 2011 was 5.8%, 13.8% in 2012, 11.0% in 2013 and 29.5% in 2014 – the highest recorded level since the mid-1970s. Since 2007, finnock return has inside the historical range in six of the eight years. These observed changes in the structure of the sea trout population and the reduction in survival suggest that the stock collapse in the late 1980s and 1990s was related to marine survival conditions.

**Freshwater Ova to smolt survival:** Between 1971 and 1988, the % output for total wild ova to smolt (equivalent) averaged 0.53% with a range of 0.24% – 0.80%. After 1988, survival rates increased significantly to an average value of 1.1% ranging from 0.56% to 1.6% between 1989 and 1999. This pattern is also seen for recruitment calculated as smolt & 1+ autumn trout and as total recruitment, with an average of 0.79% total wild ova to total recruit (1971–'88) increasing to 1.67% ('89–'99) and 2.46 between 1999 and 2010. The pattern was similar when total ova, including estimates of ova deposited by enhanced fish.

**Stock Recruitment relationship:** The total migratory trout stock includes silvered and unsilvered migrants, from which the estimated number of ova deposited annually ranged between 30 thousand to 1.64 million. Recruitment to the sea of downstream migrants from these ova was determined by trapping 0+ and 1+ autumn migrating juveniles and 2+ and 3+ spring migrating smolts using the schematic below. Total recruitment (four year classes) per annual spawning cohort ranged from 784 to 8457 and smolt output from 323 to 5813. The 1989 spawning stock collapse significantly reduced both the total number of ova deposited and subsequent levels of recruitment (Figure 7.3.1).




Ova deposition rates of more than 0.5 million gave rise to equivalent smolt recruitments in the range of 2977 to 5813, recruitments of smolts and 1+ autumn trout of 3910 to 7550 and total recruitments of 4428 to 8457 three and four years later. A marked drop in recruitment was observed when ova deposition rates fell below 0.5 million from 1987 onwards, when the observed relationship appeared to be tending towards zero.

The asymptotic Beverton-Holt relationship fitted the Burrishoole sea trout data better than the Ricker model (Poole *et al.* 2006 analysis), for all levels of stock (ova) and recruitment (Figure 7.3.1). There was little evidence of non-stationarity. The clumping of low stock levels in the latter years is due to changes in marine mortality (as evidenced by smolt-finnock return rates) and does not violate the assumptions for stock and recruitment relationships. Results to date support the view that resident trout have not compensated for the collapse in the spawning stock.

There are a number of uncertainties about the SR relationship and further consideration is being given to number of factors. It is unclear, for example, whether the SR curve should be forced through the origin and what role resident trout and unsilvered brackish water migratory trout (also referred to as slob-trout) play.

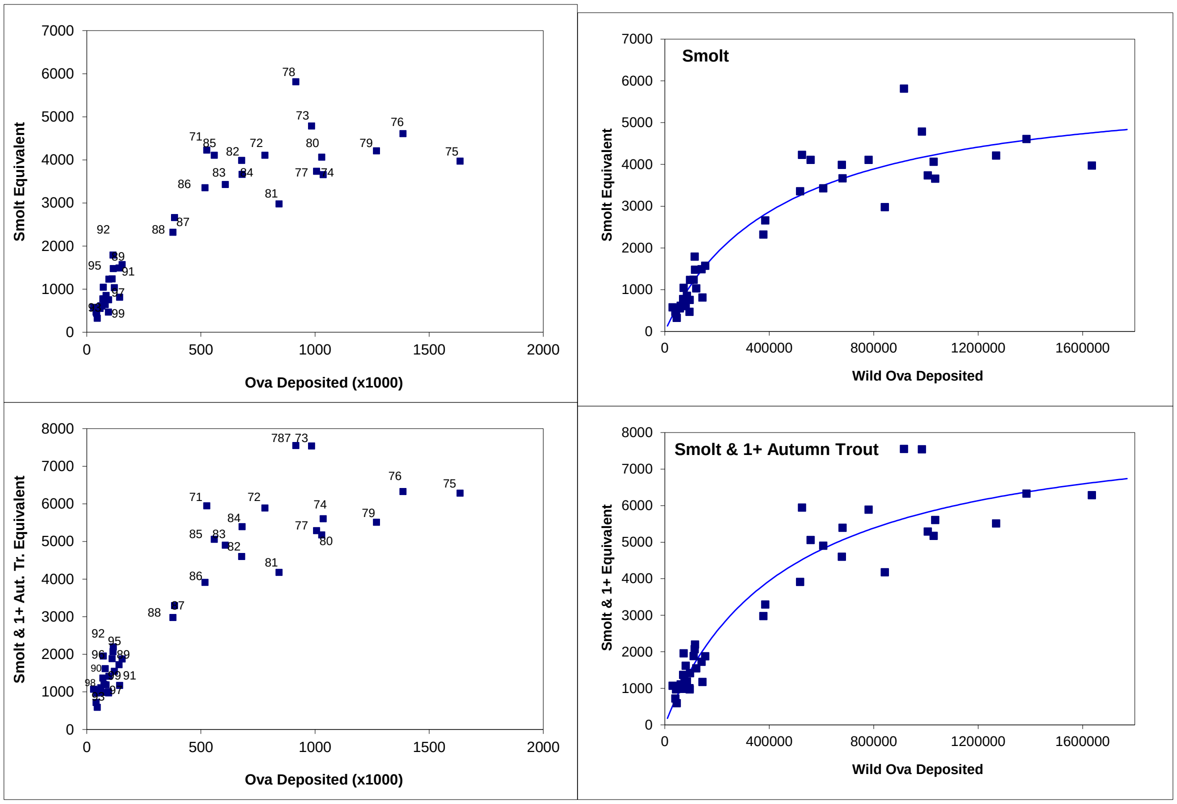



**Figure 7.3.1. Left hand panels: The number of smolts, and total recruitment of smolt & 1+ autumn trout derived from each cohort of wild ova deposited. Year of spawning is shown on graph. Right hand panels: Beverton-Holt curves fitted to the wild ova against smolt and the total of smolt and 1+ autumn trout outputs.**

**Biological Reference Points:** Table 7.3.1 gives the parameters, correlation coefficients and replacement abundances, S*, for the Beverton-Holt model for three stock options (silver anadromous only, total wild migratory, and total wild plus an estimated contribution from fish surviving to spawn from stocked parr) and recruitment as smolts only, smolts plus 1+ autumn trout and total recruitment of smolts and 0+/1+ autumn trout. The parameter *a* has the dimension recruits per unit stock and represents the slope of the curve at the "origin". Parameter *b* has the dimension 1/*S*; where *S* is the stock size above which density dependence dominates over density independence, or the point at which maximum recruitment per unit stock occurs. For the Burrishoole wild migratory trout stock, *S** approximates to 318 735 ova in the smolt relationship increasing to 444 854 in the total recruitment relationship. These levels of ova deposition have not been achieved since 1988.

These levels of ova at the stock replacement value equate approximately to a migrant trout spawning stock escapement of 993 to 1362 fish (multiple age classes). Using a relationship between upstream count of sea trout and Lough Feeagh rod catch, this replacement stock equates roughly to a rod catch of 94–133 fish.

The calculation of ova deposition and smolt recruitment rates per unit area are complicated somewhat by the inclusion of lake wetted area. This can make it difficult to compare wetted area production rates between catchments for the transport of reference limits between catchments.

Historically, mean ova deposition of 1781 ova/ha (total wetted area including lakes) or 34 000/ha of stream area yielded a mean smolt production of 8.2 smolt/ha indicating the difficulty in making comparisons between riverine catchments and lacustrine dominated catchments. Ova deposition fell to 178 ova/ha after 1989 producing 1.9 smolt/ha. The replacement abundance stock calculated from the Beverton Holt relationship was 956 ova/ha or equivalent spawning escapement of 993–1362 fish. The approximate rod catch at this escapement level was 93 to 133 fish caught (Table 7.3.2).

**Table 7.3.1. Estimates of parameters for Beverton-Holt models for the Burrishoole sea trout stock (silver anadromous only, total wild migratory, and total wild plus an estimated contribution from fish surviving to spawn from stocked parr) and recruitment as smolts only, smolts plus 1+ autumn trout and total recruitment of smolts and 0+/1+ autumn trout.**

| Stock | Recruitment | a | b | SSQResids | R^2 | *S** | Eq Sp Stck Year | *R** |
|---|---|---|---|---|---|---|---|---|
| Sea Trout | Smolt | 0.017152 | 3.08E-06 | 8691684 | 0.91 | 318,735 | 1988 | 2528 |
| Sea Trout | Smolt & 1+ | 0.022910 | 2.94E-06 | 18363618 | 0.98 | 332,792 | 1988 | 3856 |
| Sea Trout | Total Recruit | 0.026760 | 3E-06 | 23443805 | 1.01 | 324,144 | 1988 | 4396 |
| | | | | | | | | |
| Sea Trout & Unsilvered | Smolt | 0.013635 | 2.26E-06 | 9178603.9 | 0.86 | 437,391 | 1986 | 3002 |
| Sea Trout & Unsilvered | Smolt & 1+ | 0.018376 | 2.16E-06 | 17138794 | 0.93 | 453,998 | 1986 | 4210 |
| Sea Trout & Unsilvered | Total Recruit | 0.021381 | 2.2E-06 | 20999961 | 0.96 | 444,854 | 1986 | 4807 |
| | | | | | | | | |
| Total, & enhanced | Smolt | 0.012505 | 1.99E-06 | 10345094 | 0.92 | 496,369 | 1986 | 3123 |
| Total, & enhanced | Smolt & 1+ | 0.016804 | 1.89E-06 | 18491594 | 0.93 | 519,652 | 1986 | 4403 |
| Total, & enhanced | Total Recruit | 0.019467 | 1.91E-06 | 22715123 | 0.96 | 512,815 | 1986 | 5040 |

**Table 7.3.2. Burrishoole spawning escapement, rod catch, number of smolt and ova deposition rates for the 1971–1988 and 1989 to 2014 periods, and replacement abundance limits derived from the Beverton Holt relationship.**

| | Spawning Escapement of Wild Trout | | | Rod Catch of Sea Trout | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Average | Min | Max | Average | Min | Max | No. Smolt | No. smolt & 1+ | Total No ova/ha | No. smolt/ha |
| 1971-1988 | 1882 | 908 | 3206 | 194 | 41 | 453 | 3871 | 5300 | 1781 | 8.2 |
| 1989-2014 | 299 | 168 | 599 | - | - | - | 887 | 1348 | 178 | 1.9 |
| Replacement* | 993-1362 | | | 94-133 | | | 3002 | 4210 | 956 | 6.3 |
| *Replacement Abundance for Total Wild Ova and Smolt & 1+ Recruits | | | | | | | | | | |

**Resident Trout:** In 1985, a gill net survey was carried out in Lough Feeagh, using gangs of standard sized mesh gill nets, set floating and on the bottom (Mills *et al.* 1986). These produced a population estimate for trout in the lake which equated to approximately 40 000 fish >19.8cm in length. It was estimated that these fish contributed to some 3.1 million ova in the catchment and the migratory input in the same year was approximately 520 000 ova (~17%). The study assumed fecundity for lake trout of 259 ova/female which, based on current experience, may be too high. There is no information on lake trout density since 1985 although anecdotal information indicates substantial numbers of non-anadromous 'resident' trout still spawn in certain areas of the catchment and collections of broodstock have been made from the lakes and one tributary in recent years.

Annual Marine Institute index electrofishing surveys indicates that in general, densities of 0+, 1+ and older trout have not changed substantially since 1991, indicating that there is still a substantial trout spawning effort in the catchment by trout that have not originated from the migratory component of the stock. Preliminary genetics data (Magee *et al.* 2012) indicates considerable sub-stock structuring within the catchment and different components of the smolt and adult stocks being contributed to by fry originating from different tributaries. It is not known yet if this varies between years, or if it is related to different proportions of migratory and resident trout spanners.

The distribution of points around the SR curve at the lower stock levels, as shown in Figure 7.3.1, indicate a minimal contribution of smolts from the freshwater resident stock. If the resident stock was contributing significant numbers of smolts, it would be expected that the points would lie above the SR curve and give positive residuals, not as observed in Figure 7.3.1. It would appear that in some other west of Ireland lakes, the converse may have been happening in the early 1990s with smolt production continuing at relatively high levels in spite of low spawning stock (Gargan *et al.*, 2006b).

**Issues:** A number of issues that remain to be fully resolved include the following:

- The relative ova deposition by migratory and freshwater resident components of the trout stock.
- The relative contribution of the two forms of trout stock to the smolt production from the catchment.
- The role that the lakes play in the productive habitat of the catchment, in terms of habitat for smolt production and also for on-grow habitat for non-anadromous trout.

## 7.4 UK (England and Wales)

Returning Stock Estimates (RSEs) for sea trout are available for six rivers in England and Wales, obtained from resistivity fish counters (Tyne, Tamar, Fowey, Lune and Kent) or trapping and mark-recapture (Dee). Among these, the Tyne, Tamar, Dee and Lune are classed as 'Index Rivers' because of associated trapping or the equivalent sampling programmes to collect biological information, e.g. on age and size composition, sex, general condition, etc. On the Tamar and Dee, trapping and Coded Wire Tagging programmes are also carried out to estimate smolt output and return rates ('marine survival').

Ricker (1954) and Beverton and Holt (1957) stock recruitment (SR) relationships fitted to available time-series of data from these rivers (Davidson *et al.* in prep) are described in Section 3.4 of this report. In each case (Tyne, Tamar, Dee, Lune and Kent) the stock variable equates to egg numbers (from all returning fish) and the recruitment variable to resulting numbers of maiden .0+ fish.

The Ricker egg-to-adult SR curve for the Dee, which has the longest time-series of data available, is shown in Figure 7.4.1, where the recruit variable includes all returning maiden fish. Equivalent Ricker SR curves to the smolt, and fry (0+) recruit stages are shown in Figures 7.4.2 and 7.4.3. For the later, indices of recruitment ('standing stock' indices) have been used based on catchment wide timed (5-minute) electrofishing surveys (after Crozier and Kennedy, 1994).

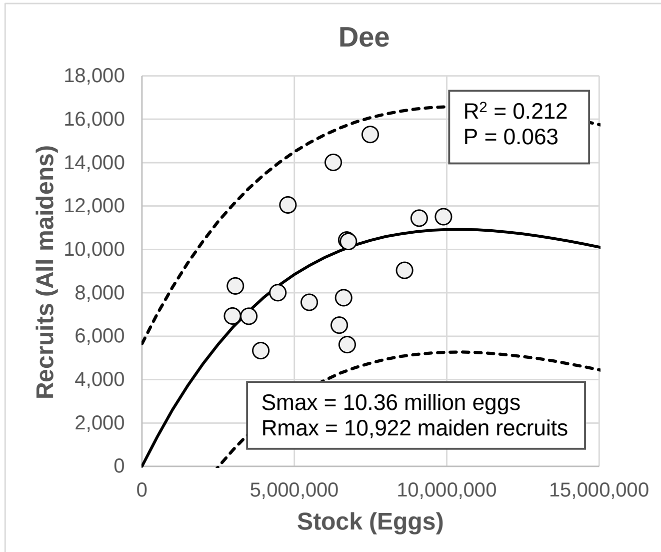



**Figure 7.4.1. Ricker egg-to-maiden adult SR curve; Welsh Dee, 1992–2009 year classes.**

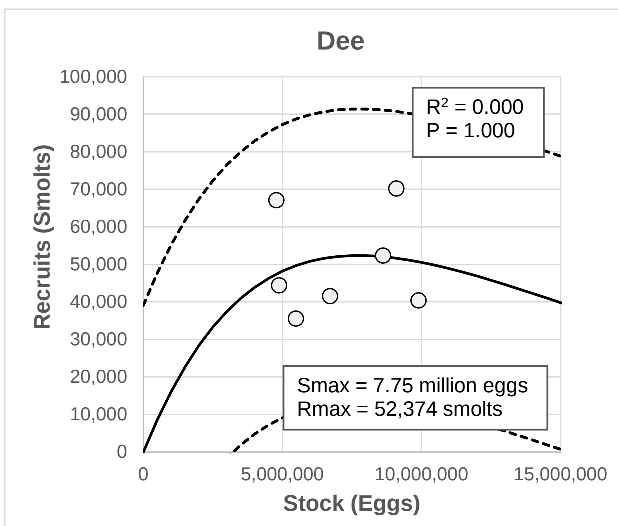



**Figure 7.4.2. Ricker egg-to-smolt SR curve; Welsh Dee, 2000–2010 year classes.**

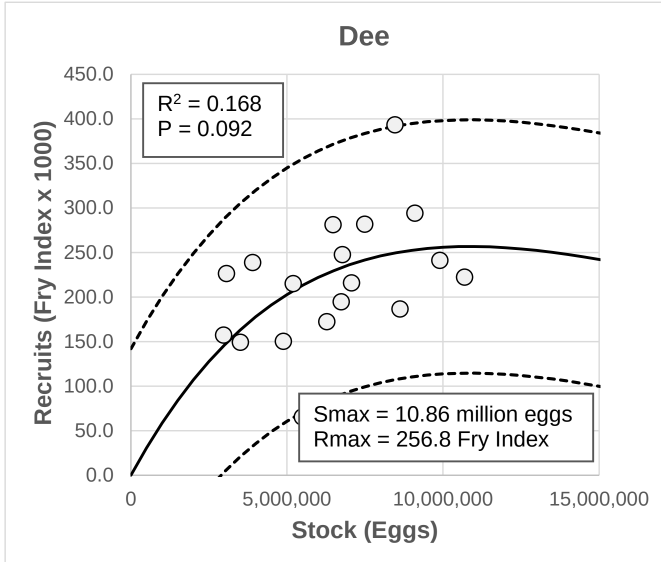



**Figure 7.4.3. Ricker egg-to-fry SR curve; Welsh Dee, 1992–2013 year classes.**

$S_{max}$ values (the stock size at maximum recruitment) are similar for the egg-to-adult and egg-to-fry SR curves at 10.9 and 10.4 million eggs, respectively, and the goodness-of-fit values for these curves are reasonable ($r^2 = 0.212$ and 0.168, respectively). In contrast, the egg-to-smolt SR curve has a notably lower $S_{max}$ value of 7.8 million eggs but is based on only seven data points; the $r^2$ value is also poor for this curve (0.00) (indicating that the Ricker SR curve provides no better fit to the data points than a horizontal line at the mean recruitment value).

Production of an SR curve using timed electrofishing data as an index of recruitment suggests, as on the River Shimna, Northern Ireland (Section 7.5), the value of this relatively low effort/low cost technique in providing what appears to be a valid recruitment measure with potential application in the development of BRPs.

## 7.5 UK (Northern Ireland) – River Shimna case study

The Shimna river is a small coastal spate stream in County Down, NI. The sea trout population on the river has been monitored using a range of annually collected abundance metrics. Adult sea trout have been assessed through rod catch and more recently using a resistivity fish counter. Detailed rod catch returns have been compiled by the local angling association for sea trout and resident brown trout and these data include raw catch and a simple CPUE metric. A three-channel crump weir with resistivity fish counter and CCTV validation equipment was installed in 2010/11. The spacing between the electrodes on the Shimna river were reduced to lower the detection threshold of the equipment and provide a consistent count of all sea trout >40cm total length. The recruitment of 0+ trout parr is assessed using a semi-quantitative (SQ) electric fishing survey (Crozier & Kennedy, 1994) conducted at 25 SQ sites through-out the catchment since 2003. The SQ electric fishing data produces a relative index of 0+ parr abundance.

Trout recruitment as described by the annual SQ index density was investigated against previous measures of adult sea trout abundance (annual catch and CPUE). A strong SR relationship was evident between both the Shimna sea trout rod catch (in year n) and sea trout CPUE (in year n-1) and resultant 0+ fry recruitment (in year n). The Ricker model, ($R = a\,S\,e^{-bS}$, where S and R are breeding stock (catch or CPUE in year n-1) and recruitment (SQ index in year n) respectively, and a and b are constants, produced the best fit and explained 63% and 70% of the respective variance against rod catch and CPUE for the Shimna stock. The use of a 0+ abundance index as an indicator of recruitment for sea trout populations may be applicable for stocks in which reproduction is dominated by migratory females and where a representative area of the spawning range is surveyed.

The Shimna programme indicates the dominance of the migratory portion of the stock to recruitment in the river, and demonstrates the potential to use alternative datasets (e.g. CPUE electric fishing indices) in the investigation and development of SR relationships for sea trout.

## 7.6 Sweden – River Åvaån – Baltic index case study

River Åvaån in a small (catchment area of 16 $km^2$) sea trout stream on the Swedish east coast, close to Stockholm. The accessible part of the river is 2.5 km and the average width 2.3 m giving a wetted area of 0.57 ha, of which 0.38 ha is good rearing habitat for sea trout. The river was investigated in 1926–1949 using a Wolf-type smolt trap and a simple spawner trap (Alm 1950). The monitoring was resumed in 1998 by the municipality of Stockholm. Counting of smolts, where the smolt from weight are divided into age classes, and trapping of spawners gives data for a SR model, although vital data for a whole population model is lacking, e.g. age of spawners, fishing mortality in the sea and estimates of the trap efficiency. Electrofishing is carried out annually. Defining the river as an index river for Baltic Sea trout has been discussed, with the aim of securing long term monitoring in the future. No fishing is carried out in the river. In the 1920s approximately 100 kg sea trout was caught annually.

From the previous period (Alm 1950) the fecundity (1600 ova per kg female) is known. The smolts are 1.9 years old (in the 1920s 2.3 years) so a Ricker curve was fitted with a lag of three years from spawners to recruits. Although a poor fit ($r^2 = 0.26$) the model ($Smolt_{t+2.5yrs} = 0.006{*}Ova^{(-5.912*10-6*Ova)}$) was significant ($p = 0.03$); (Figure 7.6.1). Due to the variation in data and low explained variation other stock/recruitment models will be tested.

MSY would correspond to 4000 ova per $m^2$ resulting in an abundance of 0+ of 99 and a smolt output of 10, giving a survival from ova to smolt of 0.25%. The cause of the comparatively low survival may be due to sediment load from agriculture areas in the lower part of the river.

The sea survival has been estimated at 29% using the average number of smolts and the average number of spawners for the whole period.

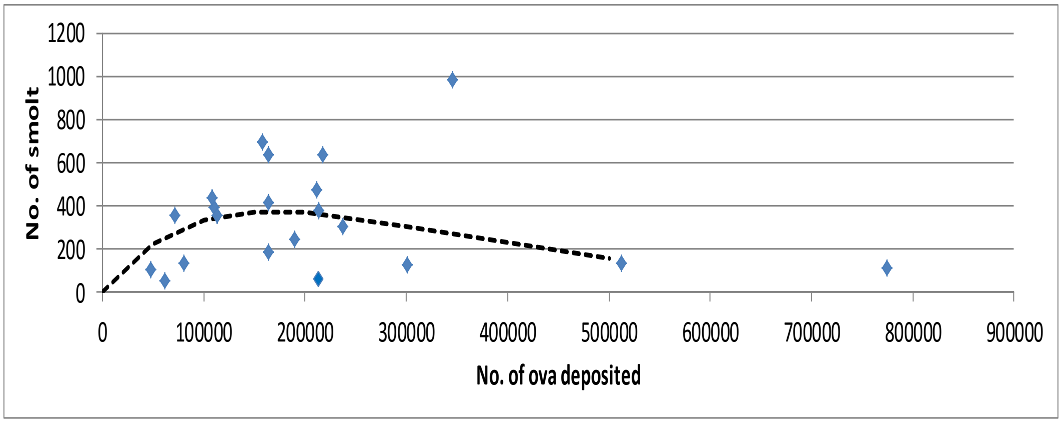



**Figure 7.6.1. A Ricker curve applied to number of deposited ova and the resulting smolt output three years later in River Åvaån.**

## 7.7 Transferring BRPs from index rivers

While the index rivers provide the best sources of data on sea trout population dynamics, there may be difficulties transferring BRPs from the very few intensively monitored systems to poorly monitored systems because of the great variability in sea trout life history strategies.

Stock-recruitment models (e.g. Beverton-Holt and Ricker) can be parameterized in terms of the maximum survival of eggs (the slope at the origin of the stock–recruitment curve when spawning stock size is defined in terms of the number of eggs) and maximum recruitment (recruitment under optimal conditions); (Pulkkinen and Mäntyniemi 2013). The maximum survival of eggs parameter can be assumed to be transferable among rivers (perhaps with the inclusion of appropriate covariates e.g. latitude). Bayesian meta-analysis methods could potentially be used to combine estimates of maximum egg survival for rivers where SR data (eggs and recruits) are available, to obtain a prior (a probability distribution summarizing knowledge and uncertainty) for the maximum survival of eggs in a new river (i.e. one for which no SR data are available).

Information about maximum recruitment/production is available in the form of estimates of the total area of rearing habitat, its quality and associated parr densities for some rivers. Together, the maximum recruitment and maximum survival of eggs from meta-analysis parameters imply a stock recruitment function that could be used in full life-cycle models or to define biological reference points for management.

# 8 Stock-recruitment relationships based on catch data

## 8.1 Background

In England and Wales, rod catch statistics for sea trout (and salmon) have been collected in a consistent way since the introduction of a single national rod licencing and catch return and reminder system in 1994. This provides river specific data, including daily records of the species, number and size (weight) of fish caught and annual estimates of fishing effort (days fished for salmon and sea trout combined). National catch declaration rates from this system (for salmon and sea trout together) are estimated to be around 90% (Environment Agency, 2003). Prior to this, the licencing and catch return/reminder systems varied by region and, although time-series extend back to at least the 1970s on most rivers (Russell *et al.*, 1995), they less comparable. For example, effort data (other than licence sales) are absent and catch declaration rates are likely to have varied between regions (Environment Agency, 2003).

This section describes the use of angling catch and catch-per-unit-effort (CPUE) data to derive 'pseudo' stock and recruitment relationships for sea trout on 13 rivers in England and Wales (Figure 8.1.1), with the aim of potentially using these relationships to define Biological Reference Points (BRPs) for stock assessment and management (Davidson *et al.* in prep). The selection of rivers includes the index/counted rivers (highlighted yellow in Figure 8.1.1) where SR relationships produced using more conventional means (i.e. using census estimates of stock and recruitment) can be compared with the equivalent pseudo SR relationships. This method includes the use of similar catch based techniques applied to the River Tweed and other Scottish rivers (ICES, 2013).

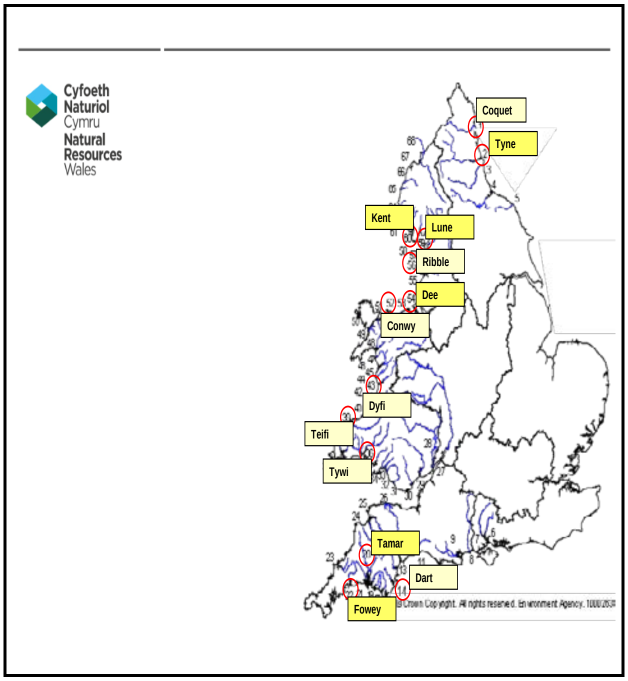



**Figure 8.1.1. Selection of 13 sea trout rivers in England and Wales for which catch-based pseudo SR relationships have been derived (includes 6 Index/counted rivers – highlighted yellow).**

## 8.2 Catch based SR variables

Two methods of deriving stock and recruitment variables from rod catch data were explored:

Use of angling CPUE data (catch per day), where:

- Stock equals catch per day for all fish in year n; and
- Recruitment equals catch per day for fish of weight <=1.5lbs in year n+3.

Use of angling catch and assumed rod exploitation rates to derive Returning Stock Estimates (RSEs), where:

- Stock equals total egg deposition for all fish returning in year n (dependent on assumed rod exploitation rates to derive RSEs from catch, as well as other information e.g. on the size and fecundity of returning fish); and
- Recruitment equals the catch derived RSE for fish of weight <=1.5 lbs in year n+3.

Fish of weight <= 1.5 lbs in year n+3 were selected as indicators of recruitment because 0+ maiden fish are strongly represented in this size class - to the exclusion of virtually all other sea age groups (i.e. they can be readily identified in the catch record). For example, from trapping data on the Welsh Dee (1994–2013) more than 90% of .0+ fish were in the <=1.5 lbs size class and only a small proportion of older fish fell below the 1.5 lbs threshold (e.g. ~5% or less of .0+SM+ and .1+ fish).

The 0+ sea age group is also a significant component (>50%) of the maiden sea trout return on many west coast rivers in England and Wales (e.g. Solomon, 1994).

Finally, on most rivers in England and Wales, the great majority (~60–90%) of sea trout appear (from adult scales) to have emigrated as 2-year-old smolts; i.e. recruitment as 0+ maidens n+3 years after the return of the parental spawning stock, is assumed to be the common pattern.

Ricker (1954) and Beverton and Holt (1957) SR relationships (below) were fitted to the data sets as the most commonly applied SR models (Hilborn and Walters, 1992), including in sea trout population studies (e.g. Elliott, 1985; Elliott and Elliott, 2006; Euzenat *et al.*, 2006 Poole *et al.* 2006).

Ricker (1954): $R = Sea(1-S/b)$

Beverton and Holt (1957): $R = aS/(b+S)$

where S = Stock and R = Recruits

The ‘a’ and ‘b’ parameters for these curves were initially derived using linear regression methods (see e.g. Hilborn and Walters, 1992), where for the Ricker model:

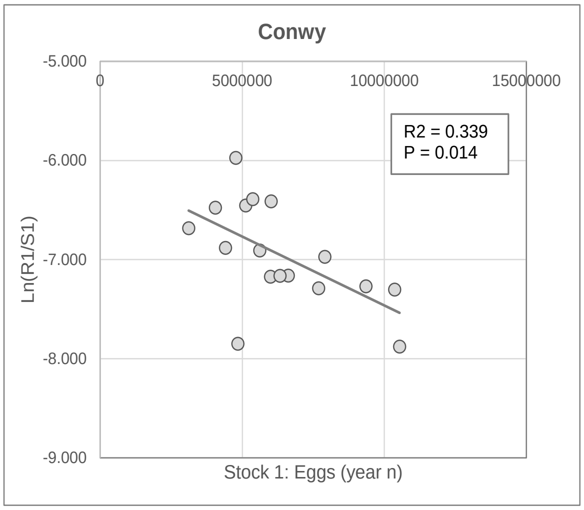
$$Log(R/S) = a - (a/b)S$$

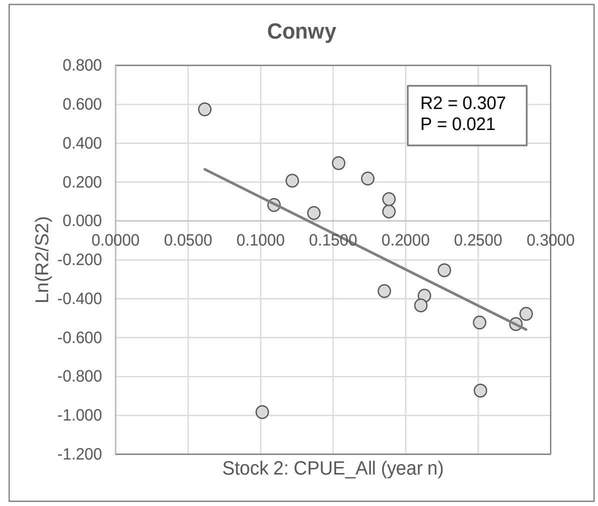
and for the Beverton and Holt model:

$$S/R = b/a + (1/a)S$$

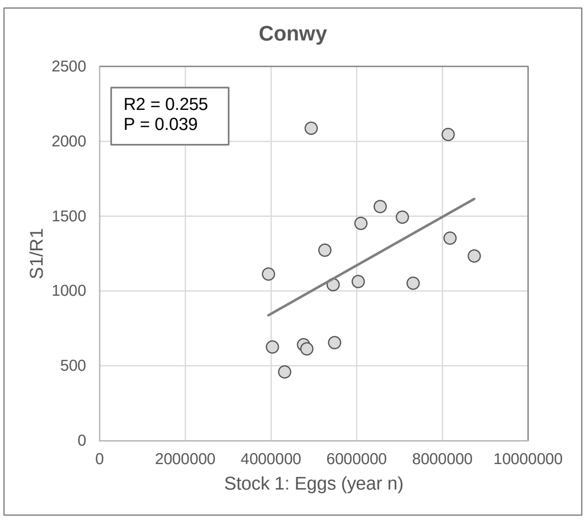
Examples of these linear regression relationships are shown for the River Conwy in Figure 8.2.1.

Ricker:




Beverton and Holt:



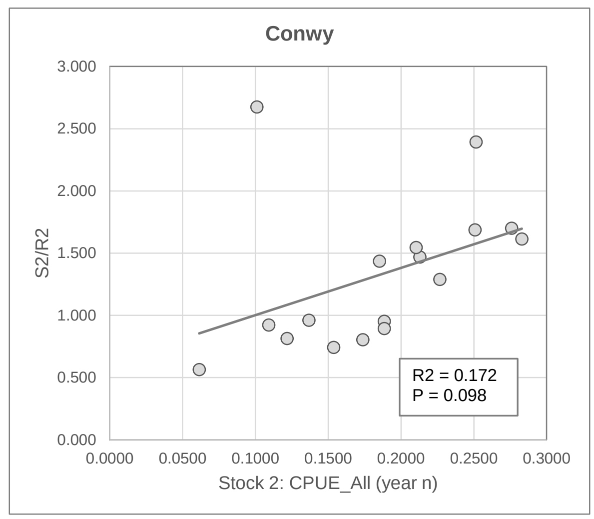
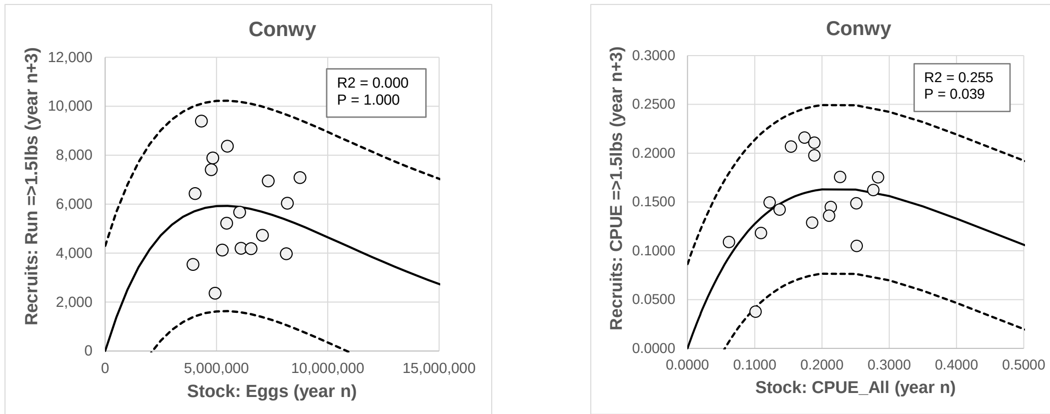




**Figure 8.2.1 Regression relationships to derive initial 'a' and 'b' parameters for Ricker and Beverton and Holt SR models using CPUE and catch generated RSE/egg stock and recruitment variables.**

Using these initial 'a' and 'b' parameters as starting values, Ricker and Beverton and Holt SR curves were fitted to the data sets using a combination of non-linear regression methods (e.g. Hilborn and Walters, 1992 Elliott, 1985) available for use in Minitab 16 (see https://www.minitab.com/en-us/ ) and Excel – for the latter applying the method of Brown (2001). Examples of fitted SR curves, again for sea trout on the River Conwy, are shown in Figure 8.2.2.

Ricker:




Beverton and Holt:

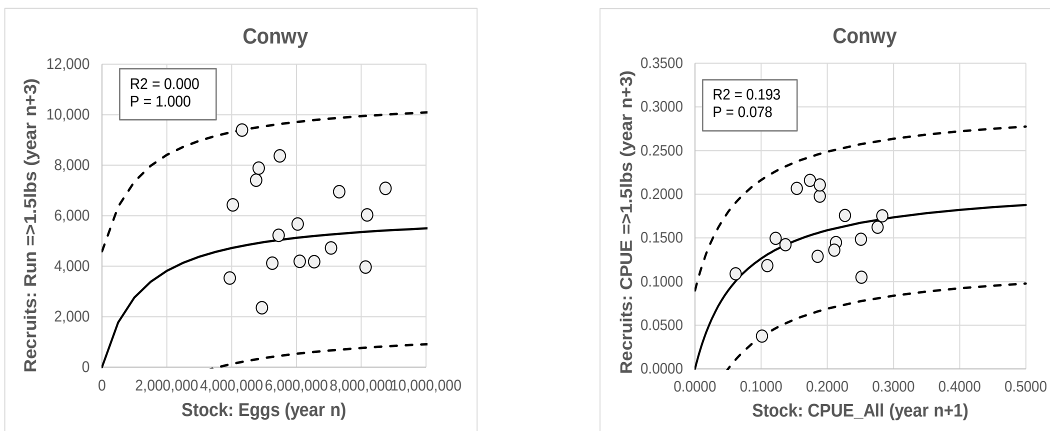



**Figure 8.2.2 Ricker and Beverton and Holt SR relationships fitted to CPUE and catch generated RSE/egg stock and recruitment variables for the River Conwy (dashed lines indicate 95% confidence limits).**

Goodness-of-fit ($r^2$) values for all SR curve permutations are summarised in Table 8.2.1; including for Ricker and Beverton and Holt curves fitted to the index/counted river data sets (in the case of the latter, the stock variable was expressed as eggs deposited by all parental spawners, and the recruit variable as the resulting number of .0+ maiden fish returning to the river).

These comparisons indicate that goodness-of-fit was generally poor with *p*-values rarely <0.100. In most cases there was little difference between the fit of Ricker and Beverton and Holt relationships, although in a number of instances it was not possible to fit the latter. Also, many of the better fitting relationships were evident where stock and recruitment variables were expressed in terms of CPUE (catch per day).

Where $r^2$ values were equal to zero, this indicated that the fitted SR relationship explained no more variation in the data set than the assumption (null hypothesis) of constant (mean) recruitment.

Among the index/counted rivers, the strongest SR relationships were recorded on the Dee where *p*-values were close to significant at the 0.05 level for both Ricker and

Beverton and Holt curves. However, the time-series of SR data available on the Dee (18 years) was notably longer than all other index/counted rivers (6–10 years).

$r^2$ values on the Dee were ~0.18 for both the fitted Ricker and Beverton and Holt curves. These compared to an $r^2$ value of 0.56 (n=24) reported for sea trout on the Black Brows Beck (Elliott and Elliott, 2006) for an egg-to-adult (Ricker) relationship broadly equivalent to that on the Dee (although the Black Brows Beck is a small, single tributary system compared to the much larger and far more complex multi-tributary system of the Dee).

Similary, an $r^2$ value of 0.62 (n=40) was reported for a more comparable (Beverton and Holt) SR curve fitted to egg-to-.0+maiden data for the Burrishoole (see Section 7 of this report). However, the $r^2$ value fell to 0.10 (n=18) when post-stock collapse data were removed from the times-series (i.e. these formed a cluster of data points close to the origin).

Given that it is reasonable to assume that the Ricker or Beverton and Holt curves will pass through the origin for populations which are effectively closed to recruitment (Hilborn and Walters, 1992), then poor goodness-of-fit statistics for SR and pseudo SR relationships where the available data points don't pass close to the origin may not necessarily indicate that a fitted curve is a poor representation of average conditions.

**Table 8.2.1 Goodness-of-fit statistics for all SR curve permutations for 13 sea trout river stocks in England and Wales .**

| | *Index/Counted rivers:* | | | *Catch - RSE/egg estimates:* | | | *CPUE:* | | |
|---|---|---|---|---|---|---|---|---|---|
| River | Years | Ricker R2 | Beverton and Holt R2 | Years | Ricker R2 | Beverton and Holt R2 | Years | Ricker R2 | Beverton and Holt R2 |
| Tyne | 7 | 0.175 | 0.135 | 17 | 0.022 | 0.038 | 17 | 0.150 | 0.155 |
| Tamar | 6 | 0.588 * | *No fit* | 17 | 0.002 | *No fit* | 17 | 0.107 | *No fit* |
| Dee | 18 | 0.183 * | 0.185 * | 17 | 0.128 | 0.138 | 17 | 0.084 | 0.098 |
| Lune | 6 | 0.003 | 0.075 | 17 | 0.118 | 0.037 | 17 | 0.035 | 0.001 |
| Kent | 10 | 0.147 | 0.152 | 17 | 0.093 | 0.051 | 17 | 0.269 ** | 0.251 ** |
| Coquet | | | | 17 | 0.139 | *No fit* | 17 | 0.226 * | *No fit* |
| Dart | | | | 17 | 0.067 | 0.054 | 17 | 0.042 | 0.027 |
| Fowey | | | | 17 | 0.123 | *No fit* | 17 | 0.265 ** | *No fit* |
| Tywi | | | | 17 | 0.000 | 0.000 | 17 | 0.000 | 0.000 |
| Teifi | | | | 17 | 0.000 | 0.006 | 17 | 0.000 | 0.002 |
| Dyfi | | | | 17 | 0.000 | 0.020 | 17 | 0.005 | 0.055 |
| Conwy | | | | 17 | 0.000 | 0.000 | 17 | 0.255 ** | 0.193 * |
| Ribble | | | | 17 | 0.018 | 0.016 | 17 | 0.089 | 0.047 |

* = $0.05 \le P < 0.10$
** = $0.01 \le P < 0.05$

## 8.3 Validation

As a means of attempting to validate these approaches, Figure 8.3.1 compares $S_{max}$ values obtained from the Ricker SR relationship (i.e. the stock size resulting in $R_{max}$ or maximum recruitment) for the index/counted river data sets with the same values obtained from the equivalent catch-derived curves (albeit for different times-series of data – see Table 8.2.1).

As might be expected, there is a broad association between the two, which, excluding the Tamar, equates to an average deviation from the $S_{max}$ value for index/counted rivers of 40% (range 13 to 54%). For the Tamar, this deviation is 370%; however, the scatter of index/counted river data points in this case is unusual (and warrants further scrutiny) as all lie well to the right on the Ricker curve – i.e. where recruitment is declining at higher stock size. The associated $S_{max}$ value is also much lower than might be expected for a river of this size.

Finally, except for the Kent, all catch derived $S_{max}$ values are higher than those from the index/counted river data sets which suggests the former approach may tend to produce more precautionary estimates of this particular reference point.

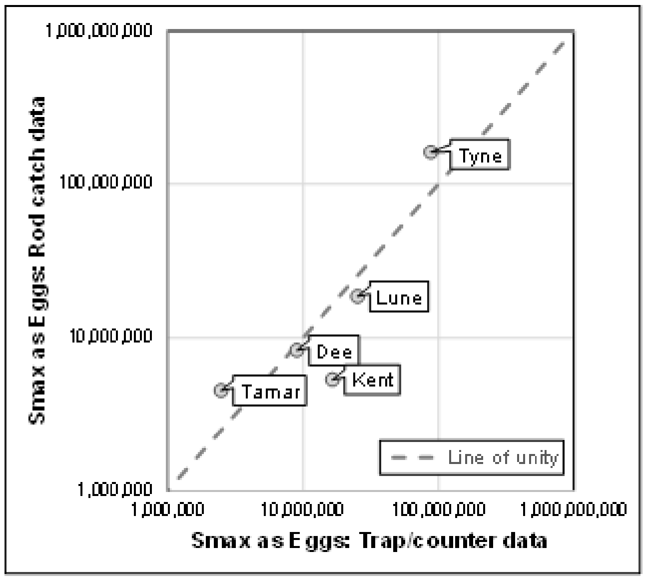



**Figure 8.3.1. Comparison of $S_{max}$ values obtained from the Ricker SR relationship for index/counted river and catch derived data sets.**

## 8.4 Compliance assessment

The two catch based approaches to deriving SR curves described here, and any associated BRPs, could result in potentially different compliance outcomes if applied to management. In England and Wales, the reference points used in the assessment and management of Atlantic salmon (i.e. Conservation Limits) and sea trout stocks (i.e. the angling CPUE method described in Section 2.4), both compare recent time-series of stock related variables to a standard.

In general terms, two of the main criteria which feature in these (and other) compliance procedures are:

i ) deviation from the standard, e.g. whether the current measure of stock status is above or below the reference level and

ii ) the recent (e.g. 10-year) trend in stock status.

These criteria have been used to explore potential differences in compliance outcome against the two catch-based stock variables (catch generated RSE/egg estimates and CPUE) compared to a common $S_{max}$ reference point derived from fitted Ricker SR curves. This process is illustrated below for the River Teifi (Figure 8.4.1) where the outcome was typical of many of the rivers examined; namely (i) that % compliance against the $S_{max}$ reference point (averaged over the time-series) was generally similar for catch based RSE/egg and CPUE stock variables but (ii) the greatest differences were evident in the trend in egg numbers which tended to be more adverse (e.g. more steeply negative) than the trend in CPUE.

The latter may be a consequence of the inclusion of measures of size (weight) as well as abundance in estimates of egg deposition, whereas the CPUE stock metric only captures changes in abundance. This limitation of the CPUE metric may mean that a biologically important component of the stock (i.e. weight composition) is overlooked and highlights one potential weakness in the current CPUE based assessment procedure applied in England and Wales (Section 3.2.8).

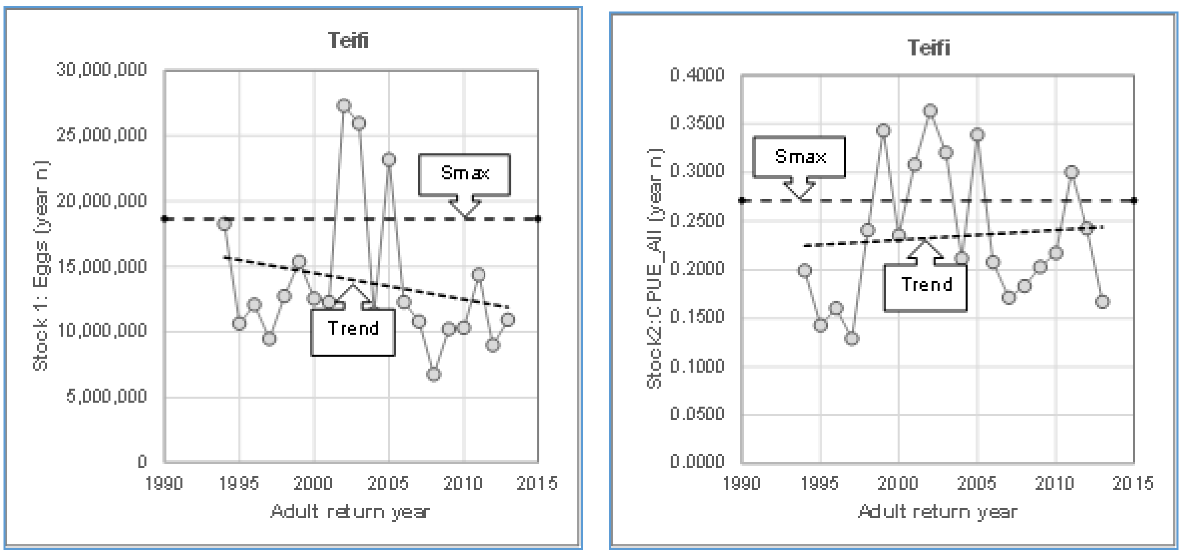



**Figure 8.4.1 Compliance assessment on River Teifi sea trout: comparing catch-based RSE/egg and CPUE stock variables to a common $S_{max}$ reference point derived from Ricker SR curves.**

## 8.5 Comparison of Index S-R and Pseudo-SR relationships

On only a few sea trout rivers, predominantly the 'Index' and counted rivers, have data on population abundance and composition been collected in sufficient detail and over enough years to allow stock and recruitment (SR) relationships to be produced. Published examples include SR relationships for sea trout on the Black Brows Beck, England (Elliott, 1985, Ellliott and Elliott, 2006), and rivers Bresle, France (Euzenat *et al.*, 2006) and Burrishoole, Ireland (Poole *et al.,* 2006). These and other examples were examined during the Workshop (Section 7). Various measures of stock and recruitment have, in each of these cases, encompassed the main life stages, including eggs, juveniles, smolts and adults. Estimates of abundance at these stages usually refer to the entire stock (e.g. smolt output or adult return) but have included indices of abundance (e.g. recruit indices of juvenile abundance related to egg deposition estimates on the Shimna, Northern Ireland – Section 5.3.5).

Methods of deriving 'pseudo' SR relationships have also been explored at this Workshop (see above) utilising angling catch data from England and Wales to produce stock and recruit indices expressed in terms of CPUE, or used to generate run/egg deposition estimates (e.g. based on assumed exploitation rates, weight fecundity relationships, etc.). In both these cases, the recruit variable (as CPUE or a catch derived run estimate) was defined in terms of the abundance of .0+ fish, on the basis that this sea age group (i) dominated returns on many west coast rivers and (ii) could be readily identified by weight class (namely all fish $\leq$ 1.5lbs)

This section of the report examines stock and recruitment data collected from the Index monitoring programmes on the rivers Burrishoole, Ireland and Dee, north Wales, primarily to investigate to what extent SR relationships with .0+ fish as the recruit variable and ova deposition as the stock variable provide a realistic surrogate for the equivalent SR relationships at other stages; namely (i) egg-to-smolt and (ii) egg-to-all maiden adults. The Beverton and Holt (1957) (Burrishoole and Dee) and Ricker (1954) (Dee) SR models have been fitted to the data sets and common 'reference points' and 'goodness-of-fit' ($r^2$) values compared.

The following reference points were obtained from the fitted SR models and were chosen simply to provide standard values which could be compared between different scenarios, and not necessarily because of their potential application to management:

Beverton and Holt:

- S* (estimated replacement stock size when R=S - after Elliott, 1985)
- $R_{max}$ (maximum recruitment)

Ricker:

- $R_{max}$ (maximum recruitment)
- $S_{max}$ (stock size producing maximum recruitment)

Among the scenarios examined for the Burrishoole were the inclusion and omission of data points after the sea trout stock collapse in 1989 (following a marked decline in sea survival). The purpose of this was to explore how the removal of a cluster of points close to the origin of the SR curve influenced the general form of the curve (as measured by common reference points) and its goodness-of-fit.

Similarly, to further explore the potential application of catch related variables as informative surrogates for 'true' measures of stock and recruitment, SR curves were generated using declared rod catch as an indicator of stock, with recruits expressed as either smolts, .0+ maidens or all maiden fish.

Results from these comparisons are given in Table 8.5.1 (scenarios 1–16) with associated graphs showing the various fitted (Beverton and Holt) SR relationships shown in Figure 8.5.1 a-l).

**Table 8.5.1 Comparison SR scenarios and associated reference points for the rivers Burrishoole and Dee.**

| Scenario | River | SR model | Stock Type | Recruit Type | Reference point: S* | Rmax | Smax | $R^2$ | n (yrs) | Fig. No. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Dee | Beverton and Holt | Ova | Smolts | 284,540 | 53,605 | ∞ | 0.00 | 7 | a |
| 2 | Dee | Beverton and Holt | Ova | .0+ fish | 4,025,030 | 16,441 | ∞ | 0.18 | 18 | b |
| 3 | Dee | Beverton and Holt | Ova | All maiden fish | 3,917,390 | 16,249 | ∞ | 0.23 | 17 | c |
| 4 | Burrishoole | Beverton and Holt | Ova | Smolts and 1+ | 453,998 | 8,073 | ∞ | 0.93 | 40 | d |
| 5 | Burrishoole | Beverton and Holt | Ova | Smolts and 1+ (pre 1989) | 437,664 | 8,130 | ∞ | 0.42 | 18 | e |
| 6 | Burrishoole | Beverton and Holt | Ova | .0+ fish | 650,581 | 1,309 | ∞ | 0.62 | 40 | f |
| 7 | Burrishoole | Beverton and Holt | Ova | .0+ fish (pre 1989) | 501,701 | 1,320 | ∞ | 0.10 | 18 | g |
| 8 | Burrishoole | Beverton and Holt | Ova | All maiden fish | 954,596 | 2,288 | ∞ | 0.60 | 40 | |
| 9 | Burrishoole | Beverton and Holt | Ova | All maiden fish (50% 1SW) | 663,772 | 1,821 | ∞ | 0.55 | 40 | h |
| 10 | Burrishoole | Beverton and Holt | Ova | All maiden fish (50% 1SW) (pre 1989) | 615,976 | 1,828 | ∞ | 0.12 | 18 | i |
| 11 | Burrishoole | Beverton and Holt | Rod Catch | Smolts and 1+ | 6,894 | 6,934 | ∞ | 0.13? 1.34 | 21 | j |
| 12 | Burrishoole | Beverton and Holt | Rod Catch | .0+ fish | 1,169 | 1,289 | ∞ | 0.67 | 21 | k |
| 13 | Burrishoole | Beverton and Holt | Rod Catch | All maiden fish | 1,668 | 1,789 | ∞ | 0.64 | 21 | l |
| 14 | Dee | Ricker | Ova | Smolts | - | 52,374 | 7,750,581 | 0.00 | 7 | - |
| 15 | Dee | Ricker | Ova | .0+ fish | - | 10,529 | 10,222,385 | 0.18 | 18 | - |
| 16 | Dee | Ricker | Ova | All maiden fish | - | 10,922 | 10,360,659 | 0.21 | 17 | - |

From the fitted Beverton and Holt relationships, the units of $R_{max}$ clearly depend on the recruit variable. Within a river (the Burrishoole in this case) it is evident that $R_{max}$ remains relatively stable for comparable scenarios - including pre-stock-collapse. For example, for the ova to smolt/1+ SR relationships (scenarios 4 and 5) $R_{max}$ values were within 100 smolts/1+ of one another (8073 and 8130 fish, respectively).

Within a river (with the notable exceptions of scenarios 1 and 8 - see below) S* values also remained relatively stable across the range of recruit stages. For example, excluding scenario 8, S* estimates on the Burrishoole were within, on average, 23% (range 4–46%) of the S* value obtained from the ova to smolt/1+ SR relationship (scenario 4). This indicates that SR relationships developed for recruit stages later than the smolt stage (i.e. post the freshwater phase of the life-cycle) retain a reasonably consistent form and so associated reference points could (with appropriate correction), potentially, be readily transported between recruit stages to suit management requirements.

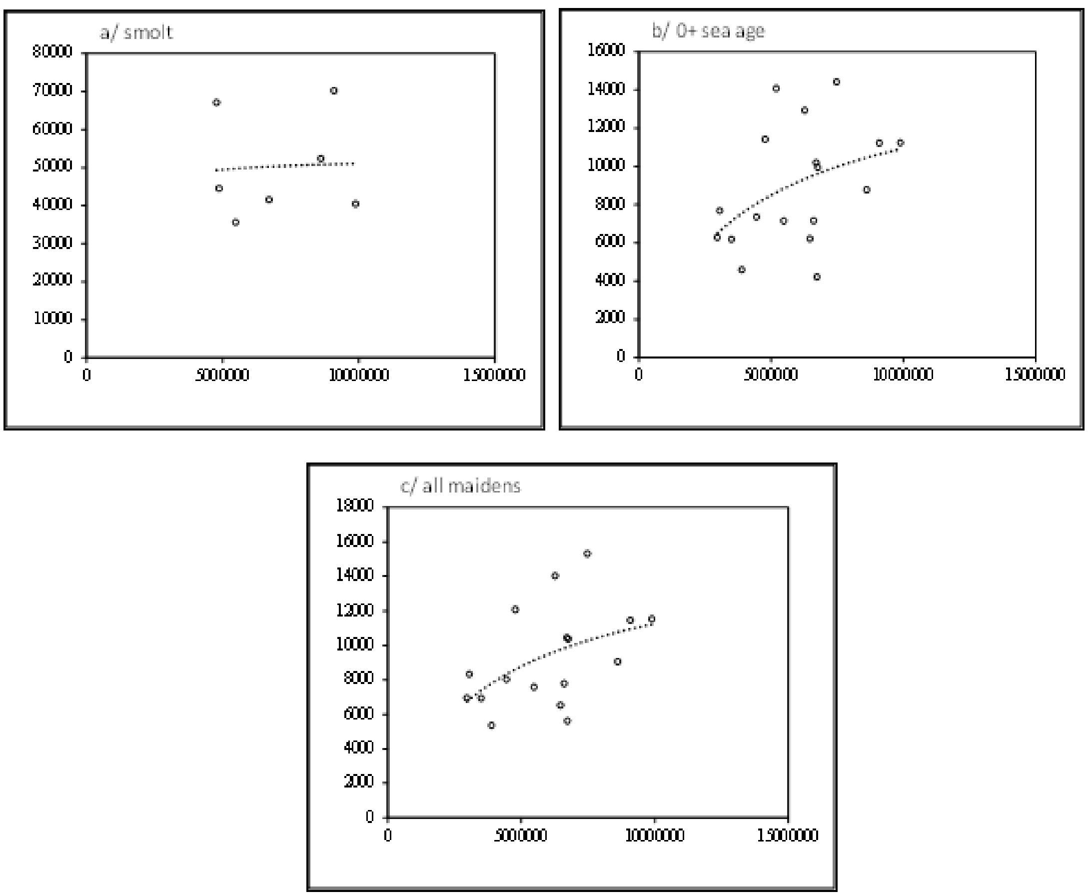
This was the case on the Burrishoole despite a marked decline in sea survival over the time-series that would have introduced a good degree of additional variability in the measure of recruits relative to the smolt stage. This is evident in the goodness of fit of SR relationships, where for example, the $r^2$ value for the ova to .0+ curve (scenario 6) is much lower at 0.62 than the equivalent $r^2$ value for the SR curve for the previous ova to smolt/1+ stage (scenario 4) at 0.93 (n = 40 in both cases). The difference in S* values for these two curves is relatively large at ~438 000 ova for the smolt curve compared to ~650 000 ova for the .0+ curve and would reflect the additional loss of fish in the sea. If the latter S* value was taken, without adjustment, as an estimate of the S* reference point for the ova to smolt stage, it would at least be conservative and protective of the stock (overestimating the true value by ~43%).

The two examples where S* values appear markedly different are (i) the Dee ova to smolt relationship (scenario 1; S*~285 000) and (ii) the Burrishoole ova to all maiden fish relationship (scenario 8; S* ~955 000). The former SR relationship is fitted to only seven data points, has an associated $r^2$ close to zero, and results in a curve which ascends very steeply initially and then becomes very flat; i.e. it is not too dissimilar from a straight line drawn through the mean level of recruitment. [In contrast, a Ricker curve drawn through the same data set (scenario14) has a $S_{max}$ value (stock size at maximum recruitment) of ~8 million eggs which is much closer to $S_{max}$ values of ~10 million eggs derived for other recruit stages (scenarios 15 and 16).]

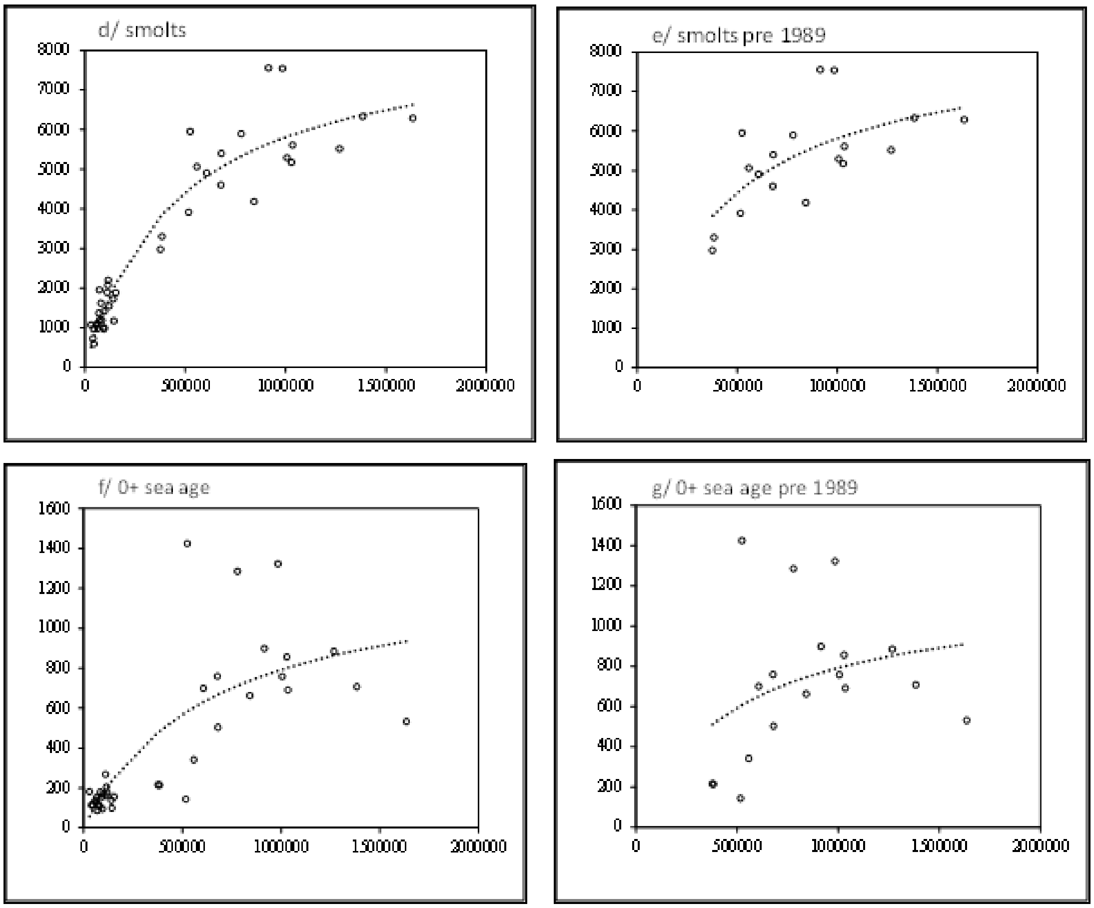
For scenario 8 on the Burrishoole (ova to all maiden fish relationship), the numbers of maiden recruits are likely to be overestimated as past observations suggests that around a third of .0+ maiden fish may not go on to spawn but return the following year as .1+ fish. To correct for this probable error, the .1+ count has been reduced by 50% in subsequent assessments and results in S* values (scenarios 9 and 10) more in-keeping with those of other life stages.

Finally, it is apparent from Burrishoole scenarios 11–13 that use of rod catch as a surrogate for spawners/egg deposition produces SR relationships and $R_{max}$ reference values that are not too dissimilar from their nearest equivalents based on stock census data (i.e. scenarios 5, 7 and 10). This provides a further indication of the value of catch data as indices of stock or recruitment and their potential application in deriving pseudo SR-relationships and associated reference points.

**a-c. Dee:**



**d-l. Burrishoole:**



**f-l. Burrishoole (continued):**

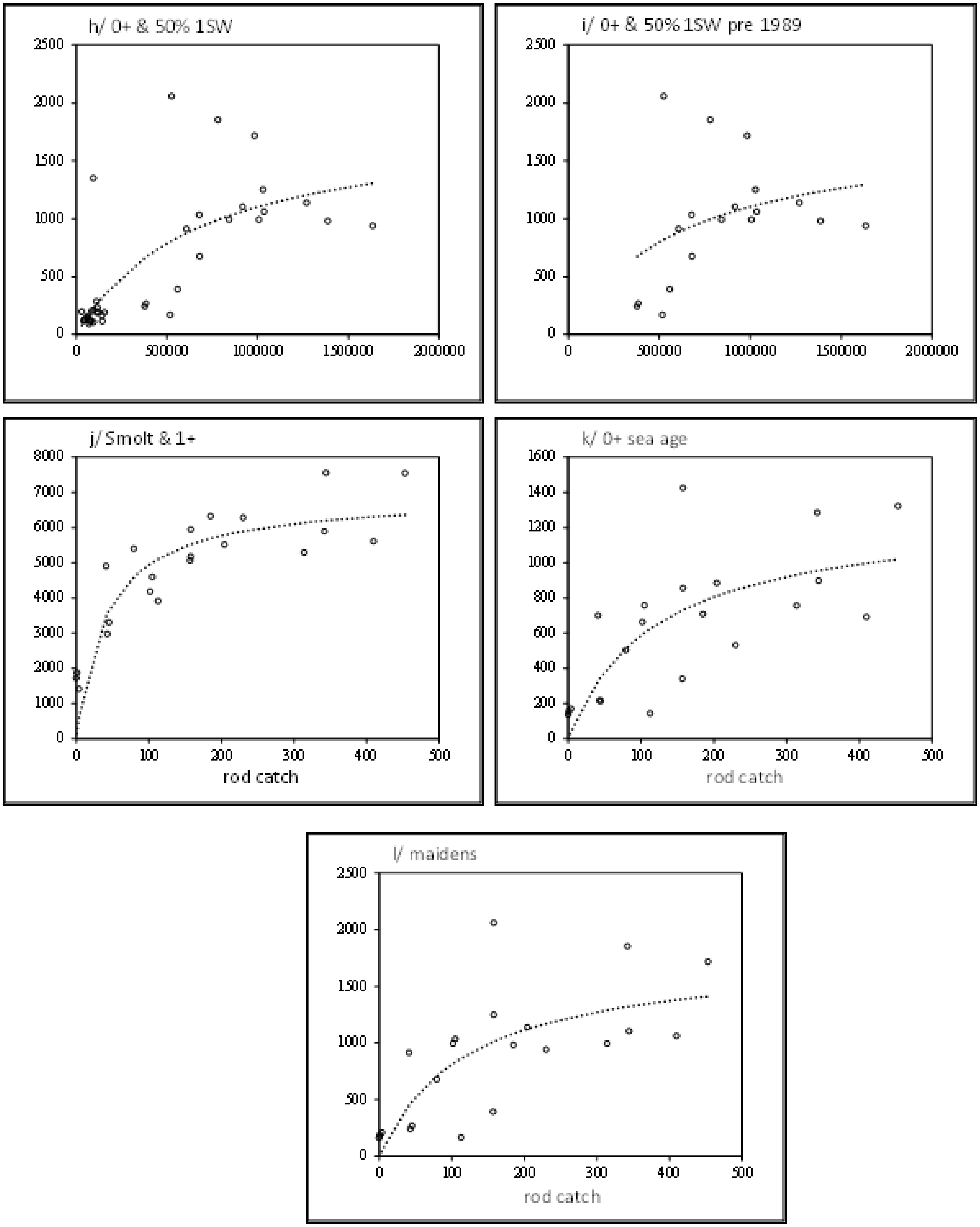



**Figure 8.5.1. Beverton and Holt relationships fitted to various stock and recruitment data sets for the rivers Burrishoole and Dee (see Table 8.5.1 for the key to graphs a-l).**

### 8.6 Conclusions

The above analysis clearly indicates that catch/CPUE derived SR curves/BRPs have potential application in sea trout stock assessment. The use of catch derived RSEs/egg estimates applies a similar concept to the CL approach used in salmon management, and so should be more readily understood/accepted by external interests and could utilise the same compliance procedures. The latter approach also has a stronger biological basis than use of CPUE, incorporates size (weight) variation as well as abundance in assessment procedures and (through the scaling effects of exploitation rate adjustment) allows comparison between rivers. It also appears more precautionary in outcome.

More rigorous and comprehensive evaluation of these methods is required, however, including:

- Application to a wider group of rivers to explore and better understand spatial variability.
- Close scrutiny of anomalous results to uncover weaknesses in data or assessment methods.
- Sensitivity analysis e.g. to examine the effects of varying smolt age; .0+ size; and other factors on model outputs.
- Possible examination of SR relationships other than the Ricker and Beverton and Holt models.

## 9 Life tables & projection models

### 9.1 Why Life tables?

This category of demographic analysis is arguably the basis of all forms of population dynamics modelling and therefore has elements in common with most other assessment models considered by WKTRUTTA2. This is particularly true for *Salmo trutta*, which has life cycles characterised by high phenotypic plasticity (Ferguson 2006). Anadromy marks a habitat shift that is thought to offer fitness benefits when the increased fitness opportunities of the marine environment outweigh the increased mortality risks incurred by migration (e.g. Jonsson and Jonsson, 2006). Variation in survival, growth, maturation and fertility determine both the likelihood of anadromy and the subsequent timing of 1$^{st}$ maturation and return to rivers, and thus, sea trout stock characteristics.

Life history traits are influenced by environmental and genetic factors in both freshwater and marine environments. Moreover, adjustments amongst them are inter-linked by trade-offs that maximise fitness in the context of spatial or environmental variation (e.g. temperature, habitat, productivity). This may be why sea trout display such wide variety in life histories and fishery characteristics. Understanding such processes is fundamental to modelling population dynamics and setting BRPs across a range of rivers. Key population life history traits can be defined and estimated through life table (LT) analysis, which assembles age or stage-specific schedules of survival, mortality and fertilities for a population. Many standard texts describe this analysis (Pitcher and Hart, 1993; Stearns, 1999; Gotelli, 2008) and only an outline is given here; the focus is on the benefits and snags that arise when LTs are applied to sea trout.

The ideas of fitness, adaptation, life history evolution, life history traits are not simple and Stearns (1999) discusses the complex concepts and definitions involved. However, LT approaches and the related matrix population modelling offer a framework for data collection and analysis anchored in a strong theoretical background (e.g. Stearns 1999; Caswell, 2001; Gotelli, 2008) that lends itself to further development as new understanding or data emerge. Life tables have rarely been applied in fishery stock assessment (Pitcher and Hart, 1993; Hilborn and Walters,1992), although more recently they have been used to study salmon population variation (Hutchings and Jones, 1998; Marschall *et al.* 1998), responses to long term environmental change (Aprahamian *et al.*, 2008) and anthropogenic impacts (e.g. Ferguson *et al.*, 2008, Lundqvist *et al.*, 2008).

The challenge is that LTs demand good data on age, size or stage-specific survival and fertility. It is important to ask if available data are suitable, can they be improved, or can the LT approach be adapted to accommodate data quality and to express resulting uncertainty.

## 9.2 Life Table examples

Data requirements for a LT are: age specific abundance, sex ratios, maturation rates and fecundities. A typical LT is shown, together with definition of terms, in Table 9.2.1, in this case for sea trout in the River Dee (data from Ian Davidson, Natural Resources Wales). The variables and terms in Table 9.2.1 are defined below:

**Age (x)** = the age in years from zero (egg) NB Age class (X) = age interval x to x+1

**Total population size (N)** = number of individuals in population, males and females

**Weight** = wet weight of individual female at age x

**Length** = fork length (cm) of individual female at age x

**Fecundity** = eggs per female, size specific, calculated in Dee case from the "UK" relationship of Solomon (1997).

**Sex ratio** = proportion of females at age x (in age class X)

**Proportion of mature females** = proportion of female mature at age x (in age class X)

$\mathbf{l_x}$ = probability of surviving to beginning of age x. From age x=0.

$\mathbf{p_x}$ = probability of surviving from age x to age (x+1)

[NB: $l_{x+1} = p_x\, l_x$ and $l_x = p_0 \times p_1 \times p_2 \ldots p_{x-1}$]

$\mathbf{m_x}$ = expected number of offspring (≈ eggs) for a female at age x (in age class X)

Various population average fitness measures can be derived from Table 9.2.1. Stearns (1999) briefly discusses and compares their attributes as fitness indices, noting three that are most commonly used ($R_0$, r and $\lambda$).

**<u>Net reproductive rate</u> ($R_0$)** is the most basic measure, being the life time number of female eggs produced by a female:

$$R_0 = \sum l_x . m_x$$

**The instantaneous rate of population increase (r)** is determined from the Euler-Lotka equation, which is solved numerically:

$$1 = \sum e^{-rx} l_x . m_x$$

**Rate of population growth per unit time, $\lambda$**

$$\lambda = e^r. \quad \text{(Note also that } N_t = \lambda . N_{(t-1)}\text{)}$$

A population with a stable age distribution (SAD) remains at constant size when r = 0, $\lambda$ =1; increases when r>0, $\lambda > 1$ and decreases when r<0 and $\lambda$ = 0 to 1.

Life table analysis assumes that the population has a stable age distribution (SAD). A population may have an unstable age distribution, in which case it will adjust and change population size to establish a SAD appropriate to the prevailing vital rates in an attempt to maximise fitness (e.g. reproductive rate) through short term responses and long term evolutionary change (Gross 1991). This becomes relevant when the two broad types of data for Nx are considered.

(1) Horizontal or age-specific tables follow the abundance (N) and other traits of an individual cohort through its life time. Such data are hard to get without long-term trapping studies.

(2) Vertical or time-specific table is based on a population sampled at any one time in the hope that it is representative of the average structure of the population over time. A single sample is clearly subject to errors through good/bad year classes and an improvement is usually to pool data from several sampling years.

**Table 9.2.1. Example life table for sea trout in the River Dee, North Wales, pooled data 2003–2007.**

| | Measured variables | | | | | | Derived variables | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age (x) | Pop size (N) | Weight kg | Length cm | Fecundity Eggs/fem | Propn female | Propn mature | $l_x$ | $P_x$ | $m_x$ | $l_x.m_x$ | $x.l_x.m_x$ | $e^{-rx}.l_x.m_x$ | $x.e^{-rx}.l_x.m_x$ |
| 0 | 758724 | | | | 0 | 0 | 1.0000 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| 1 | 37936 | | | | 0 | 0 | 0.0500 | 0.3 | 0 | 0 | 0 | 0 | 0 |
| 2 | 9484 | 0.42 | 32.7 | 711 | 0.60 | 0.55 | 0.0125 | 0.1 | 235 | 2.93 | 5.87 | 0.7332 | 1.4663 |
| 3 | 972 | 1.14 | 45.5 | 1767 | 0.72 | 0.80 | 0.0013 | 0.4 | 1018 | 1.30 | 3.91 | 0.1630 | 0.4889 |
| 4 | 364 | 2.05 | 55.2 | 3017 | 0.80 | 1.00 | 0.0005 | 0.3 | 2413 | 1.16 | 4.63 | 0.0723 | 0.2890 |
| 5 | 112 | 3.05 | 63.0 | 4343 | 1.00 | 1.00 | 0.0001 | 0.7 | 4343 | 0.64 | 3.20 | 0.0200 | 0.0999 |
| 6 | 82 | 3.84 | 68.0 | 5362 | 1.00 | 1.00 | 0.0001 | 0.4 | 5362 | 0.58 | 3.48 | 0.0091 | 0.0544 |
| 7 | 30 | 4.24 | 70.3 | 5877 | 1.00 | 1.00 | 0.0000 | 0.6 | 5877 | 0.23 | 1.62 | 0.0018 | 0.0127 |
| 8 | 19 | 4.67 | 72.6 | 6414 | 1.00 | 1.00 | 0.0000 | 0.3 | 6414 | 0.16 | 1.28 | 0.0006 | 0.0050 |
| 9 | 5 | 5.36 | 76.0 | 7278 | 1.00 | 1.00 | 0.0000 | 0.6 | 7278 | 0.05 | 0.44 | 0.0001 | 0.0009 |
| 10 | 3 | 5.30 | 75.8 | 7206 | 1.00 | 1.00 | 0.0000 | 0.4 | 7206 | 0.03 | 0.28 | 0.0000 | 0.0003 |
| 11 | 1 | 5.60 | 77.2 | 7580 | 1.00 | 1.00 | 0.0000 | 0.0 | 7580 | 0.01 | 0.12 | 0.0000 | 0.0001 |
| | | | | | | | | | SUM | 7.10 | 24.84 | 1.0000 | 2.4174 |

## 9.3 Matrix projection Models

Life tables as presented above take no explicit account of the various life history strategies of smolting and return migrations. For example, a fish allocated age (x) 5yrs could be several combinations of smolt age, or maiden fish, or previous spawner history. However, the LT presentation implicitly includes these because they are seen in the overall size structure and in the size-age key (Table 9.3.1). Matrix projection models are a means to take the prevailing population SAD and project future population size and structure in the face of changing pressures acting on the vital rates (Ferguson *et al.*, 2008). In the same way as LT, age- size- or stage-structured matrices are chosen according to the life cycles and data availabilities (Caswell, 2001). Stages might be: freshwater phase, smolts repeat spawners etc.). In this section, age-specific analysis is used. Stage-specific analysis was used by Tysklind *et al.* (2015) and described in Section 11).

Potential problems in LT or matrix projection models arise with the effects of overlapping generations, density dependent mortality, frequency dependent selection and combined migratory and non-migratory populations. Considering such issues, LT approaches might be complemented by individual based models that admit spatial structuring; and the complexity introduced by partial migration (Hayes *et al.*, 2009; Chapman *et al.*, 2012; Dodson *et al.*, 2013).

**Table 9.3.1. Example of size-age data from River Dee (courtesy of Ian Davidson, Natural Resources Wales). Showing how data were pooled to give abundance (in this scale sample) of the same age class, e.g. .0SM+ and .1+ are all fish of post smolt age. 1+. Colours correspond to fish of the same post-smolt (i.e. sea) age up to age 3; thus .0+SM+ and .1+ are both 1 sea yr, black = 0 sea yr, red = 1sea yr, blue = 2 sea yr and green = 3 sea yr.**

| R.DEE 2003 | .0 SEA WINTER MAIDENS | | | | | | | .1 SEA WINTER MAIDENS | | | | | | | .2 SEA WINTER MAIDENS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WT (kg) | 0+ | 0+SM+ | 0+2SM+ | 0+3SM+ | 0+4SM+ | 0+5SM+ | 0+6SM+ | 1+ | 1+SM+ | 1+2SM+ | 1+3SM+ | 1+4SM+ | 1+5SM+ | 1+7SM+ | 2+ | 2+SM+ | 2+2SM+ | 2+3SM+ | 2+4SM+ | 2+5SM+ | SUM |
| 0.2 | 4 | | | | | | | | | | | | | | | | | | | | 4 |
| 0.4 | 79 | | | | | | | | | | | | | | | | | | | | 79 |
| 0.6 | 97 | | | | | | | 1 | | | | | | | | | | | | | 98 |
| 0.8 | 23 | 17 | | | | | | 4 | | | | | | | | | | | | | 44 |
| 1.0 | 3 | 23 | 3 | | | | | 8 | 1 | | | | | | | | | | | | 38 |
| 1.2 | | 18 | | | | | | 8 | | | | | | | | | | | | | 26 |
| 1.4 | | 7 | 6 | | | | | 10 | | | | | | | | | | | | | 23 |
| 1.6 | | 2 | 8 | | | | | 9 | 4 | 1 | | | | | | | | | | | 24 |
| 1.8 | | 4 | 9 | | | | | 5 | | | | | | | 1 | | | | | | 19 |
| 2.0 | | 2 | 8 | | | | | 3 | | | | | | | 1 | | | | | | 14 |
| 2.2 | | 1 | 6 | 1 | | | | 3 | | 2 | | | | | | | | | | | 13 |
| 2.4 | | 1 | 1 | | | | | 2 | 4 | | | | | | | | | | | | 8 |
| 2.6 | | | 4 | 2 | 1 | | | | 2 | | | | | | | | | | | | 9 |
| 2.8 | | | 4 | 1 | | | | | 3 | | | | | | | | | | | | 8 |
| 3.0 | | | 4 | | | | | 1 | 1 | | 1 | | | | | | | | | | 7 |
| 3.2 | | | 2 | 1 | | | | | 3 | 1 | | | | | | | | | | | 7 |
| 3.4 | | 1 | 1 | 1 | 1 | | | | 2 | | | | | | | | | 1 | | | 7 |
| 3.6 | | | | | | 1 | | | 1 | | | 1 | | | | | | | | | 3 |
| 3.8 | | | | | 1 | | | | | | | | | | | | 2 | | | | 3 |
| 4.0 | | | | | | | | | | | 1 | | | | 1 | | | | | | 2 |
| 4.2 | | | | | 1 | | | | | | | | | | | | | | | | 1 |
| 4.4 | | | | | 1 | | | | 1 | | 1 | | | | | | | | 1 | | 4 |
| 4.6 | | | | | | | | | | | | | | | | | | | | | 0 |
| 4.8 | | | | | | | | | | | | | | | | 2 | | | | | 2 |
| 5.0 | | | | | | | | | | | | | | | | 1 | | | | | 1 |
| 5.2 | | | | | | | | | | | 1 | 1 | | | | | | | | | 2 |
| 5.4 | | | | | | | 1 | | | 1 | | | 1 | 1 | | | | | | | 4 |
| 5.6 | | | | | | 1 | | | | | 1 | | | | | | | | 1 | | 3 |
| SUM | 206 | 76 | 56 | 6 | 5 | 2 | 1 | 54 | 22 | 5 | 5 | 2 | 1 | 1 | 3 | 3 | 2 | 1 | 2 | 0 | 453 |

## 9.4 A preliminary life table analysis of sea trout in Wales

A preliminary study as part of the Celtic Sea Trout Project (CSTP) looked at LTs for 32 Welsh stocks (Milner 2010). The data for determining population size distribution (from which, with an age-size key, an age distribution ($N_x$) can be derived) were from rod license annual catch returns e.g. Environment Agency 2012). An issue of particular concern for sea trout applications is the varying exploitation and reporting rates for sea trout of age n.0+, which are believed to be present and caught in large numbers in the British Isles but are reported less than larger fish.

Input variables were derived as follows:

Age-specific size. For the 32 rivers, weight frequency distributions (0.2 kg class intervals) of unadjusted (for reporting efficiency) rod catches were combined for years 2003–2007 and transformed to age distributions using an age-weight key from the river Dee (Table 9.3.1) where sea trout are routinely aged from scales.

Age-specific abundance Estimated from weight-frequency data for each river and the derived age distributions. Ages of multiple spawners were pooled into true (post-smolt) sea age. Thus a n.0SM+ fish is put in the same cohort a n.1+ fish. On the River Dee, annual population estimates were derived by mark-recapture for whitling (.0+) and older fish (>.0+) (Davidson *et al.*, 2006). The >0+ group was partitioned into age groups from the scale-based ages and used to estimate the annual probability of survival (lx), for the Dee. For whitling, believed to be seriously under-reported in the rod catch generally, the Dee data for trap and rod catches were used to estimate and adjustment factor. The whitling proportion at the trap was 0.861 compared with 0.364 in angler returns, giving a raising factor of 2.4 to be applied to the rod catch in other rivers.

Age-specific fecundity. Estimated from Solomon (1997) mean relationship between fecundity (number of eggs per female, N) and fork length (L, cm) for England and Wales: $Lg_{10} N = 2.754 \text{ Log } L$. Length was calculated from midpoint of weight (W) class by $Lg_{10} L = lg_{10} W \times 0.333 + 1.6382$ (N =6,653), as derived from the River Dee samples, 1994 - 2007.

Age-specific maturity. (a) *Whitling:* from mark-recaptures the proportions of whitling that subsequently were recorded from scales as .0+SM (i.e. maturing whitling) was estimated and expressed a proportion of total whitling (.0+) calculated by applying the intervening survival (lx) to the proportion of .1+ fish (maidens, i.e. whitling that did not mature). (b) *Older fish:* the same procedure was applied to 1 sea-winter fish and all fish older than 1 SW were assumed to be mature. The estimates show recent changes in the maturation rates, but for present purposes the mean values of 0.55 and 0.80 for the period were applied to the other rivers.

Age-specific proportion of females. From River Dee data, proportions of females in .0, .1 and >.1 fish were assumed to be 0.6, 0.72 and 0.8 respectively.

## 9.5 Preliminary Results

Simple catch-based variables give a first indication of some life history features around the Welsh rivers (Figure 9.5.1). The proportion of whitling (as indexed by fish <0.45kg in rod catch) for example varies regionally (Figure 9.5.2) tending to be higher in stocks in Cardigan Bay. First sea-year survival appeared to be higher in the Bristol channel rivers (Figure 9.5.3) and the combined effect of age structure and other population features lead to spatial differences in $R_0$ (Figure 9.5.4). Across rivers $r_m$, and $R_0$ were related (Figure 9.5.5), and the fitness indices are related to the life history strategy, for example time of first return as index by proportion of whitling (Figure 9.5.5). The LH traits appeared to show some spatial variation and an initial partitioning by three marine geographic regions North, Mid and South Wales, illustrates this, although it is not intended to preclude the role of other factors or gradients.

This preliminary analysis was dependent upon the river Dee for age-size keys, maturity and proportion of females at age, population features that may be river-specific. The nature of regional marine growth patterns for example is likely to be important and when incorporated into LTs may reveal further spatial variation. The Dee data allowed individual cohorts to be followed (horizontal table), to compare with vertical tables. In this case the deviations were quite small (Figure 9.5.6). These data also allow time trends to be shown for example in fitness measures (Figure 9.5.6). Interestingly, $R_0$ and $r_m$ give contrasting trends, but with synchronous annual variation, in contrast to the expected pattern from between river comparisons (Figure 9.5.5).

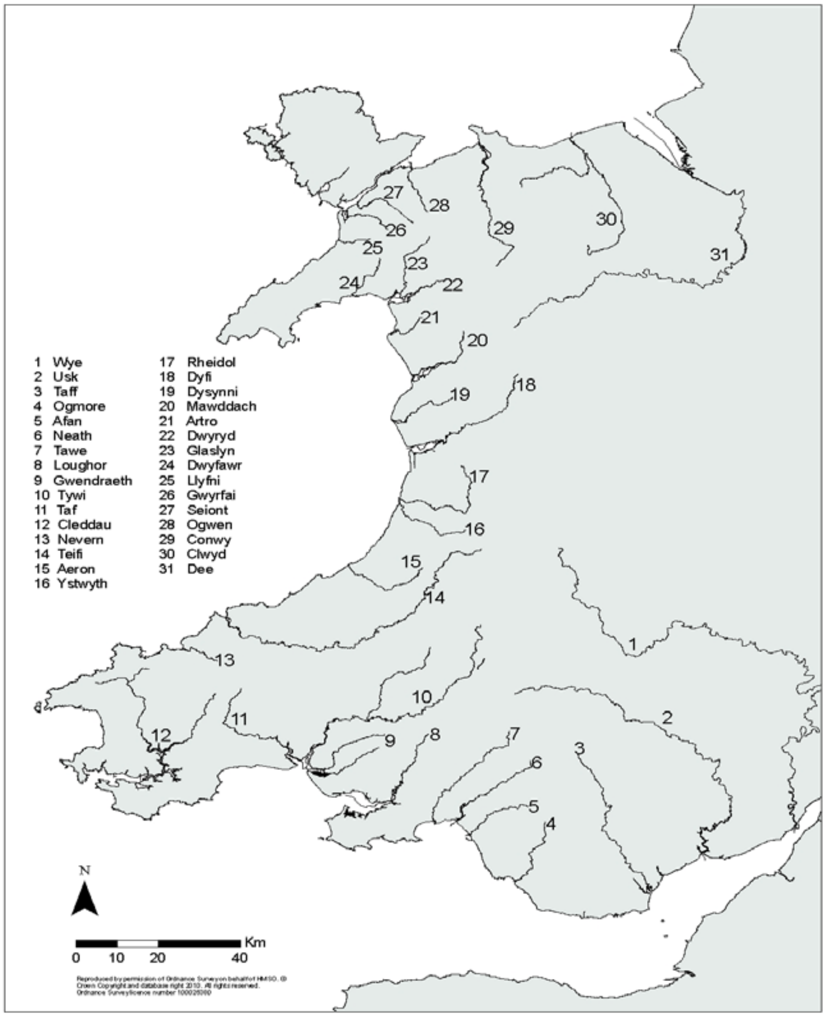



**Figure 9.5.1. Map of Welsh rivers used for sea trout life table analysis.**

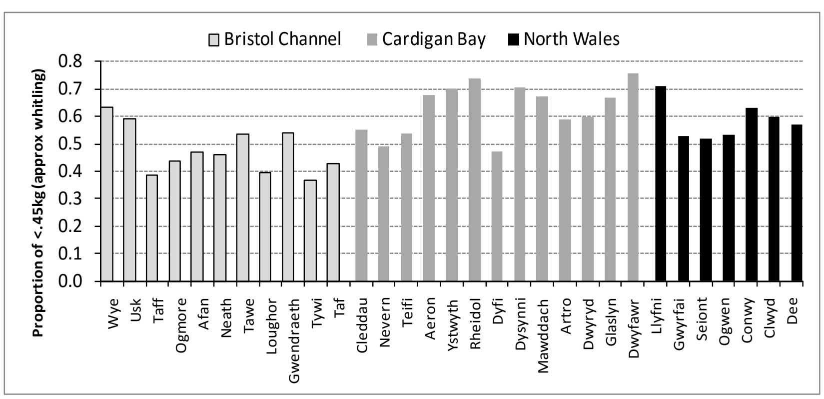



**Figure 9.5.2. Proportions of sea trout <0.45kg (mainly whitling) in reported (unadjusted) rod catch in Welsh rivers, illustrating geographical variation. Rivers ordered from south to north (Wye to Dee), mean 2003–2007.**

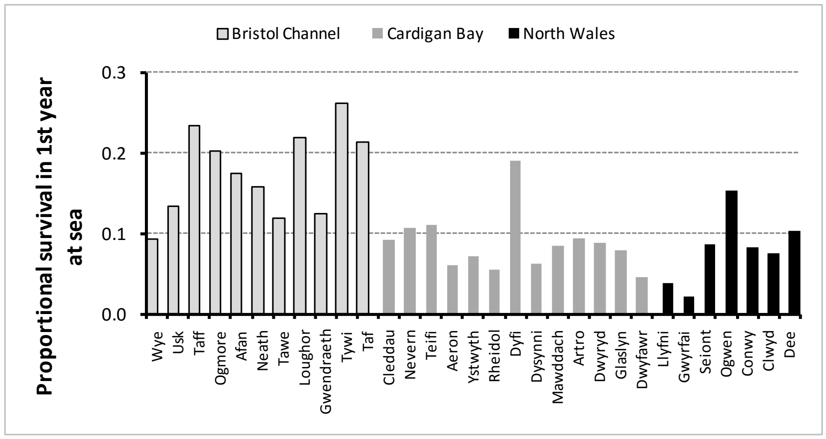



**Figure 9.5.3. First year survival (lx) for sea trout in 32 Welsh rivers (whitling N adjusted for underreporting – see text).**

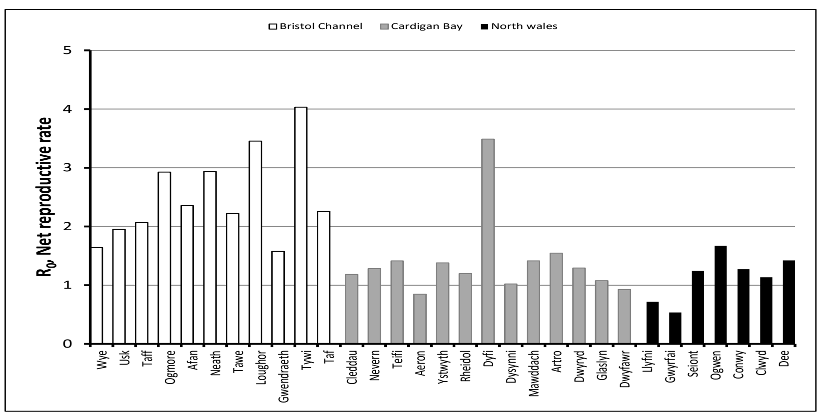



**Figure 9.5.4. Preliminary estimates of $R_0$ (net reproductive rate) in 32 Welsh rivers.**

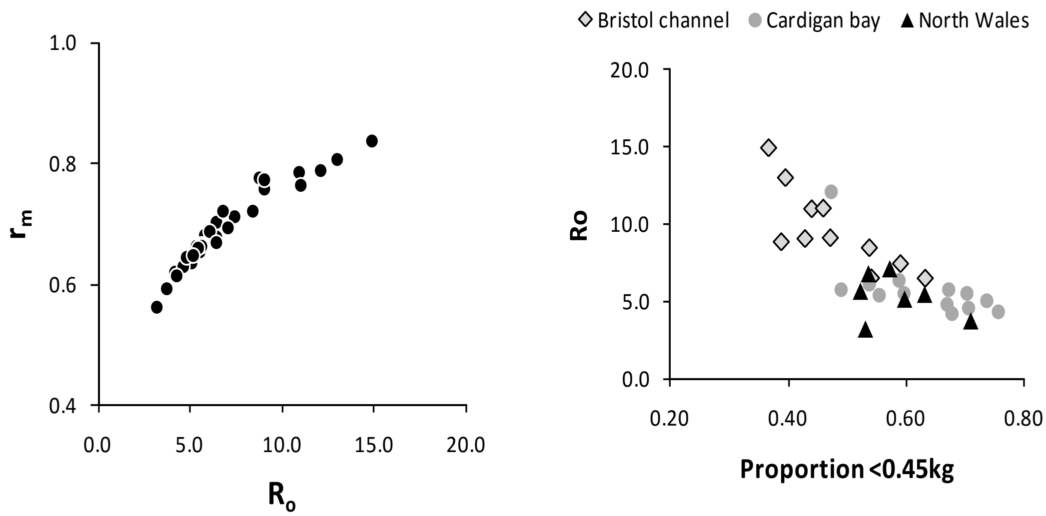



**Figure 9.5.5. Showing relationships amongst some life history variables between rivers. Left: Relationship between $R_0$ and $r_m$. Right: effect of "whitling" (indexed by fish <0.45kg) on $R_0$.**

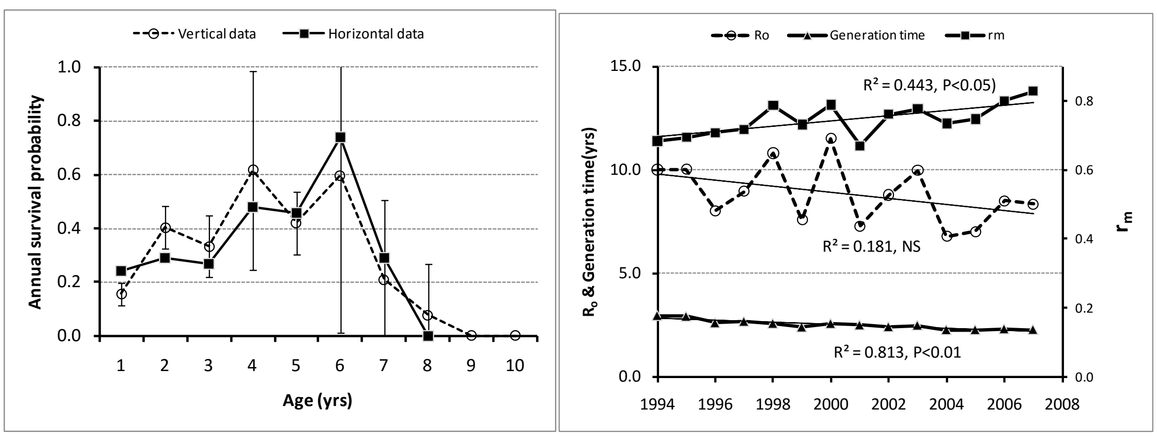



**Figure 9.5.6. Left: Marine survival in Dee sea trout. Comparison of vertical (pooled different cohorts, with 95%CL) and horizontal (mean of year classes 1989–2000) tables. Right: Temporal variation in $R_0$, $r_m$ and generation time) in the river showing contrasting trends of $R_0$ and $r_m$, River Dee.**

## 9.6 Conclusions

1) Life tables (LT) can be demanding to parameterise, but offer a theoretically robust way of assembling and analysing history features that can be interpreted in terms of population fitness, resilience and change.
2) The preliminary LT approach needs to be further tested and taken forward to projection modelling, e.g. Leslie matrices, if these found to be workable for sea trout.
3) Spatial variation in life history traits from adjacent coastal regions was indicated.

4 ) There are significant practical data-related issues to resolve:

- Review sensitivity of LT analyses to input variable data quality.
- The practicality of deriving river (or at least regional) age-weight keys and maturity estimates (*cf* Dee). It may be feasible to use other traps sites and data from some previous long term scale reading studies (Dyfi, Usk, Tawe, Taff, Dyfi, Conwy, for example), but much of this is old data and a contemporary solution is required.
- How to provide unbiased population abundance indices, combining rod and other forms of adult sampling. Whitling raise a particular problem due to angler selectivity and reporting. Exploitation rates in different rivers need to be determined. Mixed stocks due to straying will be an issue.
- How to address the issue of partial migration, i.e. the linkage between migratory and non-migratory components. The problem being that analyses of the type above, based only on returning anadromous trout, are addressing only part of the rivers' trout populations, if there is a significant degree of sympatry between migrants and non-migrants. This problem is small if all or most females are migratory, but increases as the partial migration increases. Indices of partial migration are needed.
- A related problem of how to address spatial structuring of life history traits within catchments, given that most adult stock descriptions are only available at catchment scale.
- How to incorporate uncertainty into the estimates, e.g MCMC simulation methods.

# 10 Projection models applied to Atlantic salmon

The management of sea trout and Atlantic salmon differ substantially owing to the long distance migratory behaviour of the salmon and the stocks being targeted by fisheries distant to their spawning grounds. There are however, potential similarities in the way stock forecasts may be made through application of Bayesian forecasting models. Computer applications such as Open BUGS (Bayesian inference Using Gibbs Sampling) and JAGS (Just Another Gibb Sampler) enable Bayesian mathematical models to be built with Monte-Carlo type recalculation processes, where the equation structure enables estimates to be made through a recursive manner, with the range of likelihood results monitored, and reported, giving the most probable results and their associated ranges or uncertainty. Furthermore, the Bayesian framework enables estimates to be made of unobserved quantities, and the inclusion of prior understanding of values and expert opinions.

Atlantic salmon are managed on the basis of a 'fixed escapement strategy' in recognition of the importance of the spawning stock to subsequent recruitment. Critical to this process is that spawning requirements of the rivers contributing to distant water fisheries must be defined. Management advice, expressed as allowable harvest (tonnes), is then predicated on a forecast of salmon abundance prior to the fishery such that the spawning requirements of the contributing stocks can be achieved. The provision of catch advice thus proceeds through a number of steps:

- The definition of spawning objectives;
- The development of a measure of abundance prior to the fishery; i.e. the pre-fishery abundance (PFA);
- A measure of the spawning stock contributing to the PFA;
- A model to forecast the PFA.

Estimates of these are made through a mathematical run-reconstruction of the stock status, from nationally reported catches and exploitation rates, and national estimates of the minimum sustainable sizes. These biological reference points (conservation limits) are either generated from the pseudo SR relationship between lagged egg deposition and total 1SW PFA, or more specific country/region SR estimates. Estimates of the current stock status are then compared against the reference points and national summaries produce of median spawner numbers, CLs and SERs, maturing 1SW PFA, 1SW returns, 1SW spawners, non-maturing 1SW PFA, MSW returns and MSW spawners. This approach provides insight into the current status of the stocks.

In the following Bayesian forecast analysis, the annual egg estimates (termed lagged eggs), annual return estimates and catch statistics are used to estimates a "productivity parameter", by comparing estimates of the egg production against estimates of the PFA. This productivity parameter is then projected forward in a random walk process by five years, with subsequent estimates of lagged eggs and PFA predicted. In such a way a likelihood forecast can be made of the stock exceeding its biological reference point in the following five years (ICES, 2014).

A hierarchical Bayesian life cycle model incorporating PFA calculations and foresting is currently under development (Massiot-Granier *et al.*, 2014). With the exception of the distant water migration, such a model offers an example of how sea trout could be incorporated into a forecasting approach, with the advantage of being able to accept missing data, prior belief and expert judgement in positions of missing data.

# 11 Meta-population models

Using the data collected during the Celtic Sea Trout Project (Anon 2016), an analysis was undertaken of 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. Although such an approach misses the reproductive output of the brown trout contingent, modelling the sea trout contingent allows us to uncover the relative importance of the different anadromous life-histories (whitling, sea winters, repeat spawners) in maintaining trout populations in different rivers. Considering that choice of anadromy may be partially environmental or genetically determined, such an approach may also be considered as a proxy of the dynamics of environmental cues leading to smoltification or an "anadromy gene" within trout populations.

Scales from returning sea trout were collected by anglers and scientific sampling from 22 rivers draining into the Celtic and Irish Seas. 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 analysis was based on those individuals for whom age, life history, and fecundity could be estimated (N=3,755.) The life history of each individual was reconstructed based on the year of capture and the ageing formula estimated from scales collected at the time of capture. Matrix projection models were developed using stage-specific approaches with stages defined by the recreated 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).

A stage based model was employed as they 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 facilitates modelling of the complexity in life history patterns found in sea trout prior to onset of reproduction, and preserves the variance among life histories in the length of time from fry to first reproduction. The variance among rivers in repeat spawners frequency and the associated increase in fecundity as sea trout age is captured by having several yearly spawning classes as stages. This section of the model behaves more as an age model, where individuals move exclusively from one stage to the next on a yearly basis or die. The among-population variance in encountered sea-ages is nicely captured by having multiple spawning classes. Sea trout fertility is dependent on its size, thus, to capture the among-population variance in stage-specific fertility, we needed estimates of population-specific length at age which could be converted into population-specific stage-specific fertilities. River specific somatic growth models combined with individual correction (difference between real and predicted length) were constructed. These somatic growth models were then used to reconstruct the length of individuals in previous years until age 1. The individual reconstructed lengths were only translated into fertilities if a spawning mark (SM) was identified for that individual on that year.

Transition matrices were constructed based on the recreated life histories using *popbio*. Each matrix value 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 (Table 11.1). As the ageing data came from returning adults, values for all transitions prior to first return (egg survival, parr survival, sea survival prior to first return) had to be imposed on the model. The same values were imposed on all populations to capture the variance in somatic growth rates, sea winter tendency, and longevity among sea trout populations.

**Table 11.1. Example of transition matrix showing the probabilities that an individual in a stage (columns) may go to another stage (rows)**

| | 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 |

[Stages key: FW= juveniles in freshwater; SW= sea water; IM]

The matrices can then be projected into the future and analysed to obtain valuable information about the dynamics of each population. Among them, parameters such as population annual growth rate ($\lambda$), generation time, stable-stage distribution, stage-specific reproductive values, and damping ratio (population resilience to perturbation) can be estimated (Table 11.2). Analysis of the sensitivities and elasticities of $\lambda$ to perturbation of the matrix (what-if analysis) allows understanding how population will react in terms of population growth rate if particular transitions are modified.

**Table 11.2. Population dynamics parameters as estimated from matrix projections: N= number of individuals included in the estimation; lambda ($\lambda$) = population growth rate; NetRepRate = net reproductive rate; GenTime = generation time; DampR ($\varrho$)= damping ratio; E.FW= elasticity of $\lambda$ to fresh water phase; E.Whitling = elasticity of $\lambda$ to whitling; E.SeaWinter= elasticity of $\lambda$ to the sea winter phase; E.FirstSpawn= elasticity of $\lambda$ to first spawning event; E.RepSpawn = elasticity of $\lambda$ to repeat spawners.**

| | 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 |

A fascinating feature of the elasticities of $\lambda$ is that they add up to one, and thus elasticities of particular transitions can be added up to know their relative contribution to the population growth rate. The population-specific dependence on the minimum life history (egg

-> parr -> whitiling -> egg) compared to all other life history strategies (sea winters and repeat spawners) was compared among all populations, revealing wide among population variance in their dependence of the minimum life history. For some rivers, such as the Boyne in Ireland, sea trout population growth rate is nearly exclusively dependent on such minimum life history (0.986), which is also reflected with the lowest damping ratio values (1.185), highlighting their relative weak capacity to withstand perturbations. At the other end of the spectrum, rivers such as the Lune, have sea trout populations with high dependency of alternative life histories (0.512), show slightly negative growth rates ($\lambda$=0.952) but higher damping ratios (2.180).

If elasticities of $\lambda$ are added according to life stage (whitling, sea winters, repeat spawners) and compared to important population dynamics traits such as population growth rate, generation time or damping ratio, some interesting relationships emerge:

- Low estimated population $\lambda$ was associated with higher elasticities of $\lambda$ to the sea winter phase (Figure 11.1), indicating that populations where sea winters are a common life history stage (such as the Border Esk, Lune, Ribble, 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.

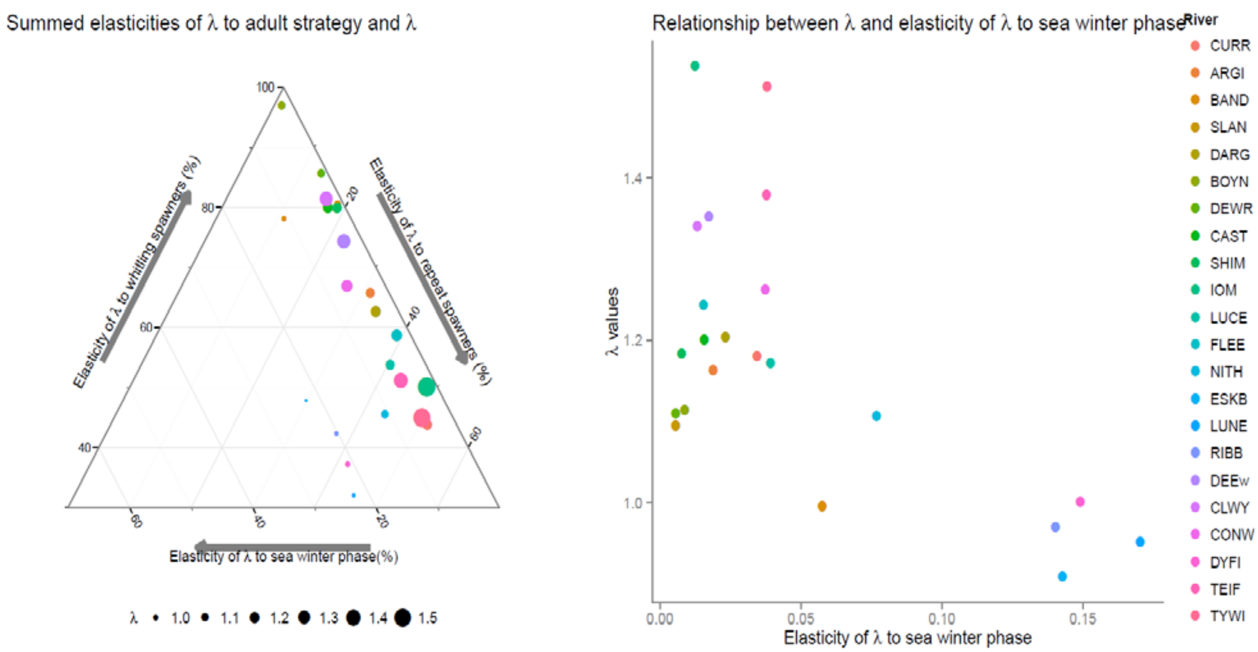



**Figure 11.1. Summed elasticities of λ to different phases of the adult life history strategy and relationship between λ and elasticity of λ to sea winter phase.**

- Longer generation times were associated with high elasticities of $\lambda$ to repeat spawners (Figure 11.2), showing the impact of repeat spawners on the time needed to increase the population size by a factor of $R_0$.

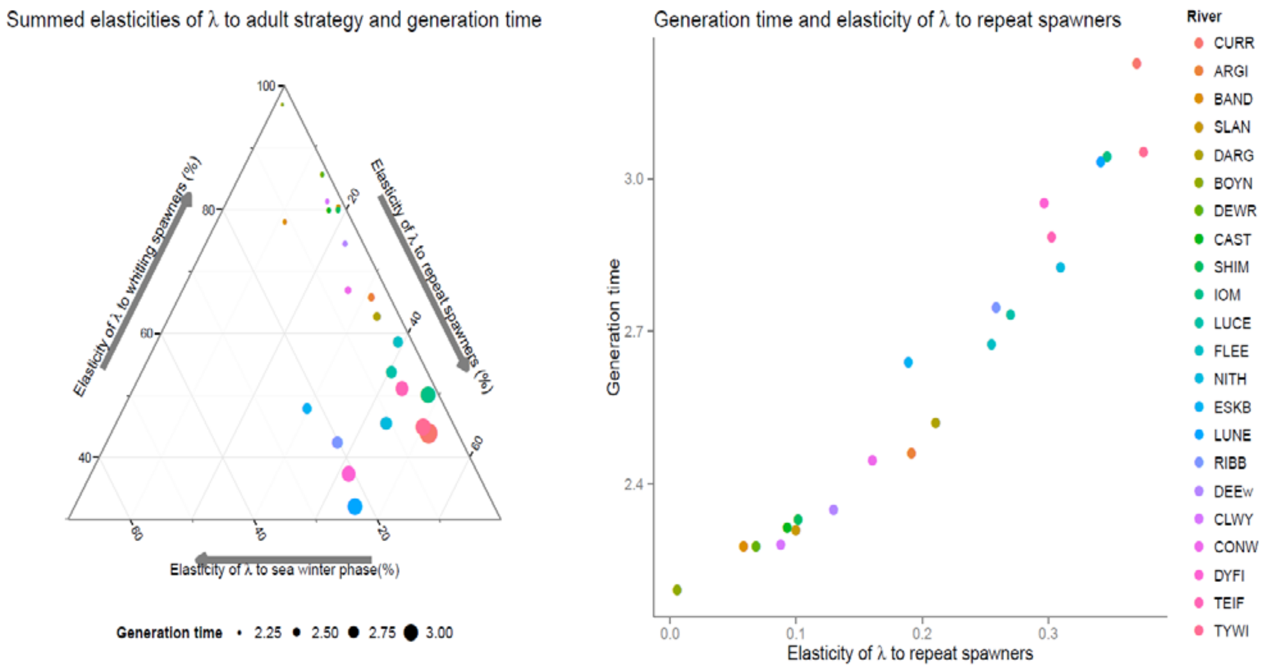



**Figure 11.2. Summed elasticities of λ to different phases of adult life history strategy and relationship between λ and elasticity of λ to repeat spawners.**

- Higher damping ratios were associated with high elasticity of λ to sea winters (Figure 11.3), illustrating how the distribution of reproductive effort across many stages, such as the inclusion of sea winters, improves the population capacity of converging to stable stage distribution.

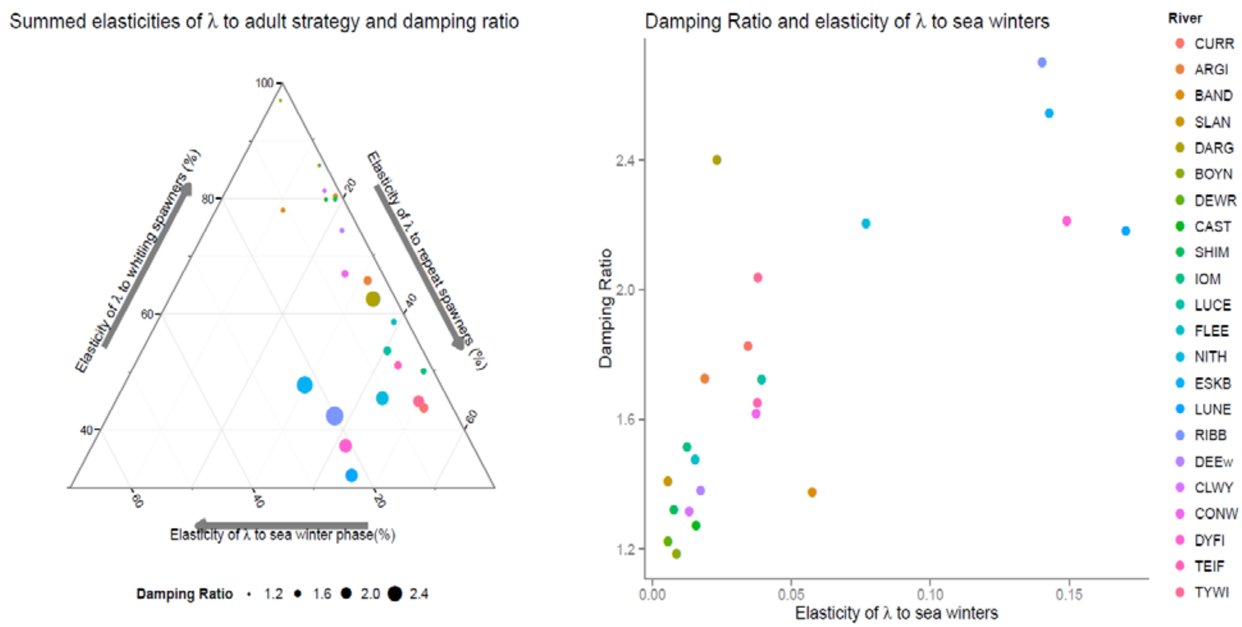



**Figure 11.3. Summed elasticities of λ to different phases of adult life history strategy and relationship between λ and elasticity of λ to sea winters**

Comparative meta-population approaches allow a more in-depth understanding of the impacts of individual life-history choice on population dynamics. By estimating population-specific transition and fertility at age values, we can start to identify the strategies employed by each river, how they optimise them to the particular needs of their environment, and whether evolutionary mechanisms are involved in the variance in population dynamic strategies. The results of the meta-population analysis can then be compared to variables that may explain the variance in population dynamic traits such river-specific environment, associated marine habitat, or population phylogenetic history and connectivity with neighbouring rivers.

These models could be vastly improved if life-histories across all life stages (egg, parr, brown trout, smolts, sea winters, whitling, and repeat spawners) could be obtained. Integrated projection models (IPMs), which could combine information from many different sources (catches, mark-recapture, size-distributions, and scale reading) and manage uncertainty, will allow to extend the current exercise to the complete life cycle of trout, and provide population specific characteristics on other life history choices, such as anadromy and smoltification age.

# 12 A size-based indicator of salmonid population state

The size (length or body mass) of a fish captures key aspects of biology (e.g., fecundity) and ecology (e.g., predator-prey and competition interactions). Size-based models seem to adequately describe fish community dynamics and have been applied to fisheries management questions, e.g. potential effects of size-selective harvest or of ‘balanced fishing’. Predictable fishing-induced curtailment of fish population/community size-structure underlies size-based indicators (e.g. the Large Fish Indicator) that contribute to state (GES) assessments under the MSFD. Declining large fish abundance has various implications at population and community scales and hence comprises impaired ecological status. Importantly, large fish (Big Old Fat Fecund Females, BOFFFs) typically produce more and larger eggs, and so their loss from a population will result in reduced potential fecundity. There may be depensation effects on fecundity of sea trout among the largest size classes, but the majority of egg production still comes from larger individuals. The impact on realized egg production of curtailed size structure will vary among populations, dependent on their baseline body mass-fecundity relationship. Several studies identify the most fecund size/age classes in given populations, allowing this relationship to be described and population-specific BOFFF size thresholds to be identified. Such population-specific thresholds would comprise the body mass corresponding to a fixed percentage (e.g., 75%) of observed maximum fecundity (Figure 12.1). Loss of fish above this BOFFF threshold would be monitored by a size-based state indicator, i.e., the proportion of individuals in a river year that are larger than the defined body mass (BOFFF) threshold for that river. Annual values for the indicator could be related to an objective state target, e.g., Froese (2004) suggested that values of 30–40% for the proportion of the population comprising BOFFFs ('megaspawners') represents a desirable healthy structure (see Figure 12.2).

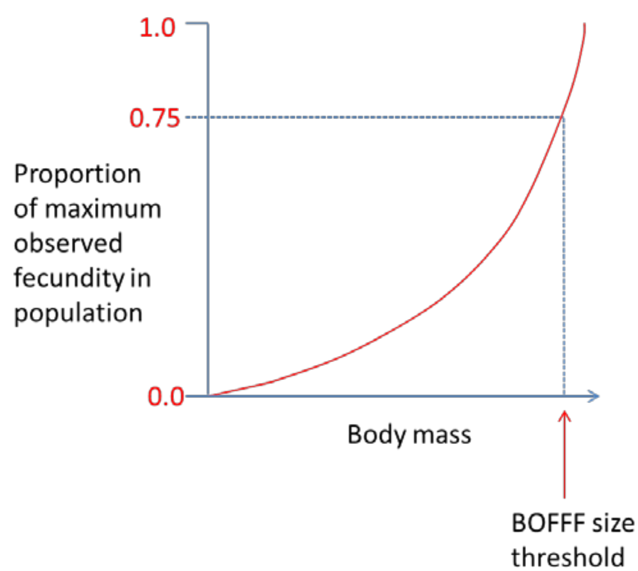



**Figure 12.1. Schematic of mass–fecundity relationship used to derive river-specific size (BOFFF) threshold.**

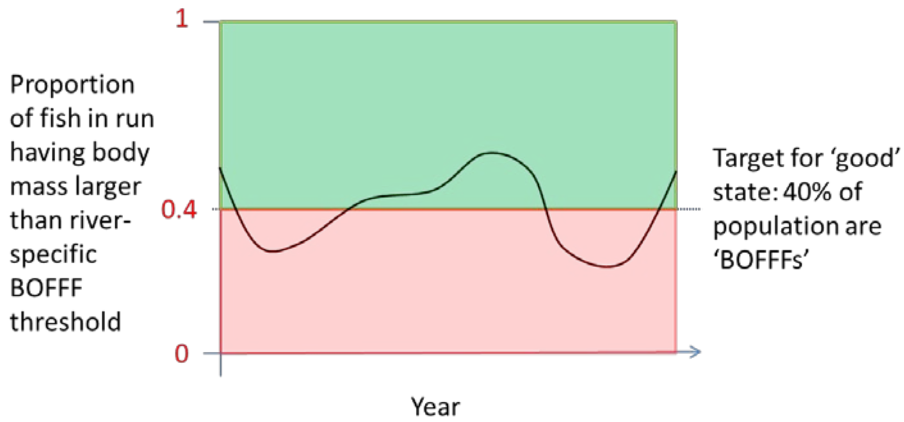



**Figure 12.2. Schematic of a time series for a size-based indicator of ecological state for migratory salmonid populations.**

### 12.1 Integrating suites of indicators to derive overall state assessment

Assessing state in salmonid populations is limited by data availability and by understanding of important ecological drivers and processes. Available data time series frequently do not extend far enough back in time to allow objective targets/thresholds to be defined empirically, e.g., from 'pristine' state. In such situations, trends-based targets offer a pragmatic solution. Greenstreet *et al.* (2012) propose a method for setting community-level indicator targets as the number (proportion) of a pool of individual species-specific metrics required to meet their trends-based metric-level targets. This method is based on demonstrating significant departures from the binomial distribution. The Workshop speculates that there may be potential to apply a similar method to suites of habitat/ecological indicators describing salmonid population state.

## 13 Predicting exploitation rate and run size from models of rod catch and counter data

### 13.1 Introduction

Rod exploitation rate $F$ is defined as the proportion of a river salmonid population (run) that is captured by recreational fishing in a given year. Empirical estimation of $F$ requires a count of running fish and a corresponding record of fish catches. Data for Irish systems are used here to develop a statistical model that can be used to predict likely exploitation rate for systems having catch but no run (counter) data. Estimates of $F$ can then be used as a multiplier to estimate run size from catch.

There are 27 Irish rivers having migratory fish counters. The counters are primarily intended to count salmon, but 15 systems are also considered to produce reasonable sea trout counts. Time series of catch/run vary in length among rivers from 5-44 years. Additional data for each river-year include system (presence or absence of a lake), management status (open or catch and release fishery) and exploitation level (an expert opinion on relative fishing intensity: light, medium or heavy).

## 13.2 Model

A binomial generalized linear mixed model (GLMM) is specified in the "R" syntax form as:

*(rodkill + rodcr) / run ~ system * status * exploit + (1|year) + (1|water) + (1|id), weights = run*

Where:

rodkill = annual rod catch,

rodcr = annual catch and release,

run = annual number of fish passing each counter,

system = type of water,

status = management status,

exploit is expert opinion on exploitation level,

(1|year) and (1|water) are random effects on the intercept of year and individual water respectively, and

(1|id) is an observation level random effect.

The model predicts ranges of likely exploitation rate for given categories of system and management status. In Ireland, exploitation rate tends to be higher in rivers than in lakes and higher in open fisheries than in catch and release fisheries (Figure 13.2.1). Additional data from other rivers, ideally in other countries, would support a more general model.

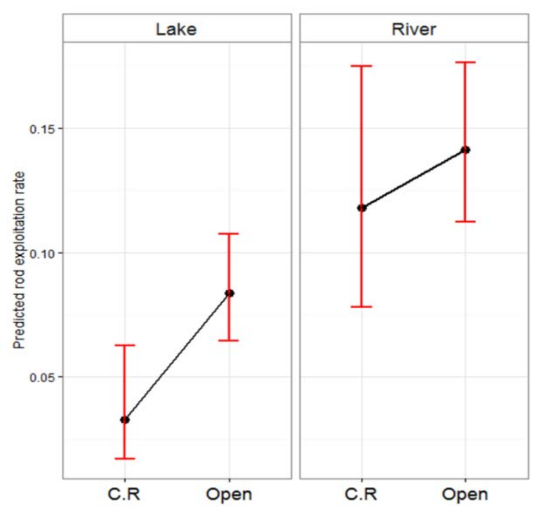



**Figure 13.2.1. Predicted exploitation rate by system and status.**

## 13.3 Application

A simple decision tree (Figure 13.3.1) could be used to classify a given system and identify the appropriate exploitation range to apply.

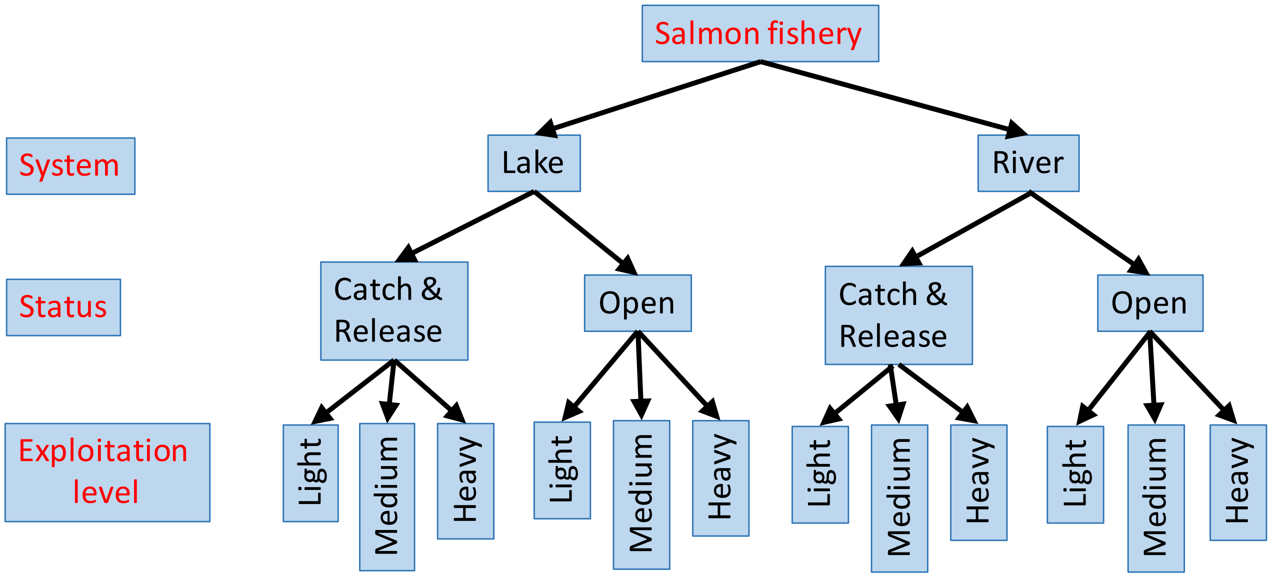



**Figure 13.3.1. Schematic of decision tree for selecting appropriate exploitation rate estimate (see Figure 13.2.1) for a data poor system.**

# 14 Application of modelling approaches to management questions

The Workshop summarised their conclusions on the need for further work on the application of modelling approaches to management questions for sea trout (Table 14.1). While there are a wide range of potential modelling applications which could greatly assist managers, there is still a basic need to develop reliable approaches for monitoring changes in stock abundance and setting BRPs to support management decisions. While detailed data on stock abundance is obtained for some stocks by means of traps and counters, such facilities are available on only a very small proportion of rivers containing sea trout. For other rivers, there is a need to use alternative methods to estimate abundance, and these are usually based on catch data. The current paucity of good historic sea trout catch records in many countries may preclude the development of historic stock estimates as has been achieved for Atlantic salmon (e.g. ICES, 2015b), but the Workshop heard that efforts were being made to improve the collection of catch statistics in many areas. Further work is required to develop models relating catches to stock abundance taking account of variations in fishing effort and environmental conditions such as river discharge

Setting BRPs for sea trout poses particular problems because of the complex and highly variable life history strategies of the species. However, **the Workshop recommended that two approaches, the THS method and the development of SR relationships from catch data, should be developed further.**

The THS provides a common habitat classification system for trout parr. It was developed for use on sea trout rivers in the Baltic Sea region and needs to be tested more widely in the North Atlantic. There is potential to develop better relationships between the stock/river descriptors and trout parr abundance, taking account of their relative importance and collinearity. While the THS method appears to provide a good method to assess the pristine productive capacity of a river, there is also a need to develop BRPs from it. This requires the THS to be compared with estimates of adult abundance and, where possible, S-R data for trout (See section 6.8).

The analysis undertaken for WKTRUTTA2 indicates that S-R relationships derived from catch or CPUE data may also have potential application in the development of BRPs for sea trout stocks. The approach has clear parallels with that used for the assessment of Atlantic salmon, although its application may be limited by the availability of good catch records. The Workshop has recommended areas for further investigation (See section 8.6 and Annex 7).

The factors affecting anadromy in trout and the relationship between resident and anadromous components of trout stocks are still poorly understood and there is a need for more population modelling to investigate these and advise managers. Population dynamics models are also required to investigate the potential impacts of fisheries, other anthropogenic factors and environmental change on sea trout and forecast future stock trends.

**Table 14.1. Workshop conclusions on the application of sea trout population models to management issues.**

| | |
|---|---|
| **Stock abundance** | ***Index Rivers:*** Rivers with traps and/or counters provide important sources of information on the changing abundance of different life-stages within a stock and support management and many other studies on sea trout (see below). *Maintain and extend the network of index rivers wherever possible, including systems with lakes.* |
| | ***Trout Habitat Score (THS) method:*** The THS has been developed for a number of rivers, and extrapolating site indices to other rivers has been started in Baltic. *Extend and test the THS method more extensively outside Baltic (where there are more variable sea trout stocks/rivers), including comparing the THS to adult production and other stock measures. Investigate the variation in THS and relate it with biological and physical characteristics of index systems geographically. both within and outside Baltic.* |
| | ***VPA & Run-reconstruction:*** These approaches have been used to estimate stock abundance for salmon for use in management advice. *Develop trial R-R models for sea trout, where suitable historic data are available.* |
| | ***Life cycle models:*** – Few such models have been developed for sea trout. *Develop models to improve understanding of the dynamics of sea trout populations and investigate relationships between life-stages and the effects of stressors.* |
| **Sustainable stock size (BRP)** | ***Index Rivers:*** Data sets from index studies provide the basis for developing true SR relationships and thereby setting BRPs using conventional approaches (e.g. as used for salmon). *Review monitoring programmes to improve comparability of data sets between rivers and improve opportunities for meta-analysis. Include systems with lakes.* |
| | ***Trout Habitat Score (THS):*** - *The THS method should be formalised into a clear BRP (e.g. pristine based system) and related to pristine levels/max production.* |
| | ***Pseudo S-R approaches:*** *Investigate approach further to develop S-R relationships based on other data sets and compare results with 'true' values calculated for index rivers. Investigate alternative proxies for S and R and variability in pseudo-BRPs between systems. Relate BRPs to other variables to evaluate transportability* |
| | ***Transporting BRPs:*** *Relate all BRP values to river/lake parameters to investigate potential for transportability.* |
| **Stock structure and diversity** | ***Residency v. anadromy:*** *Investigate resident/anadromous input to egg deposition, smolt output and adult ST return and relate to stock or environmental variables*<br>*Investigate age structures – environmental, genetic and historic impact (e.g. fishery) effects on variance of population characteristics.*<br>**Meta-population analysis, IBMs, etc:** *Develop such approaches to allow more detailed analysis of life-history tactics. Develop capture-mark-recap models to compare life history strategies.* |
| **Fisheries impacts** | ***Exploitation rates:*** *Use counts or other stock estimates (see above) and catch records. Investigate and describe relationships between catch and stock size, taking account of effort and environmental parameters, etc.* |
| | ***Long term impacts:*** *Develop population dynamics models – meta-populations & Bayesian approaches* |
| **Anthropogenic impacts** | ***Population dynamic models:*** Such models provide the basis to forecast or simulate changes in populations affected by anthropogenic factors. *Develop such models to better understand factors affecting sea trout stocks, including role of lakes.* |
| | ***Planned developments:*** *model population under pristine conditions & compare with forecast under impacted conditions* |
| | ***Identifying impacts:*** *Relate changes in stock abundance or diversity to changes in anthropogenic impacts* |
| **Environmental impacts** | ***Population dynamic models:*** *Use population models to forecast or simulate changes in populations under different environmental conditions. Forecast effects by modelling population under pristine conditions & comparing this with status under altered conditions. Ideally have range of conditions in multiple years* |
| **Data requirements** | ***All sea trout rivers*** : *Ensure that sound basic data on catches (and associated biological data - length, scales/age), effort and juveniles are collected for all sea trout stocks.* |
| | ***Index rivers:*** *More detailed data including more biological data are required to develop and run more complex models. More basic biological information on populations will improve pop model development* |
| | ***Counts and traps (inc mark-recapture, video etc):*** *Maintain and develop such monitoring to ensure the provision of reliable population parameters and time series for a sample of stocks.* |

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## Annex 1: WKTRUTTA2 Terms of Reference

**2015/2/SSGEPD07** The **Workshop on Sea Trout 2** (WKTRUTTA2), chaired by Ted Potter, UK, and Johan Höjesjö, Sweden, will meet at ICES HQ, Copenhagen, Denmark, 2–5 February 2016 to:

a ) Review the pros and cons of different approaches for modelling sea trout (anadromous *Salmo trutta*) populations taking account of parameterization, data collection and management application;

b ) Consider whether, and if so how, to take account of resident as well as migratory trout in population models;

c ) Review methods currently used and develop new approaches for assessing the status of trout stocks.

WKTRUTTA2 will report by 1 August 2016 (via SSGEPD) for the attention of the WGRECORDS and SCICOM.

**Supporting information**

| | |
|---|---|
| Priority | The activities of this Group will take forward the scene-setting work of WKTRUTTA which met in 2012. It will address key questions relating to the management of sea trout stocks in the North Atlantic and Baltic and will take advantage of the outcomes from a number of EU funded initiatives on sea trout. The inclusion of sea trout and other diadromous fish in EU policy areas including the CFP and Marine Strategy Framework Directive means that it is important to improve the methods currently available to managers to assess the status of stocks and investigate the effects of management actions. |
| Scientific justification | Term of Reference a) Compared with Atlantic salmon, relatively few sea trout stocks have been studied for sufficient time to allow the development of population models. Initiating such studies now will be very expensive and take many years to provide results that will be useful for modelling. There is therefore a need to consider alternative modelling approaches, e.g. based on catch data.<br>Term of Reference b) Resident and migratory trout within the same river are known to breed together but the relative importance of the two components in the dynamics of the overall trout population within a river is generally poorly understood. Models have often been developed on the migratory component on its own, although they may be biologically unrealistic.<br>Term of Reference c) There is a need to develop Biological Reference Points (BRPs) or alternative methods to assess the status of sea trout populations for management purposes. New approaches are being developed and applied in the Baltic and it is timely to review the progress that has been made in order to help inform other countries in determining what approaches to take.<br>The Workshop addresses several objectives and priority areas in the ICES Science Plan, particularly priority areas 6, 9, 10 and 25. Expected deliverables from the Workshop include a review of currently used monitoring methods, an initiation of the work to develop BRPs or alternative methods to assess the status of sea trout populations, and recommendations for how this work could be taken forward. The final report and recommendations will guide both individual countries in making progress on sea trout assessment and |

| | |
|---|---|
| | management and also will steer ICES on the best next steps for Sea trout science, assessment and advice. |
| Resource requirements | The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible. |
| Participants | WKTRUTTA-1 attracted over 30 participants. |
| Secretariat facilities | Requires coordinating activities from ICES secretariat for a Workshop. |
| Financial | No financial requirements other than associated with meeting at ICES HQ. |
| Linkages to advisory committees | Links to ACOM and WGBAST who provide advice on Baltic sea trout and SSGEPD and WGRECORDS regarding diadromous fish stocks, life histories, threats and sustainable use of the resource. |
| Linkages to other committees or groups | Relevant to the SSGEPI and SSGIEOM. |
| Linkages to other organizations | FAO |

## Annex 2: List of participants

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## Annex 3: Presentations to the Workshop

| WP No. | Authors | Title | Topic areas |
|---|---|---|---|
| 1 | Russell Poole et al | Burrishoole monitoring 2015 | 1, 4, 5 |
| 2 | Marie Nevoux | Monitoring *Salmo trutta* in the Oir River, France | 4, 2 |
| 3 | Sophie Launey | Sea trout sea scape | 6 |
| 4 | Nigel Milner | Sea trout life tables from catch data | 2, 3 |
| 5 | Nigel Milner | Environmental effects on traits | 2, 3 |
| 6 | Ian Davidson | CPUE based reference points for sea trout | 1, |
| 7 | Ian Davidson et al | Sea trout BRPs from catch based S-R relationships | 5 |
| 8 | Richard Kennedy | Sea Trout in Northern Ireland | 1,3,4 |
| 9 | Quentin Josset | Bresle River data | 1,2,3 |
| 10 | Sam Shephard & Jonathan White | Rod exploitation | 3, 1 |
| 11 | Johnathan White | Salmon assessment in Ireland | 6 |
| 12 | Jan Davidsen | Assessment in Norway | 1 |
| 13 | Bengt Finstad | Sea trout monitoring in Norway & Modelling | 1, 2 |
| 14 | Harry Strehlow | Recreational fisheries data collection | 3, 5 |
| 15 | Adam Lejk | Activities relating to Sea trout population from the Łeba River basin (Northern Poland) | 6 |
| 16 | Niklas Tysklind | Population dynamics of ST in British Isles | 2 |
| 17 | Rebecca Whitlock | Mark recap estimation of migration and mortality rates | 2, 3 |
| 18 | Eric Degerman | Toward S-R on a small Baltic river | 2 |
| 19 | Eric Degerman | Trout habitat score and recruitment status | 1, |
| 20 | David Aldven | Climate effects | 3, 6 |

**Topic areas:**

1. National monitoring / assessment methods for ST
2. Modelling approaches and management applications
3. Data collection and model parameterisation
4. Including resident trout in models
5. Biological reference points for ST
6. Other topics of interest

## Annex 4: Glossary of sea trout terms

**Alevin**: a newly hatched trout still carrying a yolk sac and remaining in the gravel;

**Anadromous fish:** fish born in freshwater that migrates to sea to grow and mature, and then return to freshwater as an adult to spawn (e.g. salmon, sea trout);

**Finnock/Whitling**: regional names for small sea trout in their first year after smolt migration;

**Fry:** young trout (and salmon) that have hatched out in the current year, normally in May at the stage from independence of the yolk sac as the primary source of nutrition up to dispersal from spawning areas (redds);

**Kelt**: a sea trout (and salmon) after spawning before they return the sea;

**Ova:** alternative term for eggs

**Parr:** a juvenile trout (or salmon) after its first summer in freshwater

**Post-smolt**: a smolt that has entered sea water

**Sea trout:** **a**nadromous form of the trout (*Salmo trutta*) from the post-smolt stage; the brown trout remains in freshwater throughout its life. (*Salmo trutta*)

**Smolt:** a parr that has undergone morphological, behavioural and physiological changes that enables them to migrate into a saline environment still residing in freshwater

# Annex 5: Sea trout rivers in Europe

**Preliminary table of European sea trout (Salmo trutta) rivers in ICES area, with proportion of anadromous females in adult populations**

The Workshop began work to collate information on sea trout rivers in Europe with a view to developing a database and map. The group proposed that the work should be completed by a follow-on ICES Expert Group on sea trout.

One objective of the tabulation was to obtain information on the extent of anadromy in different stocks (Col H), by allocating a 5 point (inc NA) grade of the average % of anadromous female spawners, based on available information and expert opinion

Two approaches were proposed do this:

(1) using the relative abundance of sea trout (ST) to salmon(SL) in the recorded rod catches (col H), and noting to which time period it refers (col K)

(2) using the relative abundance of sea trout (ST) to salmon(SL) in any freshwater samples available, and calculating the ratio ST/SL (col I) and noting the time period and method (e.g. EF, trap)detail (col K)

The following grades have been applied:

| GRADE | (% range) |
|---|---|
| NA | Not available |
| 1 = Low | (=<10%) |
| 2 = Moderate | (11% - 50%) |
| 3 = High | (51% - 80%) |
| 4 = Very high | (>80%) |

* Suggest use the ratio of ST to SAL in rod catches. For rivers where known systematic decline of ST has occurred, please use period when sea trout were last regarded as prevalent -and please note the time period in "details" column

** e.g. based on the ratio of ST to resident trout based on EF samples of adults in river, or other metrics. Assume that all parr larger than max smolt threshold are adult resident

| **Country codes** | | | | |
|---|---|---|---|---|
| | 1 | Eng.Wales | 7 | Denmark |
| | 2 | Scotland | 8 | Germany |
| | 3 | Norway | 9 | Poland |
| | 4 | Sweden | 10 | Finland |
| | 5 | Eire | 11 | Lithuania |
| | 6 | N.Ireland | 12 | France |

| No. | Country | River (name) | Location of est' mouth | | River size | | Grading (% anadromous) according to basis 1 or 2, outline method details, if necessary | | | | Likely causal environmental factors for the allocated grade | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | code | (name) | Lat' | Long' | Average daily flow (estuary) ($m^3 s^{-1}$) | Length from source (Km) | (1) GRADE Expert opinion NA or 1-4) | (2) catch data* NB ST/SL ratio | (3) freshwater samples ** | details | Lakes are important ? (Y/N) | Long or steep river? (Y/N) | Poor marine habitat (Y/N) | Other? |
| 1 | 1 | Aeron | | | 4.02 | 82.66 | 4 | 83.53 | | catch data 94-98 | N | Y | N | |
| 2 | 1 | Dysynni | | | 4.73 | 85.15 | 4 | 59.75 | | | | | | |
| 3 | 1 | Gwyrfai | | | 3.70 | 28.53 | 4 | 34.10 | | | | | | |
| 4 | 1 | Loughor | | | 6.56 | 59.82 | 4 | 31.97 | | | | | | |
| 5 | 1 | Afan | | | 4.42 | 42.91 | 4 | 15.00 | | | | | | |
| 6 | 1 | EW.cleddau | | | 10.89 | 296.13 | 4 | 14.03 | | | | | | |
| 7 | 1 | Glaslyn | | | 8.70 | 78.64 | 4 | 12.79 | | | | | | |
| 8 | 1 | Rheidol | | | 7.53 | 117.66 | 4 | 12.19 | | | | | | |
| 9 | 1 | Ystwyth | | | 6.04 | 120.57 | 4 | 10.87 | | | | | | |
| 10 | 1 | Avon.hants | | | 19.21 | 378.70 | 1 | 9.72 | | | | | | |
| 11 | 1 | Clwyd | | | 6.23 | 326.75 | 4 | 9.48 | | | | | | |
| 12 | 1 | Erme | | | 2.15 | 32.35 | | 8.69 | | | | | | |
| 13 | 1 | Ogmore | | | 9.17 | 97.56 | 4 | 8.68 | | | | | | |
| 14 | 1 | Dwyryd | | | 4.78 | 69.93 | 4 | 8.54 | | | | | | |
| 15 | 1 | Avon.Devon | | | 3.65 | 139.00 | | 8.19 | | | | | | |
| 16 | 1 | Artro | | | 2.89 | 25.34 | 4 | 8.00 | | | | | | |
| 17 | 1 | Esk | | | 4.52 | 79.22 | | 7.79 | | | | | | |
| 18 | 1 | Neath | | | 11.61 | 95.15 | 4 | 6.99 | | | | | | |
| 19 | 1 | Dyfi | | | 21.32 | 404.18 | 4 | 6.83 | | | | | | |
| 20 | 1 | Plym | | | 3.76 | 49.24 | | 6.75 | | | | | | |
| 21 | 1 | Mawddach | | | 8.74 | 79.58 | 4 | 6.07 | | | | | | |
| 22 | 1 | Tywi | | | 38.84 | 599.77 | 4 | 5.88 | | | | | | |
| 23 | 1 | Fowey | | | 5.36 | 80.09 | 4 | 5.80 | | | | | | |
| 24 | 1 | Lynher | | | 4.73 | 46.92 | 4 | 5.59 | | | | | | |
| 25 | 1 | Yealm | | | 1.58 | 23.95 | 3 | 5.54 | | | | | | |
| 26 | 1 | Ellen | | | | 43.32 | | 5.40 | | | | | | |
| 27 | 1 | Dart | | | 10.73 | 174.75 | | 5.20 | | | | | | |
| 28 | 1 | Teifi | | | 25.83 | 545.04 | 4 | 4.25 | | | | | | |
| 29 | 1 | Teign | | | 9.11 | 171.68 | | 3.89 | | | | | | |
| 30 | 1 | Tavy | | | 7.07 | 63.02 | | 3.89 | | | | | | |
| 31 | 1 | Tawe | | | 10.63 | 111.87 | | 3.31 | | | | | | |
| 32 | 1 | Wear | | | 15.20 | 347.26 | | 3.28 | | | | | | |
| 33 | 1 | Taf | | | 6.94 | 220.51 | | 2.87 | | | | | | |
| 34 | 1 | Camel | | | 5.64 | 107.13 | | 2.78 | | | | | | |
| 35 | 1 | Wyre | | | 6.40 | 124.82 | | 2.70 | | | | | | |

| No. | Country | River (name) | Location of est' mouth | | River size | | Grading (% anadromous) according to basis 1 or 2, outline method details, if necessary | | | | Likely causal environmental factors for the allocated grade | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | code | (name) | Lat' | Long' | Average daily flow (estuary) ($m^3 s^{-1}$) | Length from source (Km) | (1) GRADE Expert opinion NA or 1-4) | (2) catch data* NB ST/SL ratio | (3) freshwater samples ** | details | Lakes are important ? (Y/N) | Long or steep river? (Y/N) | Poor marine habitat (Y/N) | Other? |
| 36 | 1 | Duddon | | | 5.21 | 32.27 | | 2.66 | | | | | | |
| 37 | 1 | Crake | | | 0.00 | 75.00 | | 2.59 | | | | | | |
| 38 | 1 | Itchen | | | 6.00 | 93.59 | | 2.39 | | | | | | |
| 39 | 1 | Torridge | | | 15.34 | 310.46 | | 2.37 | | | | | | |
| 40 | 1 | Esk.Border | | | 27.81 | 366.03 | | 2.31 | | | | | | |
| 41 | 1 | Taw | | | 18.59 | 395.38 | | 2.23 | | | | | | |
| 42 | 1 | Seiont | | | 5.04 | 47.59 | | 2.16 | | | | | | |
| 43 | 1 | Taff | | | 22.29 | 194.14 | | 2.15 | | | | | | |
| 44 | 1 | Esk.Cumbria | | | 4.33 | 39.93 | | 2.15 | | | | | | |
| 45 | 1 | Conwy | | | 20.68 | 304.97 | | 1.98 | | | | | | |
| 46 | 1 | Piddle | | | 3.03 | 71.91 | | 1.81 | | | | | | |
| 47 | 1 | Lune | | | 34.11 | 426.89 | | 1.60 | | | | | | |
| 48 | 1 | Ribble | | | 30.68 | 263.38 | | 1.58 | | | | | | |
| 49 | 1 | Leven | | | 14.32 | 125.40 | | 1.40 | | | | | | |
| 50 | 1 | Irt | | | 3.23 | 56.85 | | 1.34 | | | | | | |
| 51 | 1 | Ehen | | | 5.78 | 81.25 | | 1.29 | | | | | | |
| 52 | 1 | Test | | | 13.15 | 229.78 | | 1.18 | | | | | | |
| 53 | 1 | Ogwen | | | 5.47 | 51.00 | | 1.14 | | | | | | |
| 54 | 1 | Tamar | | | 21.01 | 352.69 | | 1.11 | | | | | | |
| 55 | 1 | Frome | | | 7.34 | 149.99 | | 1.10 | | | | | | |
| 56 | 1 | Coquet | | | 8.98 | 181.00 | | 1.05 | | | | | | |
| 57 | 1 | Tyne | | | 47.04 | 652.64 | | 1.00 | | | | | | |
| 58 | 1 | Kent | | | 8.96 | 102.03 | | 0.82 | | | | | | |
| 59 | 1 | Derwent | | | 33.27 | 208.38 | | 0.55 | | | | | | |
| 60 | 1 | Dee | | | 38.47 | 729.76 | | 0.40 | | | | | | |
| 61 | 1 | Lyn | | | 3.65 | 68.71 | | 0.38 | | | | | | |
| 62 | 1 | Usk | | | 37.09 | 550.88 | | 0.38 | | | | | | |
| 63 | 1 | Eden | | | 59.41 | 988.61 | | 0.30 | | | | | | |
| 64 | 1 | Tees | | | 24.77 | 656.22 | | 0.29 | | | | | | |
| 65 | 1 | Calder | | | 0.00 | 106.31 | | 0.23 | | | | | | |
| 66 | 1 | Severn | | | 111.88 | 3491.75 | | 0.05 | | | | | | |
| 67 | 1 | Exe | | | 23.48 | 486.88 | | 0.05 | | | | | | |
| 68 | 1 | Wye | | | 77.47 | 1965.16 | | 0.03 | | | | | | |
| 69 | 2 | Creran | | | 5.09 | 0.00 | | 12.46 | | | | | | |
| 70 | 2 | Arnisdale | | | 2.37 | 0.00 | | 9.24 | | | | | | |

| No. | Country | River (name) | Location of est' mouth | | River size | | Grading (% anadromous) according to basis 1 or 2, outline method details, if necessary | | | | Likely causal environmental factors for the allocated grade | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | code | (name) | Lat' | Long' | Average daily flow (estuary) ($m^3 s^{-1}$) | Length from source (Km) | (1) GRADE Expert opinion NA or 1-4) | (2) catch data* NB ST/SL ratio | (3) freshwater samples ** | details | Lakes are important ? (Y/N) | Long or steep river? (Y/N) | Poor marine habitat (Y/N) | Other? |
| 71 | 2 | Torridon | | | 3.69 | 0.00 | | 8.16 | | | | | | |
| 72 | 2 | Ugie | | | 4.63 | 0.00 | | 7.15 | | | | | | |
| 73 | 2 | Ythan | | | 8.45 | 0.00 | | 6.97 | | | | | | |
| 74 | 2 | Ailne | | | 6.19 | 0.00 | | 5.22 | | | | | | |
| 75 | 2 | Fleet | | | 4.14 | 0.00 | | 4.44 | | | | | | |
| 76 | 2 | Ewe | | | 28.78 | 0.00 | | 3.90 | | | | | | |
| 77 | 2 | Lossie | | | 4.33 | 0.00 | | 2.62 | | | | | | |
| 78 | 2 | Balgay | | | 4.02 | 0.00 | | 2.18 | | | | | | |
| 79 | 2 | Carron | | | 11.42 | 0.00 | | 1.63 | | | | | | |
| 80 | 2 | Nith | | | 41.56 | 0.00 | | 1.24 | | | | | | |
| 81 | 2 | Laxford | | | 7.32 | 0.00 | | 1.23 | | | | | | |
| 82 | 2 | Cree | | | 18.24 | 0.00 | | 1.19 | | | | | | |
| 83 | 2 | Ailort | | | 3.20 | 0.00 | | 1.17 | | | | | | |
| 84 | 2 | Kinnaird | | | 4.64 | 0.00 | | 0.97 | | | | | | |
| 85 | 2 | Luce | | | 5.71 | 0.00 | | 0.95 | | | | | | |
| 86 | 2 | Ormsary | | | 1.21 | 0.00 | | 0.90 | | | | | | |
| 87 | 2 | Nairn | | | 7.24 | 0.00 | | 0.84 | | | | | | |
| 88 | 2 | Bervie | | | 2.14 | 0.00 | | 0.67 | | | | | | |
| 89 | 2 | Girvan | | | 7.29 | 0.00 | | 0.52 | | | | | | |
| 90 | 2 | Grudie | | | 1.14 | 0.00 | | 0.50 | | | | | | |
| 91 | 2 | Don | | | 24.58 | 0.00 | | 0.50 | | | | | | |
| 92 | 2 | Aberdeenshire Dee | | | 53.04 | 0.00 | | 0.45 | | | | | | |
| 93 | 2 | Kinloch | | | 2.24 | 0.00 | | 0.45 | | | | | | |
| 94 | 2 | Spey | | | 80.52 | 0.00 | | 0.45 | | | | | | |
| 95 | 2 | Deveron | | | 22.35 | 0.00 | | 0.43 | | | | | | |
| 96 | 2 | Applecross | | | 3.37 | 0.00 | | 0.43 | | | | | | |
| 97 | 2 | Kishorn | | | 1.36 | 0.00 | | 0.40 | | | | | | |
| 98 | 2 | Dee | | | 38.19 | 0.00 | | 0.37 | | | | | | |
| 99 | 2 | Ness | | | 84.81 | 0.00 | | 0.36 | | | | | | |
| 100 | 2 | Urr | | | 8.85 | 0.00 | | 0.30 | | | | | | |
| 101 | 2 | Conon | | | 51.94 | 0.00 | | 0.27 | | | | | | |
| 102 | 2 | Dunbeath | | | 2.19 | 0.00 | | 0.21 | | | | | | |
| 103 | 2 | Moidart | | | 2.57 | 0.00 | | 0.18 | | | | | | |
| 104 | 2 | North Esk | | | 17.24 | 0.00 | | 0.17 | | | | | | |
| 105 | 2 | Ayr | | | 14.36 | 0.00 | | 0.15 | | | | | | |

| No. | Country | River (name) | Location of est' | | River size | | Grading (% anadromous) according to basis 1 | | | | Likely causal environmental factors for | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | code | (name) | Lat' | Long' | Average daily flow (estuary) ($m^3 s^{-1}$) | Length from source (Km) | (1) GRADE Expert opinion NA or 1-4) | (2) catch data* NB ST/SL ratio | (3) freshwater samples ** | details | Lakes are important ? (Y/N) | Long or steep river? (Y/N) | Poor marine habitat (Y/N) | Other? |
| 106 | 2 | Tweed | | | 91.13 | 0.00 | | 0.13 | | | | | | |
| 107 | 2 | Stinchar | | | 11.04 | 0.00 | | 0.12 | | | | | | |
| 108 | 2 | Findhorn | | | 3.22 | 0.00 | | 0.12 | | | | | | |
| 109 | 2 | Tay | | | 172.69 | 0.00 | | 0.10 | | | | | | |
| 110 | 2 | Inver | | | 8.10 | 0.00 | | 0.09 | | | | | | |
| 111 | 2 | Doon | | | 10.98 | 0.00 | | 0.09 | | | | | | |
| 112 | 2 | Wick | | | 4.53 | 0.00 | | 0.03 | | | | | | |
| 113 | 2 | Ullapool | | | 4.44 | 0.00 | | 0.02 | | | | | | |
| 114 | 2 | Bladnoch | | | 9.86 | 0.00 | | 0.01 | | | | | | |
| 115 | 2 | Halladale | | | 5.85 | 0.00 | | 0.01 | | | | | | |
| 116 | 3 | Beiarvassdraget | | | 56.00 | 90.00 | | 27.25 | | | | | | |
| 117 | 3 | Strynselva | | | 30.00 | 28.50 | | 7.41 | | | | | | |
| 118 | 3 | Saltdalsvassdraget | | | 51.00 | 56.50 | | 5.12 | | | | | | |
| 119 | 3 | Oldenelva | | | 16.00 | 2.40 | | 3.40 | | | | | | |
| 120 | 3 | Årøyelva | | | 33.00 | 1.30 | | 3.34 | | | | | | |
| 121 | 3 | Fjærevassdraget | | | 1.60 | 5.00 | | 2.65 | | | | | | |
| 122 | 3 | Flåmselva | | | 17.00 | 4.00 | | 2.63 | | | | | | |
| 123 | 3 | Laukhellevassdraget | | | 13.00 | 32.50 | | 2.44 | | | | | | |
| 124 | 3 | Loneelva | | | 4.20 | 3.50 | | 2.39 | | | | | | |
| 125 | 3 | Eidselva | | | 26.00 | 38.00 | | 1.86 | | | | | | |
| 126 | 3 | Lærdalselva | | | 40.00 | 39.70 | | 1.66 | | | | | | |
| 127 | 3 | Gloppenelva | | | 45.00 | 62.00 | | 1.59 | | | | | | |
| 128 | 3 | Nærøydalselva | | | 17.00 | 10.00 | | 1.48 | | | | | | |
| 129 | 3 | Surna | | | 56.00 | 72.40 | | 1.41 | | | | | | |
| 130 | 3 | Suldalslågen | | | 62.00 | 24.50 | | 1.37 | | | | | | |
| 131 | 3 | Oselva | | | 10.00 | 26.00 | | 1.30 | | | | | | |
| 132 | 3 | Åelva og Ommedalselva | | | 13.00 | 10.50 | | 0.96 | | | | | | |
| 133 | 3 | Årdalselva | | | 19.00 | 13.00 | | 0.96 | | | | | | |
| 134 | 3 | Målselvvassdraget | | | 178.00 | 120.50 | | 0.87 | | | | | | |
| 135 | 3 | Buksnesvassdraget | | | 2.10 | 8.00 | | 0.81 | | | | | | |
| 136 | 3 | Verdalsvassdraget | | | 64.00 | 54.20 | | 0.77 | | | | | | |
| 137 | 3 | Sausvassdraget | | | 6.70 | 26.00 | | 0.75 | | | | | | |
| 138 | 3 | Altaelva | | | 74.00 | 61.00 | | 0.73 | | | | | | |
| 139 | 3 | Gaula | | | 98.00 | 150.00 | | 0.72 | | | | | | |
| 140 | 3 | Reisavassdraget | | | 53.00 | 95.00 | | 0.69 | | | | | | |

| No. | Country | River (name) | Location of est' mouth | | River size | | Grading (% anadromous) according to basis 1 or 2, outline method details, if necessary | | | | Likely causal environmental factors for the allocated grade | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | code | (name) | Lat' | Long' | Average daily flow (estuary) ($m^3 s^{-1}$) | Length from source (Km) | (1) GRADE Expert opinion NA or 1-4) | (2) catch data* NB ST/SL ratio | (3) freshwater samples ** | details | Lakes are important ? (Y/N) | Long or steep river? (Y/N) | Poor marine habitat (Y/N) | Other? |
| 141 | 3 | Stjørdalselva | | | 77.00 | 73.50 | | 0.64 | | | | | | |
| 142 | 3 | Lakselva | | | 25.00 | 61.10 | | 0.59 | | | | | | |
| 143 | 3 | Nidelva | | | 95.00 | 9.70 | | 0.55 | | | | | | |
| 144 | 3 | Namsen | | | 289.00 | 175.90 | | 0.54 | | | | | | |
| 145 | 3 | Etneelva | | | 24.00 | 31.00 | | 0.50 | | | | | | |
| 146 | 3 | Bondalselva | | | 6.10 | 15.30 | | 0.34 | | | | | | |
| 147 | 3 | Orkla | | | 72.00 | 96.50 | | 0.28 | | | | | | |
| 148 | 3 | Nausta | | | 23.00 | 11.00 | | 0.27 | | | | | | |
| 149 | 3 | Stordalselva | | | 14.00 | 24.50 | | 0.25 | | | | | | |
| 150 | 3 | Stabburselva | | | 20.00 | 28.50 | | 0.23 | | | | | | |
| 151 | 3 | Børselva | | | 27.00 | 35.00 | | 0.20 | | | | | | |
| 152 | 3 | Tanaelva | | | 169.00 | 822.50 | | 0.20 | | | | | | |
| 153 | 3 | Figgjo | | | 11.00 | 36.30 | | 0.17 | | | | | | |
| 154 | 3 | Neidenelva | | | 30.00 | 50.00 | | 0.15 | | | | | | |
| 155 | 3 | Årgårdsvassdraget | | | 23.00 | 57.50 | | 0.07 | | | | | | |
| 156 | 3 | Numedalslågen | | | 118.00 | 141.00 | | 0.06 | | | | | | |
| 157 | 3 | Håelva | | | 8.20 | 34.00 | | 0.04 | | | | | | |
| 158 | 3 | Ogna | | | 6.30 | 20.00 | | 0.04 | | | | | | |
| 159 | 4 | Löftaån | | | 2.30 | 30.00 | | 475.00 | | | | | | |
| 160 | 4 | Suseån | | | 7.60 | 50.00 | | 295.50 | | | | | | |
| 161 | 4 | Himleån | | | 8.00 | 27.00 | | 130.00 | | | | | | |
| 162 | 4 | Tvååkersån | | | 1.30 | 22.00 | | 40.50 | | | | | | |
| 163 | 4 | Kungsbackaån | | | 5.00 | 28.00 | | 16.38 | | | | | | |
| 164 | 4 | Fylleån | | | 7.00 | 50.00 | | 4.11 | | | | | | |
| 165 | 4 | Genevadsån | | | 3.70 | 37.00 | | 3.17 | | | | | | |
| 166 | 4 | Nissan | | | 38.20 | 186.00 | | 2.68 | | | | | | |
| 167 | 4 | Stensån | | | 4.73 | 47.00 | | 2.44 | | | | | | |
| 168 | 4 | Rolfsån | | | 11.10 | 75.00 | | 1.20 | | | | | | |
| 169 | 4 | Rönneån | | | 20.00 | 100.00 | | 1.18 | | | | | | |
| 170 | 4 | Ätran | | | 40.00 | 250.00 | | 0.60 | | | | | | |
| 171 | 4 | Örekilsälven | | | 22.00 | 90.00 | | 0.52 | | | | | | |
| 172 | 4 | Viskan | | | 34.00 | 141.00 | | 0.18 | | | | | | |
| 173 | 5 | Ballynahinch | | | 8.00 | 24.00 | | 15.48 | | | | | | |
| 174 | 5 | Currane | | | 2.90 | 15.00 | | 12.20 | | | | | | |
| 175 | 5 | Newport | | | 6.30 | 9.60 | | 9.51 | | | | | | |

| No. | Country | River (name) | Location of est' mouth | | River size | | Grading (% anadromous) according to basis 1 or 2, outline method details, if necessary | | | | Likely causal environmental factors for the allocated grade | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | code | (name) | Lat' | Long' | Average daily flow (estuary) ($m^3 s^{-1}$) | Length from source (Km) | (1) GRADE Expert opinion NA or 1-4) | (2) catch data* NB ST/SL ratio | (3) freshwater samples ** | details | Lakes are important ? (Y/N) | Long or steep river? (Y/N) | Poor marine habitat (Y/N) | Other? |
| 176 | 5 | Slaney | | | 20.50 | 117.00 | | 7.15 | | | | | | |
| 177 | 5 | Kylemore | | | 2.50 | 16.00 | | 6.43 | | | | | | |
| 178 | 5 | Feale | | | 17.30 | 73.60 | | 6.05 | | | | | | |
| 179 | 5 | Lackagh | | | 4.30 | 12.00 | | 5.09 | | | | | | |
| 180 | 5 | Eske | | | 3.80 | 15.00 | | 2.00 | | | | | | |
| 181 | 5 | Leannan | | | 8.00 | 30.80 | | 1.88 | | | | | | |
| 182 | 5 | Glenamoy | | | 2.80 | 12.80 | | 1.33 | | | | | | |
| 183 | 5 | Owenmore | | | 6.15 | 19.10 | | 1.31 | | | | | | |
| 184 | 5 | Eany | | | 3.00 | 24.80 | | 1.24 | | | | | | |
| 185 | 5 | Erriff | | | 8.60 | 32.00 | | 1.24 | | | | | | |
| 186 | 5 | Palmerstown | | | 3.70 | 18.00 | | 1.15 | | | | | | |
| 187 | 5 | Ray | | | 2.10 | 12.80 | | 0.99 | | | | | | |
| 188 | 5 | Glen | | | 2.70 | 15.00 | | 0.91 | | | | | | |
| 189 | 5 | Owenea | | | 4.30 | 20.80 | | 0.84 | | | | | | |
| 190 | 5 | Crana | | | 3.10 | 19.20 | | 0.84 | | | | | | |
| 191 | 5 | Owenduff | | | 6.30 | 21.10 | | 0.60 | | | | | | |
| 192 | 5 | Moy | | | 53.80 | 45.00 | | 0.32 | | | | | | |
| 193 | 5 | Burrishoole | 53 53.14 | 009 35.12 | | 20.00 | 2 | 2.00 | 2 | | Y | Steep Y, Long N. | N | |
| 194 | 6 | BUSH | 55.2 | -6.5 | 7.00 | 59.00 | Low | 0.10 | 0.001 | | N | long | Poor marine habitat | |
| 195 | 6 | SHIMNA | 54.2 | -5.9 | 2.50 | 14.00 | V High | 20.00 | 0.15 | | N | steep | Good | |
| 196 | 12 | Bresle | 50.062396 | 1.372051 | 7.30 | 72.00 | 4 | 11.00 | 6.1 | trap data 1982-2015 | N | N | N | |
| 197 | 12 | Rhin | | | | | | 1.83 | | video count 2001-08 | | | | |
| 198 | 12 | Touques | | | | | | 153.00 | | video count 2001-14 | | | | |
| 199 | 12 | Orne | | | | | | 3.40 | | video count 2011-14 | | | | |
| 200 | 12 | Vire | | | | | | 0.35 | | video count 2002-14 | | | | |
| 201 | 12 | Aulne | | | | | | 0.02 | | video count 2003-14 | | | | |
| 202 | 12 | Elorn | | | | | | 0.04 | | video count 2007-14 | | | | |
| 203 | 12 | Scorff | | | | | 1 | 0.03 | | trap data 2007-14 | | | | |
| 204 | 12 | Creuse | | | | | | 0.03 | | video count 2007-15 | | | | |
| 205 | 12 | Garonne | | | | | | 0.33 | | video count 1993-2012 | | | | |
| 206 | 12 | Dordogne | | | | | | 0.31 | | video count 1993-2012 | | | | |
| 207 | 12 | Gave d'Aspe | | | | | | 1.41 | | trap data 2000-2012 | | | | |
| 208 | 12 | Gave d'Oleron | | | | | | 1.99 | | trap data 1996-2012 | | | | |
| 209 | 12 | Gave de Pau | | | | | | 0.46 | | video count 2005-12 | | | | |
| 210 | 12 | Saison | | | | | | 0.15 | | trap data 1997-2012 | | | | |
| 211 | 12 | Nive | | | | | | 1.19 | | trap data 1998-2012 | | | | |
| 212 | 12 | Nivelle | | | | | | 0.23 | | trap data 1997-2012 | | | | |
| 213 | 12 | Oir | | | | | 1 | 0.10 | 0.16 | trap 2008-10 + EF 1998-00 | | | | |

# Annex 6: Sea trout index rivers

## 1. Location & organisation

| Ref | Organisation | Country | Contact | Region | River | Time series |
|---|---|---|---|---|---|---|
| 1 | Office National de l'Eau et des Milieux Aquatiques | France | Quentin Josset | Normandie | Bresle | 1982-2015 |
| 2 | INRA | France | Marie Nevoux (Didier Azam) | Normandie | Oir | 1984-2015 |
| 3 | Natural Resources Wales | Wales | Ian Davidson | North Wales | Dee | 1991-2015 |
| 4 | Environment Agency | England | Niall Cook | Northeast | Tyne | 2004-2015 |
| 5 | Environment Agency | England | Rob Hillman | Southwest | Tamar | 1994-2015 |
| 6 | Environment Agency | England | Rob Hurrell | Southwest | Fowey | 1995-2015 |
| 7 | Environment Agency | England | Andy Croft | Northwest | Lune | 1992-2015 |
| 8 | Environment Agency | England | Dave Spiby | Northwest | Kent | 1997-2010 |
| 9 | AFBI | N. Ireland | R. Kennedy | Antrim | Bush | 1974-2015 |
| 10 | AFBI | N. Ireland | R. Kennedy | Down | Shimna | 2003-2015 |
| 11 | Marine Institute | Ireland | Russell Poole | Mayo | Burrishoole | 1971-2015 |
| 12 | Inland Fisheries Ireland | Ireland | Paddy Gargan | Mayo | Erriff - Tawnyard | 1985-present |
| 13 | Inland Fisheries Ireland | Ireland | Paddy Gargan | Galway | Invermore | 1991-present |
| 14 | Inland Fisheries Ireland | Ireland | Paddy Gargan | Galway | Owengowla | 1991-present |
| 15 | Swedish University of agricultural Science | Sweden | Erik Degerman | Baltic | Åvaån | 1998-2015 |
| 16 | Swedish University of agricultural Science | Sweden | Erik Degerman | North Sea | Högvadsån | 1954-2015 |
| 17 | Swedish University of agricultural Science | Sweden | Stefan Palm | Baltic | Mörrumsån | 2002-2015 |
| 18 | Swedish University of agricultural Science | Sweden | Stefan Palm | Baltic | Vindelälven | 1998-2015 |
| 19 | Swedish University of agricultural Science | Sweden | Stefan Palm | Baltic | Rickleån | 2010-2015 |
| 20 | Sport fishing association | Sweden | Lars Vallin | Baltic | Själsöån | 1995-2015 |
| 21 | County of Skåne | Sweden | Anders Eklöv | North Sea | Kävlingeån | 1998-2015 |
| 22 | GEOMAR | Germany | Christoph Petereit | Schleswig-Holstein, Baltic Sea | Habernisser Au | 2013-2015 |
| 23 | GEOMAR | Germany | Christoph Petereit | Schleswig-Holstein, Baltic Sea | Lipping Au | 2013-2015 |
| 24 | GEOMAR | Germany | Christoph Petereit | Schleswig-Holstein, Baltic Sea | Koseler Au | 2013-2015 |
| 25 | GEOMAR | Germany | Christoph Petereit | Schleswig-Holstein, Baltic Sea | Aschau | 2013-2015 |
| 26 | GEOMAR | Germany | Christoph Petereit | Schleswig-Holstein, Baltic Sea | Hohenfelder Mühlenau | 2013-2015 |
| 27 | GEOMAR | Germany | Christoph Petereit | Schleswig-Holstein, Baltic Sea | Schmiedenau | 2013-2015 |
| 28 | GEOMAR | Germany | Christoph Petereit | Schleswig-Holstein, Baltic Sea | Nessendofer Mühlenau | 2013-2015 |
| 29 | GEOMAR | Germany | Christoph Petereit | Schleswig-Holstein, Baltic Sea | Farver Au | 2013-2015 |
| 30 | GEOMAR | Germany | Christoph Petereit | Schleswig-Holstein, Baltic Sea | Kremper Au | 2013-2015 |
| 31 | FuU | Germany | Harry Hantke | Mecklenburg Western Pommerania, Baltic Sea | Hellbach-System | 2011-2016 |
| 32 | FuU | Germany | Harry Hantke | Mecklenburg Western Pommerania, Baltic Sea | Peezer Bach | 2011-2016 |
| 33 | FuU | Germany | Harry Hantke | Mecklenburg Western Pommerania, Baltic Sea | Tarnewitzer Bach-System | 2011-2014 |
| 34 | FuU | Germany | Harry Hantke | Mecklenburg Western Pommerania, Baltic Sea | Zarnow | 2014-2016 |

## 2. Descriptors

| Ref | River | Wetted area | System length | Distance to sea | Latitude of tidal limit | Stream order | Lakes present | Habitat classification | Fishery present |
|---|---|---|---|---|---|---|---|---|---|
| | | (ha) | (km) | (km) | (Dec.deg.N) | | | | |
| 1 | Bresle | 101 | 70 | 3 | 50.03 | NA | No | Yes | Yes |
| 2 | Oir | ? | 21 | 12 | 48.6305 | 4 | No | Yes | Yes |
| 3 | Dee | 617 | 152 | 39 | 53.19 | 4 | Yes | Yes | Yes |
| 4 | Tyne | 542 | 94 | 44 | 54.98 | 4 | No | Yes | Yes |
| 5 | Tamar | 293 | 74 | 33 | 50.52 | 4 | No | Yes | Yes |
| 6 | Fowey | 42 | 38 | 13 | 50.41 | 3 | No | Yes | Yes |
| 7 | Lune | 423 | 75 | 22 | 54.06 | 4 | No | Yes | Yes |
| 8 | Kent | 68 | 34 | 25 | 54.25 | 4 | No | Yes | Yes |
| 9 | Bush | 74 | 67 | | 55.2 | 5 | No | Yes | Yes |
| 10 | Shimna | 10 | 12 | | 54.2 | 4 | No | Yes | Yes |
| 11 | Burrishoole | 475 | 12 | 5 | 53 55 21.85N | | Yes | Yes | Yes |
| 12 | Erriff - Tawnyard | 73.5506 | 33 | 0.05 | 55.617 | 255 | Yes | No | Yes |
| 13 | Invermore | 299 | c. 6 | 0.4 | 53.39 | 38 | Yes | No | Yes |
| 14 | Owengowla | 205 | c. 12 | 0.3 | 53.392 | 55 | Yes | No | Yes |
| 15 | Åvaån | 0.45 | 2.5 | 0 | N59.169262; E18.364992 | 2 | No | Yes | No |
| 16 | Högvadsån | 51 | 31 | 20 | N57.032636; E12.657157 | 3 | No | Yes | Yes |
| 17 | Mörrumsån | 75 | 20 | 0 | N56.154198; E14.749940 | 4 | No | Yes | Yes |
| 18 | Vindelälven | 2000 | 300 | 35 | N63.921422; E19.860244 | 5 | No | Yes | Yes |
| 19 | Rickleån | 80 | 25 | 0 | N64.085265, E20.944715 | 4 | No | No | Yes |
| 20 | Själsöån | 0.06 | 0.3 | 0 | N57.692938; E18.357151 | 1 | No | No | No |
| 21 | Kävlingeån | 33 | 48 | 0 | N55.729587; E12.999207 | 4 | No | Yes | Yes |
| 22 | Habernisser Au | 2 | 5.4 | . | 54.797025 | 2 | No | Yes | No |
| 23 | Lipping Au | 3 | 10.6 | 2.95 | 54.760135 | 1 | No | Yes | No |
| 24 | Koseler Au | 5 | 55.4 | | 54.523731 | 2 | No | Yes | No |
| 25 | Aschau | 2 | 8.6 | | 54.458384 | 1 | No | Yes | No |
| 26 | Hohenfelder Mühlenau | 2 | 10.3 | | 54.385333 | 1 | No | Yes | No |
| 27 | Schmiedenau | 1 | 30.6 | | 54.31039 | 1 | Yes | Yes | No |
| 28 | Nessendofer Mühlenau | 3 | 30.6 | | 54.31039 | 1 | Yes | Yes | No |
| 29 | Farver Au | 2 | 14.4 | | 54.310285 | 2 | No | Yes | No |
| 30 | Kremper Au | 2 | 21 | | 54.131007 | 1 | Yes | Yes | No |
| 31 | Hellbach-System | 30 | 89 | 0 | 54.07 | 1 | No | Yes | No |
| 32 | Peezer Bach | 1 | 18.1 | 4.8 | 54.16 | 2 | No | Yes | No |
| 33 | Tarnewitzer Bach-System | 1 | 41.6 | 0 | 53.97 | 1 | No | Yes | No |
| 34 | Zarnow | 0 | 15.7 | 26 | 54 | 2 | No | Yes | No |

### 3. Monitoring methods

| | | Trap or counter: | | | | | | Electrofishing | | | | Tagging | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ref | River | Type | | Juvenile (stage) | Adult | | | | | | | | | Time Series |
| | | Trap or counter: | Partial/Full | | | Time Series | Quality | Juv' | Adult | Time Series | Quality | Juv' | Adult | 1982-2015 |
| 1 | Bresle | Trap | Partial | Smolt | Yes | 1982-2015 | Good | Yes | Yes | 1983/1987/1989 | Variable | Yes | Yes | 1993-2015 |
| 2 | Oir | Trap | Partial | Smolt | Yes | 1985-2015 | good (but low upstream trap efficiency since 2008) | Yes | Yes | 2006-2015 | good | Yes | Yes | 1991-2015 |
| 3 | Dee | Trap/RST | Partial | Smolt (RST) | Yes | 1991-2015 | Good | Yes | No | 1980s onward | Variable | Yes | Yes | 2004-2015 |
| 4 | Tyne | Counter | Full | No | Yes | 2004-2015 | Good | Yes | Yes | 1980s onward | Variable | No | No | 1994-2015 |
| 5 | Tamar | Counter/Trap/RST | Full | Smolt (RST) | Yes | 1994-2015 | Good | Yes | No | 1980s onward | Variable | Yes | No | 1995-2015 |
| 6 | Fowey | Counter | Full | No | Yes | 1995-2015 | Good | Yes | No | 1980s onward | Variable | No | No | 1992-2015 |
| 7 | Lune | Counter/Trap | Full | No | Yes | 1992-2015 | Good | Yes | No | 1980s onward | Variable | No | No | 1997-2010 |
| 8 | Kent | Counter | Full | No | Yes | 1997-2010 | Good | Yes | No | 1980s onward | Variable | No | No | |
| 9 | Bush | Trap | Full | Smolt | Yes | 1974-2015 | Good (but Has a minor sea trout run in comparison to residents) | Yes | No | 1974-2015 | Good | No | N0 | |
| 10 | Shimna | Counter | Full | No | Yes | 2011-2015 | good | Yes | No | 2004- | Good | No | No | 1970-2000 |
| 11 | Burrishoole | Trap | Full | Parr & Smolt | Yes | 1971-2015 | Good | Yes | No | 1991-2015 | Good | Yes | Yes | 1986-2015 |
| 12 | Erriff - Tawnyard | Trap & Counter | Full | Smolt | Yes | 1985-2015 | Good | Yes | No | 1990-2015 | Good | Yes | Yes | 1995-2005 |
| 13 | Invermore | Trap & Counter | Full | Smolt | Yes | 1991-2015 | Good | Limited | No | 1983 & 1994 | | Yes | | 1995-2005 |
| 14 | Owengowla | Trap & Counter | Full | Smolt | Yes | 1991-2015 | Good | Limited | No | 1983& 1994 | | Yes | | |
| 15 | Åvaån | Trap | Full | Smolt | Yes | 1998-2015 | Moderate | Yes | No | 1998-20145 | Good | No | No | |
| 16 | Högvadsån | Trap | Full | Smolt | Yes | 1954-2015 | Good | Yes | No | 1978-2015 | Good | No | No | |
| 17 | Mörrumsån | Counter | Partil | Smolt | Yes | 2002-2015 | Moderate | Yes | No | 1988-2015 | Good | No | No | |
| 18 | Vindelälven | Trap | Partial | Smolt | Yes | 1998-2015 | Moderate | Yes | No | 1999-2015 | Good | No | No | |
| 19 | Rickleån | Counter | Partial | Smolt | Yes | 2010-2015 | Moderate | Yes | No | 1989-2015 | Good | No | No | |
| 20 | Själsöån | Trap | Full | No | Yes | 1995-2015 | Good | Yes | No | 1995-2015 | Good | No | No | |
| 21 | Kävlingeån | Trap | Full | Smolt | No | 1998-2015 | Moderate | Yes | No | 1998-2015 | Good | No | No | |
| 22 | Habernisser Au | No | | | | | | Yes | No | | | No | | 2016- |
| 23 | Lipping Au | Trap | Full | Smolt | No | 2016- | unknown | Yes | No | | | Yes | | |
| 24 | Koseler Au | No | | | | | | Yes | No | | | No | | |
| 25 | Aschau | No | | | | | | Yes | No | | | No | | |
| 26 | Hohenfelder Mühlenau | No | | | | | | Yes | No | | | No | | |
| 27 | Schmiedenau | No | | | | | | Yes | No | | | No | | |
| 28 | Nessendofer Mühlenau | No | | | | | | Yes | No | | | No | | 2016- |
| 29 | Farver Au | No | | | | | | Yes | Yes | 2015- | unknown | No | Yes | |
| 30 | Kremper Au | No | | | | | | Yes | No | | | No | | 2007-2015 |
| 31 | Hellbach-System | Video-Counter | Partial | No | Yes | 2009-2016 | Good | Yes | Yes | 2007-2015 | Good | No | Yes | |
| 32 | Peezer Bach | Video-Counter | Partial | No | Yes | 2011-2016 | Good | Yes | Yes | 2011-2015 | Good | No | No | |
| 33 | Tarnewitzer Bach-System | Video-Counter | Partial | No | Yes | 2011-2014 | Good | Yes | Yes | 2011-2014 | Good | No | No | |
| 34 | Zarnow | Video-Counter | Partial | No | Yes | 2014-2016 | Good | Yes | Yes | 2015 | Good | No | No | |

**4. Monitoring methods**

| | | In river catch | | | | | | | | | | | | | | | Sea catch | | | | | Sea catch | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Catch method: | | | | | | | | | | | | | | | Catch method: | | | | | Catch method: | | | | |
| Ref | River | Rod kill | | | | | Rod C&R | | | | | Net/other | | | | | Rod | | | | | Net/other | | | | |
| | | Catch | Effort | Time Series | Compulsory reporting | Quality | Catch | Effort | Time Series | Compulsory reporting | Quality | Catch | Effort | Time Series | Compulsory reporting | Quality | Catch | Effort | Time Series | Compulsory reporting | Quality | Catch | Effort | Time Series | Compulsory reporting | Quality |
| 1 | Bresle | Yes | No | 1987-2015 | No | Variable | Yes | No | 1987-2015 | No | Variable | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 2 | Oir | No | No | NA | No | NA | No | No | NA | No | NA | No | No | NA | No | NA | No | No | No | NA | NA | No | No | No | NA | NA |
| 3 | Dee | Yes | Yes | 1994-2015 | Yes | Good | Yes | Yes | 1992-2015 | Yes | Good | Yes | Yes | 1990-2015 | Yes | Good | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 4 | Tyne | Yes | Yes | 1994-2015 | Yes | Good | Yes | Yes | 1992-2015 | Yes | Good | Yes | Yes | 1990-2015 | Yes | Good | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 5 | Tamar | Yes | Yes | 1994-2015 | Yes | Good | Yes | Yes | 1992-2015 | Yes | Good | Yes | Yes | 1990-2015 | Yes | Good | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 6 | Fowey | Yes | Yes | 1994-2015 | Yes | Good | Yes | Yes | 1992-2015 | Yes | Good | Yes | Yes | 1990-2015 | Yes | Good | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 7 | Lune | Yes | Yes | 1994-2015 | Yes | Good | Yes | Yes | 1992-2015 | Yes | Good | Yes | Yes | 1990-2015 | Yes | Good | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 8 | Kent | Yes | Yes | 1994-2015 | Yes | Good | Yes | Yes | 1992-2015 | Yes | Good | Yes | Yes | 1990-2015 | Yes | Good | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 9 | Bush | No | No | NA | No | NA | No | No | NA | No | NA | No | No | NA | No | NA | No | No | No | NA | NA | No | No | No | NA | NA |
| 10 | Shimna | Yes | Yes | 2003-2015 | No | good | Yes | Yes | 2003-2015 | No | good | No | No | NA | No | NA | No | No | No | NA | NA | No | No | No | NA | NA |
| 11 | Burrishoole | Yes | Yes | 1971-1990 | Yes | Variable/gd | Yes | Yes | 1990-2015 | Yes | Variable, lake trout confuse the data | Yes | beach seine | 1990-2015 | survey data | variable | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 12 | Erriff - Tawnyard | Yes | Yes | 1985-2015 | Yes (≥40 cm) | Good | Yes | Yes | 1990-2015 | Yes (≥40 cm) | Good | NA | | | | | No | | | | | No | | | | |
| 13 | Invermore | Yes | Yes | 1975-1990 | Yes (≥40 cm) | Good | Yes | No | 1990-2015 | Yes (≥40 cm) | Variable | NA | | | | | No | | | | | No | | | | |
| 14 | Owengowla | Yes | Yes | 1975-1990 | Yes (≥40 cm) | Good | Yes | No | 1990-2015 | Yes (≥40 cm) | Variable | NA | | | | | No | | | | | No | | | | |
| 15 | Åvaån | NA | NA | NA | NA | NA | NA | NA | | NA | NA | No | NA | | | NA | No | No | No | No | NA | No | No | No | No | NA |
| 16 | Högvadsån | Yes | No | 1970-2015 | No | Good | NA | NA | | No | NA | No | NA | | | NA | No | No | No | No | NA | No | No | No | No | NA |
| 17 | Mörrumsån | Yes | Yes | 1984-2015 | Yes | Good | Yes | Yes | 2002-2015 | No | Moderate | No | NA | | | NA | No | No | No | No | NA | No | No | No | No | NA |
| 18 | Vindelälven | Yes | No | | Yes | Moderate | No | No | | No | NA | No | NA | | | NA | No | No | No | No | NA | No | No | No | No | NA |
| 19 | Rickleån | Yes | No | | Yes | Good | No | No | | No | NA | No | NA | | | NA | No | No | No | No | NA | No | No | No | No | NA |
| 20 | Själsöån | NA | NA | NA | NA | NA | NA | NA | | NA | NA | NA | NA | | | NA | No | No | No | No | NA | No | No | No | No | NA |
| 21 | Kävlingeån | NA | NA | NA | NA | NA | No | No | | NA | NA | NA | NA | | | NA | No | No | No | No | NA | No | No | No | No | NA |
| 22 | Habernisser Au | No | | | | | No | | | | | No | | | | | No | | | | | No | | | | |
| 23 | Lipping Au | No | | | | | No | | | | | No | | | | | No | | | | | No | | | | |
| 24 | Koseler Au | No | | | | | No | | | | | No | | | | | No | | | | | No | | | | |
| 25 | Aschau | No | | | | | No | | | | | No | | | | | No | | | | | No | | | | |
| 26 | Hohenfelder Mühlenau | No | | | | | No | | | | | No | | | | | No | | | | | No | | | | |
| 27 | Schmiedenau | No | | | | | No | | | | | No | | | | | No | | | | | No | | | | |
| 28 | Nessendofer Mühlenau | No | | | | | No | | | | | No | | | | | No | | | | | No | | | | |
| 29 | Farver Au | No | | | | | No | | | | | No | | | | | No | | | | | No | | | | |
| 30 | Kremper Au | No | | | | | No | | | | | No | | | | | No | | | | | No | | | | |
| 31 | Hellbach-System | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No |
| 32 | Peezer Bach | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No |
| 33 | Tarnewitzer Bach-System | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No |
| 34 | Zarnow | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No | No |

## 5. Estimates (i) biological

| Ref | River | Weights | | Lengths | | Fecundity | | Run Dates | | Smolt age composition | | Adult age composition | | Sex composition | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Population | by sea age | Population | by sea age | Population | by sea age | Spawning run | Smolt run | Population | by sea age | Population | by sea age | Population | by sea age |
| 1 | Bresle | Yes | No | Yes | No | Yes | No | Yes | Yes | Yes | No | Yes | No | Yes | No |
| 2 | Oir | Yes | Yes | Yes | Yes | No | No | partial | Yes | Yes | Yes | Yes | Yes | No | No |
| 3 | Dee | Yes | Yes | Yes | Yes | No | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 4 | Tyne | Yes | Yes | Yes | Yes | No | No | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes |
| 5 | Tamar | Yes | Yes | Yes | Yes | No | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 6 | Fowey | Yes | No | No | No | No | No | Yes | No | No | No | No | No | No | No |
| 7 | Lune | Yes | Yes | Yes | Yes | No | No | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes |
| 8 | Kent | Yes | No | No | No | No | No | Yes | No | No | No | No | No | No | No |
| 9 | Bush | No | No | No | No | No | No | partial | Yes | Yes | No | Yes | No | No | No |
| 10 | Shimna | Yes | Yes | Yes | Yes | No | No | Yes | No | Yes | No | Yes | No | Yes | No |
| 11 | Burrishoole | No | No | Yes | Yes | Estimates | Yes | Yes | Yes | Yes | Sporadic | Yes | Sporadic | No | No |
| 12 | Erriff - Tawnyard | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | |
| 13 | Invermore | NA | | Yes | Yes | No | No | Yes | Yes | Yes | Yes | Yes | Yes | NA | |
| 14 | Owengowla | NA | | Yes | Yes | No | No | Yes | Yes | Yes | Yes | Yes | Yes | NA | |
| 15 | Åvaån | Yes | No | Yes | No | Estimates | No | Yes | Yes | Yes | No | No | No | Estimate | No |
| 16 | Högvadsån | No | No | Yes | No | Estimates | No | Yes | Yes | No | No | No | No | No | No |
| 17 | Mörrumsån | Yes | No | Yes | No | Estimates | No | Yes | Yes | Yes | No | No | No | No | No |
| 18 | Vindelälven | Yes | No | Yes | No | No | No | Yes | Yes | No | No | No | No | Yes | No |
| 19 | Rickleån | No | No | Yes | No | No | No | Yes | Yes | No | No | No | No | Yes | No |
| 20 | Själsöån | Yes | No | Yes | No | No | No | Yes | No | No | No | Yes | No | Yes | No |
| 21 | Kävlingeån | Yes | No | Yes | No | No | No | No | Yes | Yes | No | No | No | No | No |
| 22 | Habernisser Au | No | No | No | No | No | No | No | No | No | | No | No | No | No |
| 23 | Lipping Au | No | No | No | No | No | No | No | Yes | Yes | | No | No | No | No |
| 24 | Koseler Au | No | No | No | No | No | No | No | No | No | | No | No | No | No |
| 25 | Aschau | No | No | No | No | No | No | No | No | No | | No | No | No | No |
| 26 | Hohenfelder Mühlenau | No | No | No | No | No | No | No | No | No | | No | No | No | No |
| 27 | Schmiedenau | No | No | No | No | No | No | No | No | No | | No | No | No | No |
| 28 | Nessendofer Mühlenau | No | No | No | No | No | No | No | No | No | | No | No | No | No |
| 29 | Farver Au | No | No | No | No | No | No | No | No | No | | No | No | Yes | No |
| 30 | Kremper Au | No | No | No | No | No | No | No | No | No | | No | No | No | No |
| 31 | Hellbach-System | Yes | Yes | Yes | Yes | No | No | Yes | No | No | | Yes | | Yes | |
| 32 | Peezer Bach | | | | | | | | | | | | | | |
| 33 | Tarnewitzer Bach-System | | | | | | | | | | | | | | |
| 34 | Zarnow | | | | | | | | | | | | | | |

## 6. Estimates (ii) Reference point

| Ref | River | Adult (Spawning stock) estimates | Smolt estimates | Parr estimates | Ova estimates |
|---|---|---|---|---|---|
| 1 | Bresle | Yes | Yes | No | Yes |
| 2 | Oir | Partial | Yes | Yes | No |
| 3 | Dee | Yes | Yes | Yes | Yes |
| 4 | Tyne | Yes | No | No | Yes |
| 5 | Tamar | Yes | Yes | No | Yes |
| 6 | Fowey | No | No | No | No |
| 7 | Lune | Yes | No | No | Yes |
| 8 | Kent | Yes | No | No | Yes |
| 9 | Bush | No | No | No | No |
| 10 | Shimna | Yes | No | Yes | No |
| 11 | Burrishoole | Yes | Yes | Yes | Yes |
| 12 | Erriff - Tawnyard | Yes | Yes | Yes | Yes |
| 13 | Invermore | Yes | Yes | NA | NA |
| 14 | Owengowla | Yes | Yes | NA | NA |
| 15 | Åvaån | Yes | Yes | Yes | Yes |
| 16 | Högvadsån | No | No | Yes | Yes |
| 17 | Mörrumsån | No | No | Yes | No |
| 18 | Vindelälven | No | No | No | No |
| 19 | Rickleån | No | No | No | No |
| 20 | Själsöån | No | No | Yes | No |
| 21 | Kävlingeån | No | No | Yes | No |
| 22 | Habernisser Au | No | No | Yes | No |
| 23 | Lipping Au | No | Yes | Yes | No |
| 24 | Koseler Au | No | No | Yes | No |
| 25 | Aschau | No | No | Yes | No |
| 26 | Hohenfelder Mühlenau | No | No | Yes | No |
| 27 | Schmiedenau | No | No | Yes | No |
| 28 | Nessendofer Mühlenau | No | No | Yes | No |
| 29 | Farver Au | Yes | No | Yes | No |
| 30 | Kremper Au | No | No | Yes | No |
| 31 | Hellbach-System | Yes | No | No | No |
| 32 | Peezer Bach | | | | |
| 33 | Tarnewitzer Bach-System | | | | |
| 34 | Zarnow | | | | |

## Annex 7: Terms of Reference for a new Working Group (WGTRUTTA)

The **Working Group with the Aim to Develop Assessment Models and Establish Biological Reference Points for Sea Trout (Anadromous *Salmo trutta*) Populations (WGTRUTTA)**, chaired by Johan Höjesjö*, Sweden, and Alan Walker*, UK, will work on ToRs and generate deliverables as listed in the Table below.

| | Meeting dates | Venue | Reporting details | Comments (change in Chair, etc.) |
|---|---|---|---|---|
| Year 2017 | 24–26 April | Gothenburg, Sweden | Interim report by 1 November to SSGEPD | The interim reports in 2017 and 2018 will be delivered late in the year in relation to the meeting dates since they will also report on intersessional work by several sub-groups, compiling databases and developing and fine-tuning population models. |
| Year 2018 | DATE February<br>DATE September | Copenhagen, Denmark<br>Lisbon, Portugal | Interim report by1 November to SSGEPD | |
| Year 2019 | DATE April | UK | Final report by 1 December to SCICOM | |

### ToR descriptors

| ToR | Description | Background | Science Plan topics addressed | Duration | Expected Deliverables |
|---|---|---|---|---|---|
| a | Compile information from a selection of suitable rivers across Europe with long-term data on parameters such as juvenile densities, habitat characteristics and, if available, abundances of ascending spawners and out-migrating smolts. | To facilitate the development of population dynamic models, an important first step is to compile available information/data. The outcomes from WKTRUTTA2 in combination with data from research collaborations on sea trout will be an important starting point for this work. The compiled data will provide basic information on population dynamics and life history variation of sea trout in different areas and stream types and will be used as a basis for the development of population models under ToR b. This exercise will also facilitate identification of geographical areas with data deficiencies (e.g. absence of stock-recruitment data) that hampers the development of assessment methods and which should therefore be prioritized in future monitoring and research programmes. | 4, 25, 31 | Year 1 | A database on juvenile densities, habitat characteristics and other important information along a south/north and coastal/inland gradient across Europe. |
| b | Develop new, and validate and fine tune existing population models for sea trout. | There are different approaches available for modelling fish populations. By using abundance data from different life stages, information on habitat quality and fisheries data etc, the group will develop and evaluate different ways to | 4, 9, 15, 25, 27, 31 | Year 1-3 | Evaluation of approaches / methods for modelling sea trout populations, with respect to assessment needs, availability of data, geo- |

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| | | model sea trout populations. This work will, to a large extent, be based on already existing data, such as stock-recruitment relationships derived from monitoring data on abundance and/or fisheries data (catch and CPUE-data) from a number of rivers across Europe. Models with different levels of complexity (taking into account e.g. habitat variation within rivers and between catchments, occurrence of lakes, migration obstacles and resident trout etc), as well as the representativeness of index rivers for larger areas with sparse information will be evaluated. | | | graphical coverage, complexity etc. Presentation of new models and a summary at the ASC meeting in 2019. In addition a peer-reviewed article on population modelling in Sea Trout will be produced. |
| c | Establish and evaluate different approaches for estimating Biological Reference Points (BRPs) across regions with different characteristics and conditions for sea trout. | There is a growing need to develop assessment methods for sea trout populations. Establishment of BRPs is a prerequisite to be able to assess status of populations. Different ways of estimating BRPs from population models developed under ToR b, based on e.g. stock-recruitment relationships or estimated pristine abundance levels, will be evaluated. This in turn enables assessment of status in relation to BRPs across Europe (on area or individual stock level). | 4, 9, 10, 15, 25, 27, 31 | Year 2-3 | Establishment of Biological Reference Points by using different approaches depending on e.g. data availability and type of population model used. |

## Summary of the Work Plan

The working group will address key questions relating to the assessment of sea trout stocks in the North Atlantic and Baltic. The overall plan is to establish the working group in 2017 with subgroups across Europe. Over the 3-year period, there will be 4 meetings in total; Sweden (Gothenburg), Denmark (Copenhagen), Portugal (Lisbon) and UK (place to be decided). Subgroups will work on the ToRs between these meetings with regular contact through email and/or webinars. Most of the work regarding deliverables for the different ToRs will be planned and performed in parallel. The main goal of WGTRUTTA is to take on the work initiated during WKTRUTTA2, i.e. develop and evaluate different methods for modelling sea trout populations, and define BRPs and a protocol that can be used to assess status of sea trout populations in different regions.

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| Year 1 | In year 1, the working group will be established and divide tasks among group members and prioritize among available data sources. The group will start to create a database in a gradient across European rivers to be able to develop new and existing population models. The database will be finalized in November 2017 and one of the outcomes of this work will be a recommendation on suitable index rivers in different areas, and identification of gaps and weaknesses in current monitoring programs. In parallel, the group will start to develop population models based on the available data. The starting point for the work during year 1 will be the output from WKTRUTTA2. |
| Year 2 | In year 2, the group will continue to work on the database and potentially add new data and stream systems. Development of population models will continue. The group will also start to evaluate different approaches for estimating Biological Reference Points (BRPs), based on the population modelling work. |

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| Year 3 | During year 3, the focus will be to continue the development and validation of different population models, and the work to establish BRPs in different regions across Europe. At the completion of the year, WGTRUTTA should be able to recommend suitable population models and approaches to estimate BRPs, which could be used to assess status of sea trout populations across Europe. |

## Supporting information

| | |
|---|---|
| Priority | The inclusion of sea trout and other diadromous fish in EU policy areas including the CFP and Marine Strategy Framework Directive means that it is important to improve the methods currently available to managers to assess the status of stocks and investigate the effects of management actions.<br>The final report and recommendations will guide both individual countries in making progress on sea trout assessment and management and will steer ICES on the best next steps for sea trout science, assessment and advice. |
| Resource requirements | The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resources required to undertake additional activities in the framework of this group are negligible. |
| Participants | The Group will be attended by some 15-20 members and invited guests. |
| Secretariat facilities | Requires coordinating activities from ICES secretariat for the 4 meetings. |
| Financial | No financial implications. |
| Linkages to ACOM and groups under ACOM | Links to ACOM and WGBAST who provide advice on Baltic sea trout and SSGEPD and WGRECORDS regarding diadromous fish stocks, life histories, threats and sustainable use of the resource. |
| Linkages to other committees or groups | Relevant to SSGEPI and SSGIEOM. The activities of this group will take forward the scene-setting work of WKTRUTTA which met in 2012 and WKTRUTTA2 that met in 2016. |
| Linkages to other organizations | FAO |