WORKING GROUP WITH THE AIM TO DEVELOP ASSESSMENT MODELS AND ESTABLISH BIOLOGICAL REFERENCE POINTS FOR SEA TROUT (ANADROMOUS *SALMO TRUTTA*) POPULATIONS (WGTRUTTA; outputs from 2019 meeting)

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i Executive summary

The Working Group WGTRUTTA was established in 2017 with the Aim to Develop Assessment Models and Establish Biological Reference Points for Sea Trout (Anadromous *Salmo trutta*) Populations. The WG has representatives from every country containing a self-reproducing population of sea trout throughout Europe, in total 19 countries.

Four subgroups worked to deliver the three ToR: 1) 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; 2) develop new, validate and fine tune existing population models for sea trout; 3) establish and evaluate different approaches for estimating Biological Reference Points (BRPs) across regions with different characteristics and conditions for sea trout.

The sea trout database structure was completed and populating it with data is well underway. This database is designed to provide a central depository for data used by the WG, and consists of two components: for environmental and bio-ecological data. The WG has created an inventory of data collection methods across the 19 countries of the natural range. There are common methodological approaches but few, if any, that are uniform across all countries. An inventory of Passive Integrated Transponder (PIT) tagging infrastructure has also been created and will be made available via a mapping tool. The WG are liaising with ICES and their Regional Database and Estimation System (RDBES), working towards a time when ICES will host the WGTRUTTA database.

The WG undertook a comprehensive review of the scientific literature on ecological factors affecting the abundance and life history of anadromous fish, which has been published in Fish and Fisheries (Nevoux *et al.* 2019). This provides the knowledge base to support development of population models, taking into account these complexities in the life history of the resident and anadromous components of stocks.

The WG has developed a set of length-based indicators to assess the status of a stock (after the Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (WKLIFE)), using index catchments to demonstrate these indicators and to identify where pressures may have had an impact. Two papers, both published, have been developed describing the development and application of these length-based indicators of sea trout stock status (Shephard 2018a, Shephard, 2019).

The WG has extended the development and application of the Trout Habitat Scores (THS) model using Baltic data from Sweden, and commenced testing this with data from Northern Ireland. A theoretical Bayesian Population Dynamics Model for Baltic Sea trout is also being developed.

The challenges of developing and applying a BRP approach to sea trout were further explored by applying several curve fitting approaches (including Beverton-Holt, Ricker, Hockey Stick) to 'data rich' stocks with data from counts, returning stock estimates, catches, and juvenile abundance surveys. A 'one-size-fits-all' option is highly unlikely, but a suite of tools is more promising, especially if they can be targeted towards a relatively small number of sea trout stock groupings. A grouping proposed for 16 sea trout stocks in England and Wales, based on growth rates and longevity, has been identified as a potential stock grouping tool and it is proposed to test and develop this across the natural range of the species in future research. Such groupings might be used as the basis for focussing stock-recruitment or other model approaches, and/or to make recommendations on selecting index rivers and data collection programs.

ii Expert group information

Expert group name	Working Group with the Aim to Develop Assessment Models and Establish Biological Reference Points for Sea Trout (Anadromous *Salmo trutta*) Populations (WGTRUTTA)
Expert group cycle	multiannual
Year cycle started	2017
Reporting year in cycle	3/3
Chair(s)	Johan Höjesjö, Sweden
	Alan Walker, United Kingdom
Meeting venue(s) and dates	24–26 April 2017, Gothenburg, Sweden, 33 participants
	6–8 February 2018, Copenhagen, Denmark, 22 participants
	15–19 October 2018, Lisbon, Portugal, 16 participants
	25 February–1 March 2019, Dorchester, United Kingdom, 15 participants

1 Introduction

Sea trout are the anadromous migratory form of the brown trout (*Salmo trutta*) which go to sea to feed and mature 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, WKTRUTTA2); (ICES, 2013, 2016). In addition, two international symposia on sea trout, held in Cardiff, UK in 2004 (Harris, 2006) and in Dundalk, Ireland in 2015 (Harris, 2017) have made proposals for future management and research priorities. This Working Group (WG) builds on the scene-setting work of WKTRUTTA 1 and 2.

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 limited knowledge of the complex and variable life cycle of this species and of the manner in which man-made pressures affect stocks. 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 in sufficient detail and for sufficient time to permit the development of population models that would allow us to make and test predictions about the effects of past, present and future pressures.

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 WG has developed and evaluated several ways to model sea trout populations. This work has been, to a large extent, based on 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 were evaluated.

Sea trout play an important ecological and socio-economic role in the majority of freshwaters of many countries in northern Europe (Walker, Pawson and Potter 2006). Despite this, efforts to manage sea trout have been largely reactionary rather than proactive or precautionary, with the exception of the sea trout in the Baltic Sea region where a formal assessment of the exploitation of sea trout and the status of the stocks is required by the annual agreement between ICES and the European Commission (need MoU reference; ICES 2019). Many sea trout stocks have undergone radical changes over the past 30 years (Poole *et al.* 2006; Gargan, Poole & Forde, 2006a; Gargan *et al.* 2006b, Thorstad *et al.* 2015), often due to anthropogenic pressures (Thorstad *et al.* 2015, Nevoux *et al.* 2019; Hesthagen *et al.* 2017, Birnie-Gauvin *et al.*, 2017), but no concerted efforts have been made to introduce a common or even regional scientifically-based management system. In England and Wales, a similar process to salmon is being developed for sea trout (Thornton, 2008), based on angling catch and CPUE and the development of pseudo-stock recruitment relationships and associated Biological Reference Points (BRPs) (Davidson *et al.* 2017a). However, out of the 80 principal sea trout rivers in England and Wales, only four can be considered as data rich index rivers against which these pseudo-S/R models can be tested (Davidson *et al.* 2017a,b). The inclusion of sea trout and other diadromous fish in EU policy areas including the Common Fisheries Policy (CFP) and Marine Strategy Framework Directive (MSFD) means that it is important to improve the methods available to managers to assess the status of stocks and investigate the effects of management actions.

Thus, there is a growing need to develop assessment methods for sea trout populations. The establishment of BRPs is a prerequisite to being able to assess status of populations. Different ways of estimating BRPs from population models that have been developed from e.g. stock-recruitment relationships or estimated pristine abundance levels, have been evaluated.

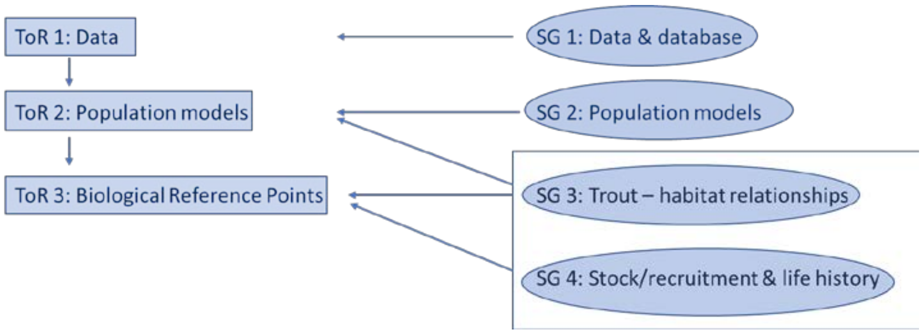
The main goal of WGTRUTTA has been to build on the work initiated during WKTRUTTA2, i.e. develop and evaluate different methods for modelling sea trout populations, examine options for, and define, appropriate BRPs and a protocol that can be used to assess status of sea trout populations in different regions. The WG Terms of Reference (ToR) were set with this goal in mind.

2 Terms of Reference

The WG has delivered and addressed the ToR through 4 sub-groups (SG):

- SG1: Database group
- SG2: Population models, examining the effects of salmon, and resident trout
- SG3: Trout recruitment versus habitat score systems
- SG4: Stock recruitment relationships based on sea trout life history

These SG map to the three ToR as shown in this schematic below:



The WG delivered the ToR though a combination of meetings (workshops) and intersessional work.

3 Delivery of ToR a)

ToR a) to **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**

This was achieved by developing and populating a **database** (DB) with the purpose to inform the WG of available data and to compile information from a selection of rivers across Europe with long-term data on parameters such as juvenile densities, habitat characteristics and, where available, the abundances of ascending spawners and emigrating smolts. This database was designed to:

- facilitate the development of population dynamic models for sea trout;
- provide basic information on population dynamics and life history variation of sea trout in different areas and stream types;
- facilitate identification of geographical areas with data deficiencies (e.g. absence of stock-recruitment data) that hampers the development of assessment methods;
- prioritize regions or specific areas for future monitoring and research programs.

3.1 Database development

During the first WG meeting, in April 2017 (Gothenburg, Sweden), the DB SG1 worked on the development of the fundamentals for the DB creation, discussed the data that should be included in this data source and organized a guiding schedule for the development and creation of this resource. Moreover, during this first meeting, the DB group conducted the first set of meetings with other WGTRUTTA sub-groups to prepare a first input of what types of sea trout population and habitat data would be required for specific SG objectives.

After the first meeting, and before the second one (Copenhagen, February 2018), SG1 developed the following tasks:

- E-mail Sent to other SG Leaders in October 2017 to assess and confirm data needs and availabilities;
- E-mail Sent in October 2017, separately, for all members in each SG;
- Most WG members assumed to be both data users and providers.

Based on the information collected during the first WG meeting, and on the inputs received in the following months, the first draft of the DB template was created. This template was elaborated according to the types of data that were described by other SGs as being available and/or needed. The DB template also received input from tables created in WKTRUTTA 2, the HELCOM SALAR DATABANK (Salmon and Sea trout data), and SGBALANST (Baltic Sea trout data). Finally, the DB SG decided to develop on two separate DB templates: i) Environmental Data for the characterization of sea trout sites; and, ii) Bio-ecological Data for the characterization and data gathering on sea trout populations.

During the second WG meeting (Copenhagen, February 2018), the SG1 extended the work to define and optimize the DB templates. The included: i) Meeting with all other SG 2 – 4 to evaluate the proposed drafts of the environmental and bioecological database templates; ii) SGs 2-4 suggested changes to the current template drafts and informed SG1 members on their required data-types; iii) SG1 members had a meeting with the person in charge of the ICES databases to evaluate the possibility to host the WGTRUTTA database. During the second WG meeting, the SG1 also worked on defining the rules for data sharing and acknowledgments of sources. It was defined that: i) Data providers will explain any conditions when they submit to the Database; ii) Significant contribution warrants co-authorship in resultant manuscripts, minor editing warrants acknowledgment; and, at the end, iii) Each case needs discussion.

After the conclusion of the second WG meeting, and before the third one, SG1 worked on the revision and preparation of the final DB environmental and bioecological templates. SG1 considered the suggestions and inputs made by all the SGs, prepared the two database templates and send them for revision until September 2018.

During the third meeting (Lisbon, October 2018), SG1 continued previous work and several meetings were conducted with all the remaining SGs to evaluate the DB templates, in which minor changes were suggested. However, the two complete templates were considered too complex to be suitably filled in a reasonable amount of time, especially considering the different ways that data are organized for different providers/sea trout rivers. Therefore, SG1 decided to maintain the complex templates for future reference and completion but first to provide simpler templates with only the information that was prioritized by the other SGs. Also, during this third meeting, while reviewing sea trout data from different countries, some questions were raised regarding the amount and high variability of methods and techniques used for sea trout juvenile monitoring. To clarify this issue and evaluate at which stage the SGs would be able to merge and analyse all the data together, SG1 developed a questionnaire, for each participating country, regarding local sampling methods and techniques (Annex 4). More detail about this questionnaire and obtained results will be presented in section 3.2 below.

Reduced and revised database templates were sent to SG leaders in January for confirmation and validation. During the fourth WG meeting (Dorchester, February 2019), all the templates were reviewed to agree a final version of the templates ready to be populated by data from different country members. The DB templates (Environmental and Reduced Bioecological) were uploaded to the WG SharePoint and a specific data call was made to all WG members. The population of the DB with data is well underway and the analysis, validation and future use of uploaded data is one of the tasks planned for the next phase of the WG.

The WG liaised with ICES and their Regional Database and Estimation System (RDBES) during the development of the sea trout database so that it is future-proofed for a time when ICES will host the WGTRUTTA DB within the wider fisheries and environment data framework.

3.2 Exploration of juvenile trout sampling methods

The questionnaire (Annex 4) provided information by experts from all 19 countries with native sea trout populations. There are common methodological approaches but few, if any, that are uniform across all countries. A complication is that in at least some countries, different approaches exist for between providers/sea trout rivers depending on circumstances and therefore, these were nationally recorded as separate categories whereas they might be combined in an international-scale analysis. A summary discussion of the commonalities and differences in data collection is presented below.

The majority of fish sampling is done at 'whole site' scale (i.e. fishing throughout the wetted area of the site) although some is targeted at selected habitat types within the site. The quantity of fish sampling is most often based on a specified wetted area (e.g. 100 m bank length) rather than for a unit of time (e.g. timed 5 min surveys). The number of electrofishing passes varies from 1 to 3, so affecting the fishing efficiency. Stop nets are sometimes used, so there might be more or less risk of fish leaving the site before they can be sampled. Most surveys target both trout and salmon, and in fact may target all fish species present. Surveys are conducted mostly in spring and autumn, but some in the summer, so affecting the size and age structures of the sampled fish (Figure 1).

Habitat characterization (Figure 2) has been described by water velocity, depth, substrates (e.g. particle size classes), aquatic vegetation, the proportion of shade/cover and slope. Velocity is most often measured only through observation with fewer direct measures using a flow meter. The same applies to substrate, aquatic vegetation and shade. In a further complication, there seems to be substantial variation in the substrate classification and categorization, for example in the size classes used for granulometric characterization and shade evaluation. In contrast, depth is typically directly measured, using calibrated poles. Slope is most often measured from maps or a geographic information system (GIS). The information collected with these questionnaires is being further examined and will be included in a manuscript that is *in prep*.

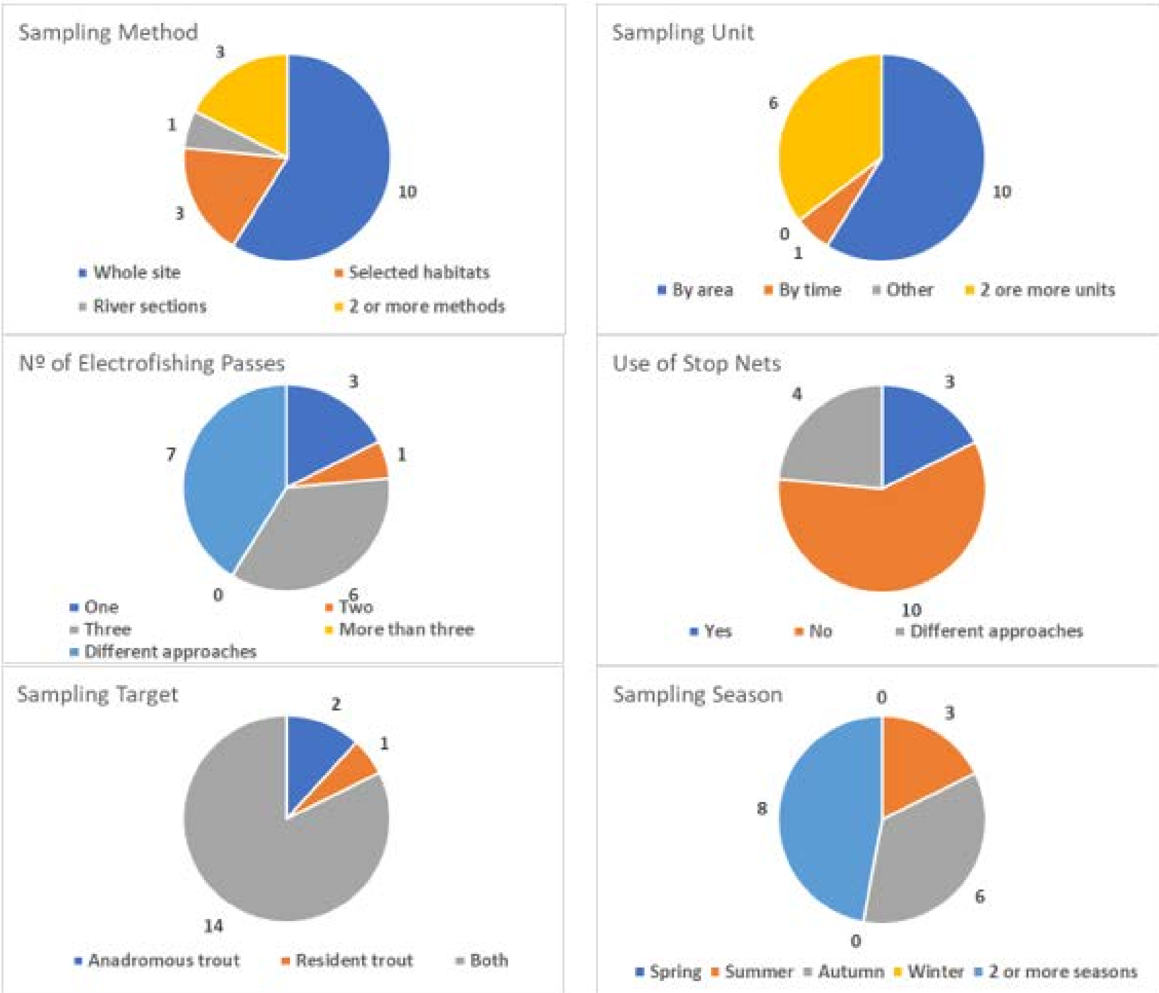


Figure 1. Results of the comparative analysis on sampling methods directed to juvenile trout, based on the questionnaire filled by the representatives of countries participating in WGTRUTTA.

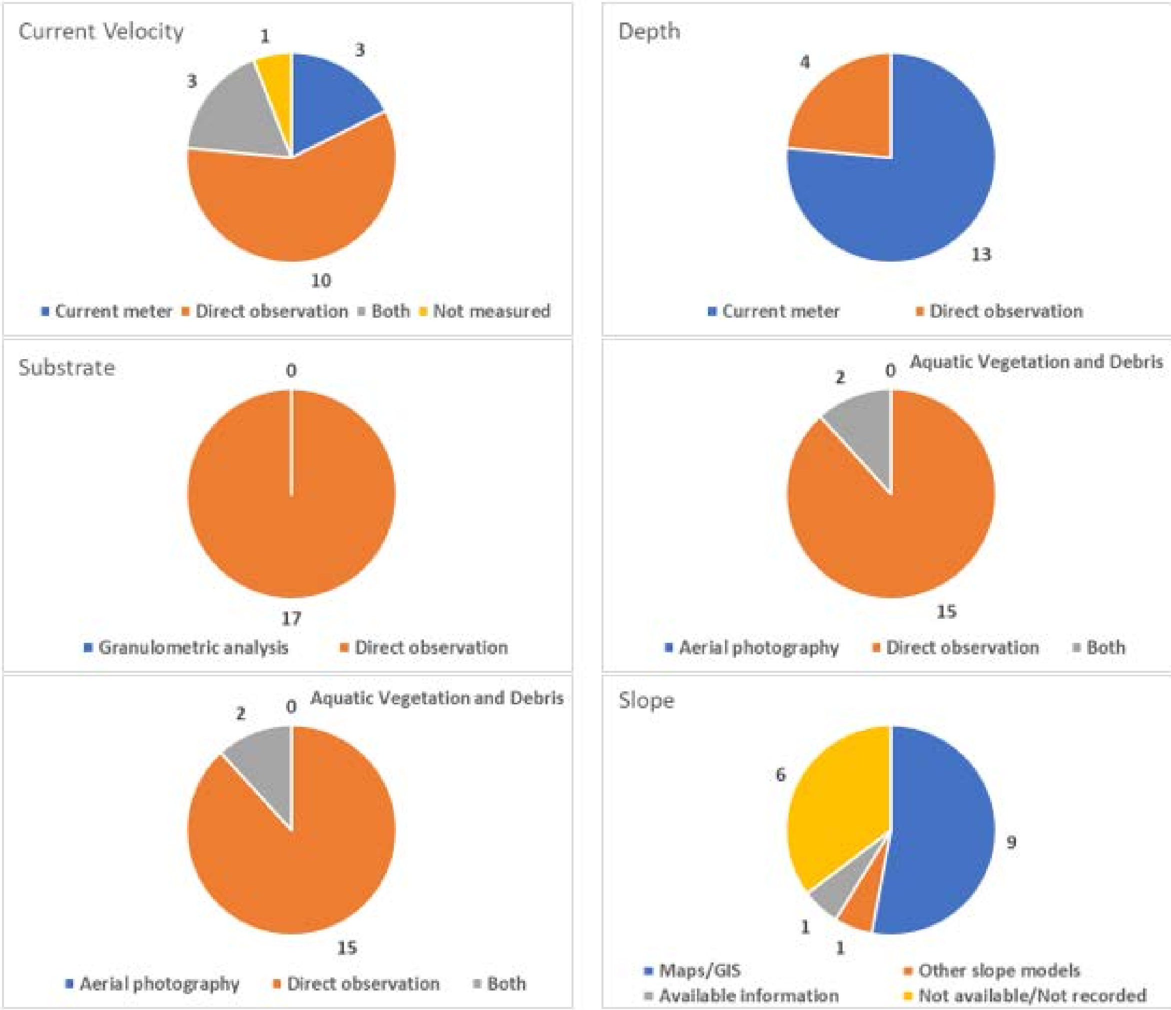


Figure 2. Results of the comparative analysis on the methods for characterization of trout habitat, based on the questionnaire filled by the representatives of countries participating in WGTRUTTA.

3.3 Index river inventory

Between the second and fourth WG meetings, another major focus of the SG1 was to collect all the available information from WG members and produce an inventory of PIT tagging infrastructure throughout all the participating countries, that could provide previously collected data and also be used in future studies about the target species. This inventory was created and added to the developed DB and will also be made available through a mapping tool (Google Earth kmz file). An example of the map created based on this data collection is presented in Figure 3.

Overall, a total of 27 PIT tag systems, from eight participating countries (i.e., Portugal, France, Belgium, England, Ireland, Northern Ireland, Denmark and Norway) were presented as being available for data collection. Sea trout data from these PIT tags systems will be periodically provided to the DB, and new PIT tag systems will be added to this DB as they become available.

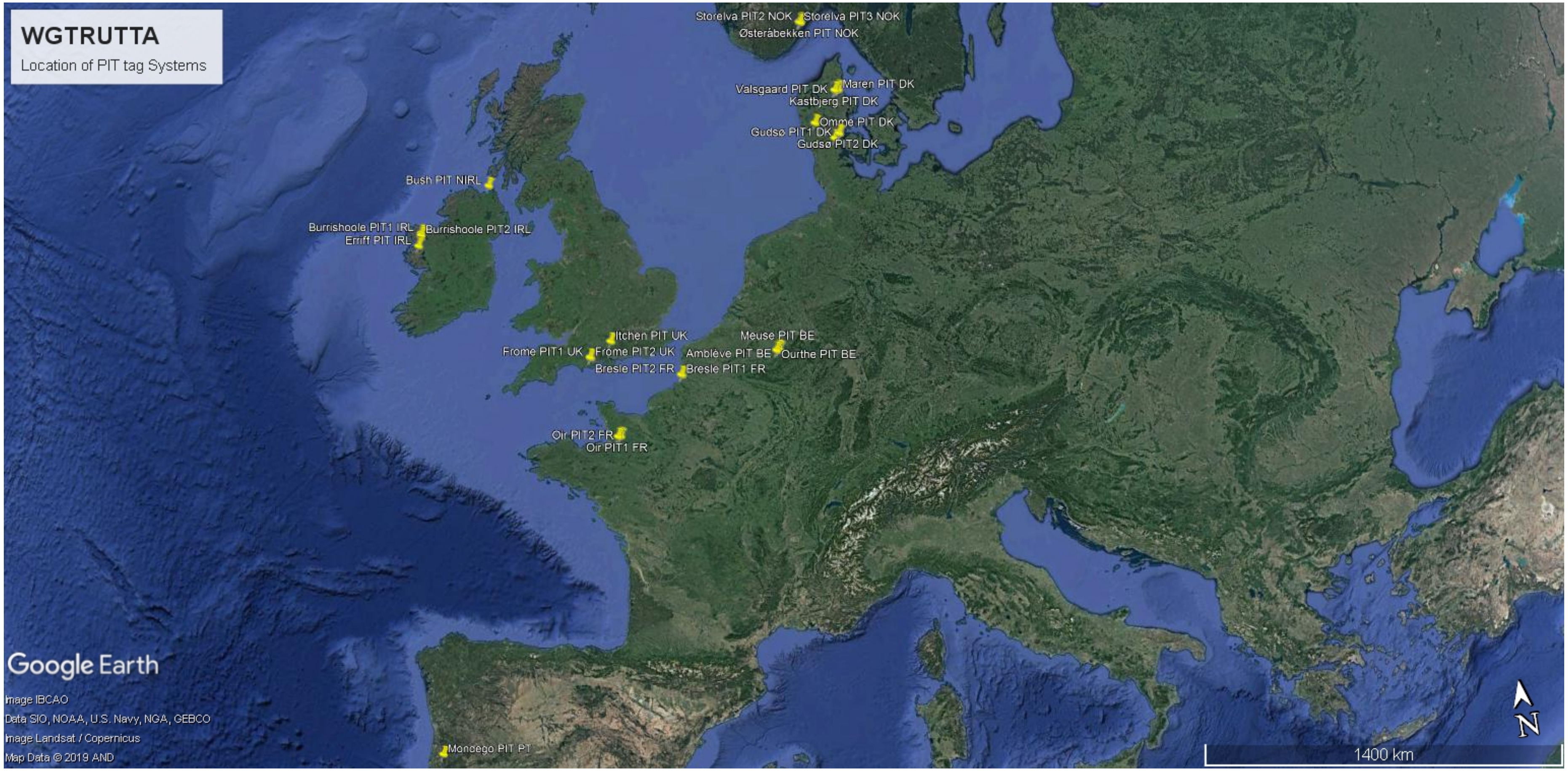


Figure 3. Location of the available PIT tag systems across WGTRUTTA member countries.

3.4 ToR summary

Overall, the sea trout database, consisting of both environmental and bio-ecological components, was completed and populating it with data is well underway. The WG has further created an inventory of data collection methods across the distribution area highlighting the fact that there are few common and uniform methodological approaches across all countries. An inventory of PIT tagging infrastructure has also been created and will be made available via a mapping tool.

4 Delivery of ToR b)

ToR b) **to develop new, validate and fine tune existing population models for sea trout**

This ToR was achieved by a comprehensive review of the scientific literature on ecological factors affecting the abundance and life history of anadromous fish, the development of Length-Based Indicators (LBI) and advancement of the Trout Habitat Scores (THS) scheme to assess state of sea trout stocks.

4.1 Ecological factors affecting abundance and life history of sea trout

Links between anadromous and freshwater resident brown trout were examined and large-scale patterns in ratios of anadromy:residence described. A comprehensive review of the scientific literature entitled "Brown trout *Salmo trutta*: a review of ecological factors affecting the abundance and life history of anadromous fish" was published in the journal "Fish and Fisheries" (Nevoux *et al.* 2019).

The review compares growth rates between resident and migratory trout, and sex ratio, with empirical data across Europe. Typically, there is an excess of males in resident vs females in sympatric anadromous trout, underlining the fact that the population splitting is associated with the reproductive biology of the species with alternative male, but not female, reproductive spawning behaviours. Females of anadromous trout are generally larger than males in small but not large rivers, pinpointing the close association between spawning habitat and phenotypic variation of trout. Unfortunately, there are few data on freshwater resident trout from the trout rivers limiting our possibility to compare the two trout forms from the same rivers. It remains challenging to identify resident vs anadromous origin, and to predict future life history - while growth rate is implicated it is not a simple predictor.

Nevoux M, Finstad B, Davidsen JG, *et al.* 2019. Environmental influences of life history strategies in partial anadromous brown trout (*Salmo trutta*, Salmonidae). *Fish Fish*. 2019; 00:1–32. https://doi.org/10.1111/faf.12396

Abstract

This paper reviews the life history of brown trout and factors influencing decisions to migrate. Decisions that maximize fitness appear dependent on size at age. In partly anadromous populations, individuals that attain maturity at the parr stage typically become freshwater resident. For individual fish, the life history is not genetically fixed and can be modified by the previous growth history and energetic state in early life. This phenotypic plasticity may be influenced by epigenetic modifications of the genome. Thus, factors influencing survival and growth determine life-history decisions. These are intra- and interspecific competition, feeding and shelter opportunities in freshwater and salt water, temperature in alternative habitats and flow conditions in running water. Male trout exhibit alternative mating strategies and can spawn as a subordinate sneaker or a dominant competitor. Females do not exhibit alternative mating behaviour. The relationship between growth, size and reproductive success differs between sexes in that females exhibit a higher tendency to migrate than males. Southern populations are sensitive to global warming. In addition, fisheries, aquaculture with increased spreading of salmon lice, introduction of new species, weirs and river regulation, poor water quality and coastal developments all threaten trout populations. The paper summarizes life-history data from six populations across Europe and ends by presenting new research questions and directions for future research.

The original plan to review or develop population models that would explicitly account for the interaction between freshwater resident and anadromous trout was not pursued because it was found that several sea trout models are available or are being developed elsewhere. Thus, efforts focussed on the review, advocating the inclusion of the resident trout in models describing life histories and dynamics of sea trout populations, as coastal populations of this species are partly anadromous.

A new model on climate change effects would be useful, but not pursued within this WG term because not enough is known about the explanatory relationships.

4.2 Length-based Indicators (LBI)

The approach of using length-based indicators (LBIs) utilises data relatively easy to collect from rod fisheries including length data and some form of relative abundance such as catch, CPUE, or a measure of recruitment (smolt index or fry density). During this WG, a system utilising the framework from the series of ICES WKLIFE workshops, was examined, initially for the data rich Dee system (Shephard *et al.* 2018a) and then for six data rich rivers throughout Europe, in France, Ireland, Wales, Northern Ireland and Sweden (Shephard *et al.* 2019).

LBIs are useful to give an overview of changes in stock structure. However, it would be useful for managers to understand the consequences of any changes observed, such as changes in spawning escapement or levels of recruitment. Ultimately, changes in the size of fish will have an impact on the fecundity of the stock and the quantities of eggs laid in any one season. For example, a switch from an abundance of largely female big fish to one of immature finnock/whitling, will be apparent in the LBI, may not be apparent in the Stock Abundance but should be reflected in the ova deposited. Empirical surveillance indicators of relative abundance and population size-structure may provide an accessible first-step for monitoring such stocks. These indicators could be informed and interpreted via expert knowledge of specific systems and stock histories. Here, indicators were selected, and time series of abundance- and length-based metrics for each river were presented on a new visual indicator plot. Expert knowledge from each system was elicited through one-to-one interviews to provide a corresponding stock narrative, in which indicator trends reflected known historical pressure-state events. The accessible presentation of simple empirical indicators supports elicitation of local expert knowledge and provides a user-friendly framework for surveillance and reference-direction assessment of data-limited sea trout stocks. This approach could be applied to inland or diadromous stocks where available data are restricted to estimates of relative abundance and size-structure. A similar system has also been proposed for lamprey in Ireland (Shephard *et al.* 2018b).

This approach will be further developed by applying data from a larger series of rivers across more countries within the framework of the next WG term.

Shephard, S., Davidson, I. C., Walker, A. M., & Gargan, P. G. 2018a. Length based indicators and reference points for assessing data-poor stocks of diadromous trout *Salmo trutta*. *Fisheries Research*, *199*, 36–43. https://doi.org/10.1016/j.fishres.2017.11.024.

Abstract: Many populations of diadromous fish have declined, but data are limited and there are very few quantitative stock assessments. Length-based indicators (LBIs) and reference points (RPs) have been proposed for assessment of data-poor fish stocks. It is likely that RPs will need to be tuned for fish with 'unusual' life history traits such as diadromy. Long-term records of the size-distribution of the catch in the rod fishery, and in a fisheries-independent trapping programme are available for sea trout Salmo trutta stocks from the River Dee (Wales, UK). These data were used to estimate a length-based harvest rate (LHR) and *a suite of LBIs for the fishery. Appropriate RPs (with uncertainty) were derived for length-based assessment of sea trout. The LBIs and a decision tree suggest that the stock is likely to be sustainably exploited with regard to length-based and a spawner biomass RP. Increasing the overall harvest rate would result in a greater proportion of rare very large sea trout being taken by anglers. Appropriate length-based RPs for sea trout differ to those proposed for marine demersal species. Expected values for the proportion of megaspawners in the catch are very low, which may be explained by fishing gear (hook and line) selection and the cost of multiple spawning migrations in diadromous fish.*

Shephard, S., Josset, Q., Davidson, I., Kennedy, R., Magnusson, K., Gargan, P.G., Walker, A.M., Poole, R. 2019. Combining empirical indicators and expert knowledge for surveillance of data-limited sea trout stocks. *Ecological Indicators,* 104; 96–106.

Abstract: Inland and diadromous fish stocks can support important ecological, social and cultural functions. However, many of these stocks are data-limited and do not have formal state assessments or management reference points. Empirical surveillance indicators of relative abundance and population size-structure may provide an accessible first-step for monitoring such stocks. These indicators could be informed and interpreted via expert knowledge of specific systems and stock histories. The current study focused on an international scientific working group that met in 2017–2019. The group collated long-term monitoring data for sea trout Salmo trutta from six salmonid 'index rivers' in France, Ireland, Wales, Northern Ireland and Sweden. Indicators were selected, and time series of abundance- and length-based metrics for each river were presented on a new visual indicator plot. Expert knowledge from each system was elicited through one-to-one interviews to provide a corresponding stock narrative, in which indicator trends reflected known historical pressure-state events. The accessible presentation of simple empirical indicators supports elicitation of local expert knowledge, and provides an accessible framework for surveillance and reference-direction assessment of data-limited sea trout stocks. This approach could be applied to inland or diadromous stocks where available data are restricted to estimates of relative abundance and size-structure.

4.3 Trout Habitat Scores (THS)

The objective was to carry out an evaluation of the potential smolt production capacity of rivers, by combining the THS Model with juvenile trout density data. THS is categorised according to substrate, velocity, shade, width, depth and slope of section (ICES 2011).

The THS models were developed further during the WG, first using data from Sweden, testing the importance of different habitats and adding other descriptor variables (such as Latitude and Longitude). This exercise demonstrated that stream width and depth were important as continuous variables and that by adding covariates such as distance to the sea, Latitude, Longitude and Altitude, the model explained 75% of the variation in juvenile densities.

With a model based on the abundance of both fry and parr, the best fit was the one including the new THS and Latitude & Longitude. The Random Forest model with depth, altitude, distance to the sea, latitude, longitude and year explained much of the variation in juvenile trout density, but a linear model may be more appropriate when extending the geographic area outside Sweden.

The random forest regression models were also tested focusing on fry only, with similar results but with slightly lower explained variation. Additional models indicated that alkalinity is one of the most important variables and preliminary results show that the model performed better for the Swedish West coast than for the Swedish East coast. In agreements with findings from SG1, it was recognized that protocols for juvenile trout sampling and habitat characterization differ between countries.

Latterly, the methods were explored for estimating potential trout fry 'carrying capacity' (i.e. a guide to the abundance of fry expected under good conditions) based on electro-fishing data for individual sites with long time series (15+ years). Such series were used to plot the empirical cumulative distribution function (ecdf) of 0+ trout in order to identify potential break-points that could be used as a proxy for 'reference' 0+ density under the different THS scores and classes.

The breakpoint analysis was applied to 0+ trout data from rivers in Northern Ireland that are expected to be predominantly derived from sea trout rather than resident trout, to identify potential reference levels. This was successful for THS score 1, 2 and 3 but not 0. Further examination of the data and analyses are required but this testing so far at least suggests it will be worth pursuing this further outside the Baltic within the framework of the next WG term.

A Short Communication is being drafted to explain the potential based on a Pilot Scheme, and a second paper is anticipated based on a wider exploration of additional time-series of electrofishing data with information on THS.

4.4 Other model approaches

A theoretical Bayesian Population Dynamics Model for Baltic Sea Trout (*Salmo trutta* L.) was identified, having been partly developed in Finland with inputs from the WG (Tolvanen, in progress). This model was not fully developed and tested during the WG term, but this is anticipated within the next WG term.

4.5 ToR summary

Overall, a review of the scientific literature on ecological factors affecting the abundance and complex life history of sea trout has been produced and published in Fish and Fisheries (Nevoux *et al.* 2019) providing the necessary tool for validating and developing population models. Further, two papers have been produced using a set of length-based indicators in different catchments to assess the status of a stock and identify where pressures may have had an impact (Shephard *et al.*2018, 2019). Lastly, Trout Habitat Scores (THS) model being developed for the Baltic have been further developed using data both from Sweden and Northern Ireland.

5 Delivery of ToR c)

ToR c) **to establish and evaluate different approaches for estimating Biological Reference Points (BRPs) across regions with different characteristics and conditions for sea trout**

5.1 Introduction

Recent workshops on sea trout (ICES 2013, 2016) concluded that, with the exception of the habitat/parr production models being applied in the Baltic Sea area, there were no examples of Biological Reference Points (BRPs) being developed and nothing equivalent to the use of Conservation Limits (CLs) in the management of Atlantic salmon.

One goal of fisheries management is the determination of the relationship between stock and recruitment (Hilborn & Walters, 1992). Strong evidence exists that within suitable habitats, trout and salmon *Salmo salar* L. populations are regulated by density-dependent mortality during the freshwater stages (Ricker, 1954; Beverton & Holt, 1957; Elliott 1984a,b, 1985a; Solomon, 1985). For additional details on concepts, models and setting BRPs, see Hindar *et al.*, 2011) where they describe stock-recruitment (S/R) modelling fairly extensively for salmon; concepts, spatial and temporal variation in S/R-relationships, transfer from data-rich to data-poor rivers, uncertainties and management implications.

The relationship between spawners and recruits can be summarised in a density-dependent stock-recruitment relationship, and several model types can be applied, corresponding to various theoretical and empirical models. The two main types are the 'Ricker' model – represented by a dome-shaped curve where recruits are maximised at some intermediate stock level; and the 'Beverton-Holt' model – represented by an asymptotic curve where recruit level remains constant above some level of spawning stock (Environment Agency 2003). A third three-parameter model, the Shepherd model, may also be applied. When the 3rd parameter "c"< 1 gives a Cushing curve (no asymptote), c=1 an asymptotic Beverton-Holt curve and as c >1 a dome-shaped Ricker curve. Such curves define freshwater survival, whilst marine survival is described by a 'replacement line', representing the density-independent survival of smolts to returning adults (e.g. Jonsson & Jonsson 2009).

Stock recruitment models can be used to derive various categories of spawning reference point for use in management. However, few studies have described in detail the relationships between stock and recruitment, and most of these involve Atlantic salmon (e.g. Gee, Milner & Hemsworth, 1978; Buck & Hay, 1984; Gardiner & Shackley, 1991; Hindar *et al.*, 2011; Jonsson & Jonsson 2017). With the exception of the comprehensive study on migratory trout in Black Brows Beck (see Elliott, 1994; Elliott & Elliott, 2006), stock-recruitment relationships for trout populations that include the sea-run form remain poorly documented. Some additional time series have now been published (Burrishoole, Erriff, Bresle, Shimna, Dee) and have been examined for possible S/R relationships – these form the basis of this chapter and are reviewed further down. The complexity of life history patterns of *S. trutta*, their aptitude for multiple spawning and, in particular, the lack of understanding regarding the relationships between resident and anadromous trout stocks within the same catchment, have complicated attempts to establish realistic S/R relationships introducing additional variation in the data and uncertainty in the models (see Nevoux *et al.* 2019 for a comprehensive review).

The present approach to managing salmon stocks throughout the North Atlantic region follows the agreement by Parties to the North Atlantic Salmon Conservation Organization (NASCO) that salmon stocks should be conserved by ensuring that an adequate number of spawners enter each river to optimise annual production (NASCO, 1998; Walker, Pawson & Potter, 2006). The derivation of an 'adequate' spawning stock size is based on the assumption that the number of fish produced in the next generation (recruitment) is related to the number of adult fish in the previous generation (stock). Salmonids are among the few fish species studied where this premise has been clearly demonstrated (Crozier *et al.* 2003; Chaput & Prevost, 2001). Recruitment in anadromous salmonids is largely determined by density-dependent regulation in the early life stages because of limited resources (chiefly space and food) in fresh water (Gibson, 1993; Elliott, 1994). Though salmonid recruitment is strongly influenced both by intrinsic (genetic) and extrinsic (environmental) factors, long-term studies indicate that a density-dependent S/R model should generally apply (reviewed by Elliott, 2001).

Like salmon, trout often adopt a sea going lifestyle (anadromy) but unlike salmon, this is not obligatory and the life history strategies of trout are far more complex (see Ferguson *et al.* 2017; Nevoux *et al.* 2019). Trout behaviour in the sea is also more complex than salmon, often remaining in coastal waters and closer to their natal river but often "straying" into neighbouring rivers (Stevens Ch. 5) of this report; Jensen *et al.*, 2015) and adding to the exploitation, and stock assessment, of the trout in that river. The interaction with, or at least the presence of, non-anadromous trout stocks in the same rivers as their anadromous counterparts add a level of complexity not present in salmon stock assessments and the varying habitat types utilised by trout in lakes and rivers, also make stock assessment and setting of reference points for trout a challenge and hence a similar system has not yet been developed for sea trout as has been for salmon (Crozier *et al.* 2003; Chaput & & Prevost 2001, Chaput *et al.*, 1998). In fact, Walker *et al.* (2006) proposed that such a system might not be easily applicable to sea trout and that some form of reference point system relating to juvenile abundance and carrying capacity might be more applicable. Such a system is currently being applied in the Baltic area (see ICES 2019, Chapter 4.3 and associated references) but this has not yet been tested in the wider European context. Furthermore, the presence of resident trout and large areas of lacustrine water in some catchments still pose problems for the estimation of anadromous stock reference points from juvenile trout assessments. Davidson *et al.* (2017a) and Natural Resources Wales (NRW), (2017; 2018) have introduced CLs for individual river stocks of sea trout in Wales based on rod catch derived ('pseudo') S/R relationships. As with salmon, formal assessment of sea trout stock performance against CLs is undertaken annually on all (43) principal sea trout rivers in Wales to evaluate the need for additional protective measures.

Catch-based methods involve the use of angling catch or CPUE as indices of stock performance and include: (i) comparisons of recent catch metrics with historic reference levels, and (ii) (as described above) derivation of 'pseudo' S/R relationships and associated BRPs (Davidson *et al.* 2017a). In developing the latter approach, a combination of these pseudo S/R and more conventional stock models from "data rich" index rivers were applied to other rivers in England and Wales where there was a paucity of data. Both Davidson *et al.* (2017a) and ICES (2016) proposed that there appeared to be merit in this approach and ICES (2016) went some way towards validating the methods and making comparisons between index rivers and different types of stock and recruit data (ICES 2016 Chapter 8.5).

The above indicates that catch/CPUE-derived S/R curves/BRPs along with ground truthing from more data rich index rivers 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. ICES (2016) recommended that a 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 S/R relationships other than the Ricker and Beverton-Holt models.

The paucity of information from rivers rich in data and the regional distribution of those rivers also creates a challenge for such an assessment. This is even more obvious in sea trout compared to the situation for salmon. More recently, the S/R relationships from a number of intensively studied rivers have been published, such as the Burrishoole (Poole *et al.* 2006) and the Erriff (Gargan *et al.* 2016) in Ireland, the Shimna in N. Ireland (Kennedy *et al.* 2017), the Bresle in France (Euzenat *et al.* 2007) and a suite of rivers in England and Wales (Davidson *et al.* 2017a).

Additional unpublished data were also made available to the WG for the Högvadsån and Åvaån rivers (Sweden) (Magnusson, Degerman, Palm pers. comm.). These published S/R relationships for sea trout are summarised below. We have not included the Black Brows Beck data (Elliott & Elliott 2006) in this chapter as we are attempting to address the topic at a whole catchment level.

This chapter will review these data, compute some reference values for stock and recruitment and provide some insight into whether any relationships exist, and whether these would be any basis for further concerted action on using such S/R type modelling as a basis for sea trout management outside of the specific individual rivers where the data were originally collected.

Finally, the potential difficulties in determining biological reference points for sea trout based on S/R relationships are explored in Sections 5.4 & 5.5.

5.2 Data sources

Figure 4 shows the locations of the nine catchments that supplied data for this analysis.

Figure 4. Nine rivers in Europe where sea trout stock and recruit data were available for stock-recruitment type modelling.

5.2.1 Burrishoole

The Burrishoole in the west of Ireland (53° 55' N 009° 34' W) has been fully monitored since 1970 for upstream and downstream migrating juvenile and adult sea trout (Poole *et al.*, 1996; 2006). The catchment (circa 15 km from sea to source) is dominated by lakes, with approximately 70 km of spate streams. Full annual counts of upstream returning silvered sea trout were available along with individual size measurements since 1985, and these values were used as the abundance index. The rod catches of sea trout in Lough Furnace (below the trap) were measured in 1985 to 1987. A proportion of fish were measured in the upstream trap in the 1980s, and from 1990 onwards almost all fish were measured.

Spawning escapement of Burrishoole sea trout comprised fish in all three sea age categories. Between 1971 and 1989, the annual number of ≥1 sea-winter spawners was estimated by Mills *et al.* (1990); after 1989, numbers were determined by scale reading and length distributions. Sex ratios and mean fecundities were estimated from the historical trap and rod catch data, including ovaries removed from 102 females rod-caught between 1984 and 1987 (Anon., 1970–2003; O'Flynn, 1988; Mills *et al.*, 1990; Poole *et al.*, 1996). These estimates of fecundity at size were raised to the total annual catch to derive estimates of annual egg deposition.

5.2.2 Erriff

The Erriff in the west of Ireland (53° 37' N 009° 40' W) is approximately 30 km in length and is principally a salmon river. The Black River (3 km length) is a major tributary (approximately 8 km upstream from the tide); it leads to Tawnyard Lough (56 ha) and is the principal sea trout fishery. Sea trout are monitored with a downstream Wolf-type trap, which has been in operation on the Black River since 1985. The number and size of downstream migrating sea trout smolts and kelts was recorded at the trap over the period 1985−2004 (Gargan *et al.*, 2016). No sampling of upstream migrants was undertaken.

The abundance index used in this report was the annual downstream kelt count from the Wolf trap. Egg deposition in the Tawnyard sub-catchment was calculated based on length-based fecundity rates updated from Gargan *et al.* (2016).

5.2.3 Shimna

The Shimna River is a small (circa 12 km length) coastal spate stream in Northern Ireland (54° 13' N 005° 53' W) with a locally significant sea trout fishery. Significant monitoring of the catchment and fishery was instigated in 2003 (Kennedy *et al.*, 2017). Detailed rod catch returns have been tabulated by the local angling association, and raw catch and CPUE have been compiled. The tidal reaches of the river are dominated by finnock, but many of these sea trout do not subsequently migrate over the fish counter located circa 300 m upstream of the head of tide (Kennedy *et al.* 2017).

Two versions of the Shimna data were analysed in this study. The first version included an egg production estimate (stock) and a smolt production estimate (recruits). The individual egg production was estimated for sea age length classes measured at the fish counter, and set against previously published fecundity levels (Solomon, 1997). This was plotted against estimated smolt recruitment (See also Shephard *et al.* 2019).

Annual egg deposition was estimated using a quadratic curve fit to historically-observed numbers of eggs at fish body length, raised to the total annual catch. This estimate includes finnock, which are known to be mostly immature and/or don't migrate into the Shimna.

Recruitment was the estimated annual smolt output. Smolt estimates are obtained for the Shimna river based on intensive (27 sites) annual catchment-wide electric fishing surveys of 0+ age class parr from which site densities are extrapolated by the spatial extent of available nursery habitat to estimate the total catchment production (Kennedy *et al.*, 2017). Data collected from annual monitoring of biological characteristics on the Shimna stock (e.g. survival estimates, smolt age profiles) are then utilised to produce an overall annual estimate of smolt production from each recruited 0+ cohort.

The second dataset used (known as the Shimna Original) was the rod catch CPUE to reflect stock and the electrofishing derived 0+ fry index as recruits: The abundance index used in the current analysis for the Stock was rod CPUE (annual number of trout per angler).

Annual semi-quantitative (SQ) electrofishing surveys were used to determine recruitment as 0+ age fry and expressed as a relative abundance index (= mean no. 0+ trout per 5 mins).

5.2.4 Bresle

The Bresle River (approximately 72 km in length) is located in the northwest of France, and flows into the English Channel (50° 03' N 001° 23' E) at Le Tréport. Annual sea trout runs were estimated by double trapping and mark-recapture, and used as the abundance series. Three trapping facilities are used to target the main life stages: smolt (emigrating juvenile), adult (see above) and kelt (downstream migrating post-spawning adult). These are an upstream trap (adults) at Eu (3 km from the sea), a main downstream trap (kelts and smolts) at Beauchamps (12 km from the sea) and a smaller, secondary downstream trap (smolts) at Eu. These traps have operated from 1981 (adults), 1982 (smolts) and 1984 (kelts) (Euzenat *et al.*, 2007). Each adult fish was measured (nearest mm) and weighed (10 g intervals until 1991 and 1 g from 1992 to the present).

Length measurements taken in the upstream trap were used for the current study (total lengths in 1981–1983 and fork lengths from 1984 to present). The upstream traps in Eu are not 100% efficient, but it was assumed that total number of fish measured in the trap is reflective of the overall run, and these counts provided the abundance index (Euzenat *et al.*, 2007). Sex of adult fish was defined using external criteria on the autumn run only. Annual egg deposition upstream of the Eu trap was estimated using a curve fit to number of eggs at sea trout length, based on data from the Shimna river.

5.2.5 Dee

The River Dee rises in the Cambrian Mountains and flows 160 km through mainly rural areas before entering the Irish Sea in Liverpool Bay (53° 47' N 003° 24' W). It is one of the largest rivers in Wales (catchment area 2088 km^2), with flows controlled by a series of headwater reservoirs for flood control and water supply. A long-term programme to monitor stocks of sea trout (and salmon) began on the Dee in 1991. This programme focuses on upstream trapping and tagging of fish at a main stem, head-of-tide trap at Chester Weir. Annual run estimates for finnock and older sea trout are obtained by mark-recapture and are based on the screening of returning fish at Chester Weir one year after tagging. Biological information collected from trap sampled fish is used to estimate the egg contribution of returning stocks and survival of resulting recruits. Annual egg deposition estimates combine total run figures with data on size, sex composition, fecundity and maturation as described in Davidson *et al.* (2006; 2017b). In this case, fecundity-size relationships are taken from Solomon (1994). Likely in-river losses, e.g. resulting from the intervening rod fishery and other sources, are also incorporated into egg deposition estimates.

In addition to the above, estimates of smolt output are available on the Dee in some years – obtained from Rotary Screw Trapping and Coded Wire Tagging at a lower river sites.

5.2.6 Tamar

The River Tamar rises 10 km from the north coast of the SW peninsula of England and flows in a southerly direction through predominantly low-lying agricultural land into the English Channel via Plymouth Sound (50° 40' N 4° 21' W). The Tamar catchment has an area of 927.75 km^2, and the main river is 139 km long – forming a natural boundary between the counties of Devon and Cornwall.

Returns of sea trout (and salmon) entering the river each year have been assessed from the operation of a resistivity fish counter and associated upstream trapping facility at Gunnislake Weir close to head-of-tide (Hillman, 2011). Time-series of run estimates for sea trout at this site have been available since 1994. Egg deposition estimates are obtained using methods similar to those described for the River Dee (above). In addition, to the above, estimates of smolt output are available on the Tamar in some years – obtained from Rotary Screw Trapping and Coded Wire Tagging at a lower main river site.

5.2.7 Lune

The River Lune rises in Cumbria in North West England and flows westward entering Morecambe Bay (53° 98′ N 2° 88′ W), south of Lancaster, some 105 km from its source (Aprahamian, Wyatt and Shields, 2006).

The catchment (1223 km^2) is mainly rural, with pasture for cattle and sheep, and hay and silage production being the primary land use. The river passes through several small towns and villages, with Lancaster, situated close to its confluence with Morecambe Bay, being the main urban area.

Numbers of adult sea trout (and salmon) entering the river each year are assessed from operation of a resistivity fish counter and associated upstream trapping facility at Forge Weir - situated approximately 4 km upstream from the tidal limit.

Time-series of run estimates for sea trout at this site have been available since 1992. Egg deposition estimates are obtained using methods similar to those described for the River Dee (above).

5.2.8 Högvadsan

Högvadsån is 52 km long fourth order stream (476 km^2 catchment area, mean width 16 m, and mean depth 0.24 m) that mainly runs through forests and some agriculture landscape into river Ätran (57° 1′ N 12° 39′ E), 26 km from the sea on the Swedish west coast. Högvadsån and Ätran is the most important production area for salmon on the Swedish west coast. Högvadsån has a total wetted area of 81.7 ha of which about 25 ha is suitable for trout and salmon production. Liming has taken place since 1978 to prevent water acidification. The number of descending smolts has been counted in a smolt trap at Nydala kvarn since 1959 (from March to the end of smolt run) with a trap efficiency of about 20% (related to flow). The number of ascending spawners has been recorded in a salmon trap since 1954 (April to November) with an estimated trap efficiency of 25–50%.

5.2.9 Åvaån

Åvaån is a 7.4 km long first order stream (16 km^2 catchment area, mean width 2.3 m, and mean depth of 0.2 m) that runs through a national park from Lake Långsjön to Åvaviken south of Stockholm (59° 10′ N 18° 22′ E) on the Swedish east coast. The Åvaån has a total wetted area of 0.73 ha, of which 0.38 ha is suitable for trout. Smolt and spawners are captured in traps at the outlet, with unknown trap efficiency. Liming and habitat restorations regularly takes place in Åvaån, and 10% of the spawners are used for rearing and stocking of trout.

5.3 Analysis

5.3.1 Descriptors

The main descriptors of the catchments and their sea trout stock, and the basic derived variables are presented in Table 1. The Burrishoole and the Erriff were the only catchments containing lakes whereas the other catchments ranged from relatively small rivers (Åvaån, Shimna) to relatively large rivers (Dee, Lune, Tamar).

The spawning stock of trout in a river is usually comprised of a number of sea ages and different spawning histories. This makes a single number a relatively meaningless parameter, especially if there is a diversity of sea ages, and therefore fecundities. Hence, Stock was calculated as the annual amount of ova deposited (according to estimates of numbers and weights of mature female trout and fecundity-weight relationships) and where available this was used in the S/R models. The stock in the Högvadsån was an estimate from a trap efficiency of 25–50%.

Likewise, annual smolt output data were not available for five of the rivers, although the smolt output related to each spawning cohort, or smolt equivalent was available for all the rivers except the Lune. The estimate for the Högvadsån should be treated with caution as it is derived from a trap with estimated efficiency of about 20%.

From the data available (Table 2, Figure 5), there was a considerable range in average ova deposition rates from a maximum of 5225 ova/100m^2 of fluvial habitat in the Åvaån to a minimum of 238 ova/100m^2 in the Tamar and post stock collapse in the Burrishoole of 22.3 ova/100m^2.

Smolt output ranged from 862 smolts/ha in the Åvaån to 7.7 in the Högvadsån in the pre-liming period and 8.1 smolts/ha in the Burrishoole pre-stock collapse. High rates of smolt production also occurred in Shimna, the Bresle and the Tamar.

Low rates of smolt production seem to occur where deep lakes are present, or possibly where considerable areas of habitat might be unsuitable for trout (such as big rivers with salmon e.g. the Dee). Previous data from Ireland (STWG 1994) indicated two levels of smolt production both before and after the sea trout stock collapse in 1989, the lower smolt productions tending to come from catchments with large deep lakes. This potential influence of habitat types and quality should be the subject of further investigation.

However, ova-to-smolt survival data for sea trout needs to be treated with caution. The main assumption used is that only sea trout ova produce outward migrating sea trout smolts, but spawning stock/ova from freshwater resident trout may also generate recruits to sea trout smolts

Also, the estimation of smolt output in some catchments is not complete and this can also introduce some error. Sea trout ova-to-smolt survival rates ranged from 0.2% in the Åvaån to 2.2% in the Shimna and 3.7% in the Erriff. The lower survival rates tended to be associated with higher egg deposition rates, and even in the Bresle, survival fell from 0.6% to 0.4% as the egg deposition increased whereas the converse occurred in the Burrishoole.

It should be noted that all these rates (i.e. freshwater survival rates) will be influenced by the stock's relative position on the S/R curve and by density-dependent effects. Furthermore, Allee effects (i.e. reduced individual fitness at low density) may also become evident at particularly low levels of stock.

Standardisation of approach and metrics (e.g. ova deposition, survival rates, smolt production rate) would be advisable in the future.

Table 1. Catchment details for the nine rivers with sea trout stock and recruit data. Smolt equivalent is the cumulative smolt output from each spawning year.

River	Country	Grid Reference	Period	Total Accessible Wetted Area (ha)	Fluvial Accessible Wetted Area (ha)	Fluvial Accessible % of Total WA	Average Stock Spawning Stock	Average Annual Smolt count	Smolt Output Equivalent to annual Spawning Stock	Data Type
Burrishoole	Ireland	53° 55' N 009° 34' W	1971-1988	475.0	25.0	5.3	1795	4227	3871	Ova to Smolt
Burrishoole	Ireland		1989-2017				204	1050	828	Ova to Smolt
Erriff	Ireland	53° 37' N 009° 40' W	1985-2017	56.0	1.5	2.7	409	2339	2404	Ova to Smolt
Shimna	UK - N. Ireland	54° 13' N 005° 53' W	2002-2018	9.9	9.9	100.0	313	4154	4041	Ova to Smolt
Shimna "Original"	UK - N. Ireland	54° 13' N 005° 53' W	2002-2018	9.9	9.9	100.0	-	-	-	CPUE - 0+ fry
Bresle	France	50° 03' N 001° 23' E	1984-2003	33.1	33.1	100.0	863	6247	6483	Ova to Smolt
Bresle	France		2004-2017					7948	7698	Ova to Smolt
Dee	UK - Wales	53° 47' N 003° 24' W	1991-2013	617.0	617.0	100.0	10298	50257	50257	Ova to Smolt
Lune	UK - England	54° 03' N 002° 47' W	1995-2014	422.7	422.7	100.0	22338	-	-	Ova - 0+ Fck
Tamar	UK - England	50° 26' N 004°12' W	1992-2014	292.6	292.6	100.0	9965	50778	50778	Ova - 0+ Fck

Hogvad-san	Sweden	57° 2′ N, 012° 39' E	1962-1998	25.0	25.0	100.0	8	-	193	Adlt No. - Smlt
Hogvad-san	Sweden		1999-2015				31	-	1636	Adlt No. - Smlt
Avaan	Sweden	59° 10′ N, 018° 22' E	1929-'37 & '00-2015	0.4	0.4	100.0	-	-	345	Ova to Smolt

Table 2. Ova deposition rates and smolt production rates for the nine river catchments where data were available.

River	Period	Average Annual Ova Deposited	Ova deposition Ova/100m2 fluvial wetted area	Smolt Output Smolt/ha total wetted area	Ova to Smolt survival %
Burrishoole	1971-1988	805,629	322.3	8.1	0.5
Burrishoole	1989-2017	55,764	22.3	1.7	1.4
Erriff	1985-2017	118,896	792.6	42.9	3.7
Shimna	2002-2018	356,616	360.2	408.2	2.2
Shimna "Original"	2002-2018	-	-	-	-
Bresle	1984-2003	2,147,409	648.8	195.9	0.6
Bresle	2004-2017	2,943,139	889.2	232.6	0.4
Dee	1991-2013	6,295,754	102.0	81.5	0.8
Lune	1995-2014	21,396,750	506.2	-	-
Tamar	1992-2014	6,949,683	237.5	173.5	0.6
Hogvadsan	1962-1998	-	-	7.7	-
Hogvadsan	1999-2015	-	-	65.4	-
Avaan	1929-'37 & '00-2015	209,035	5,225.9	862.5	0.2

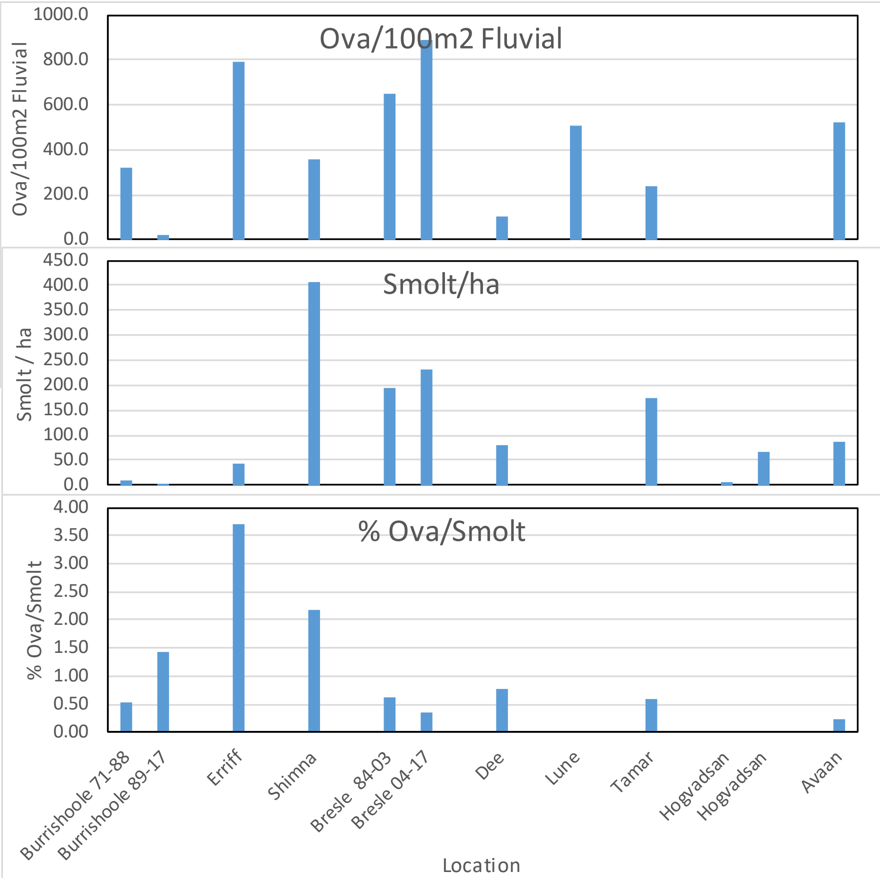


Figure 5. Descriptors for the nine catchments with ova deposition (top), smolt production (middle) and ova to smolt survival (bottom). Note the Åvaån ova deposition and smolt production values have been divided by 10.

5.4 Stock Recruitment Relationships

Stock recruitment (S/R) relationships were examined for each of the nine rivers, and in some cases (Dee, Shimna) for different types of data from the same river (Figures 6 to 8). Thornton (2008) carried out a similar exercise with fewer rivers and a number of these have also been published independently (Burrishoole, Bresle, Shimna, Dee, Tamar, Lune) although for the Burrishoole, Shimna and Bresle, additional years have been added to the time series since their publication.

There are a number of issues relating to the use of S/R relationships for deriving BRPs:

- These data do not take into account spawning stock/ova from freshwater resident trout, but they may include recruits originating from resident trout. Therefore, the models should probably be run with, and without, the origin value (0, 0). Note, we tried including (0, 0) in the Tamar data to see if it improved the fit, but the model was unable to fit to the data. This warrants further investigation.
- Following the previous note regarding the inclusion of the origin, caution should be applied when dealing with data close to the origin, as we would expect other mechanisms to kick in, such as Allee Effects.
- Low stock levels can lead to density-independent effects such as changes in survival, hot-spot spawning, isolation etc. Such effects have been observed in the Burrishoole sea trout S/R data (Poole *et al.* 2006). This also warrants further attention.

- Different data types make comparisons difficult, such as Stock as counts, rod catch CPUE, absolute stock, estimated stock from trap efficiency or mark recapture. However, an exercise in comparing different metrics using data sourced from the same river was carried out in WKTRUTTA2 (ICES 2016, Sections 7.4 and 8.5) and this could be extended to other river systems. It would aid in identifying the best approach, the required data and therefore the most-cost effective.
- Different measures of recruitment, such as 0+ fry index, absolute or estimated smolt count, or returning maiden fish (0+ sea age (finnock), and total .0+ & .1+ sea ages (maidens)) also make comparisons difficult. However, it should be noted that some recruitment data from different life stages may not be that problematic, depending on at which stage we believe the density regulation kicks in and what we want to use the model for. If, for example, the goal is to set a CL from the max recruitment, any life stage with just density-independent mortality will not change the shape of the S/R curve but just rescale the y-axis.
- There is the potential, as demonstrated above, to use 'indices' of stock and recruitment (e.g. as on the Shimna) to define S/R curves and BRPs (i.e. something less resources intensive than the more conventional full 'index' monitoring programme gathering absolute estimates e.g. of smolt output and adult return).
- Non-stationarity for a number of different reasons, such as liming in the Högvadsån after 1978, changes in marine survival (known – Burrishoole, or unknown – rivers that use finnock as a proxy for smolt count), changes in trapping efficiency. This is important to remember – many factors may have changed over time, and temporal variance in a S/R-relationship may yield spurious models or outputs.

Tables 3 to 5 present the details for the S/R relationships. We attempted to fit two parameter Beverton-Holt and Ricker S/R models to each dataset and also the three parameter Shepherd model to five of the datasets. For details of these approaches, see Elliott (1994) and Elliott & Elliott (2006). We used the AIC to estimate the best quality fit of the models (Tables 3 to 5) and in some cases the model would not fit the data (see Figures 6 to 8).

5.4.1 Some general observations

The Beverton–Holt relationship appeared to fit the data from the catchments with large habitats, such as lakes (Burrishoole, Erriff), or big salmon rivers such as the Dee (Figure 6). Smolt production rates from these catchments were also relatively low. Data from the "sea trout" rivers were better fitted to a Ricker model (Figure 7). The Shepherd model made little difference to the rivers where the Beverton-Holt relationship already fitted well (Figure 8). Data from some rivers did not suit S/R models, such as Högvadsån, Tamar and Lune.

Both the Burrishoole and the Erriff show the result of a severe reduction in marine survival leading to a significant reduction in stock, more pronounced in Burrishoole. In a way this is a natural experiment we would not want to conduct, i.e. reduce stock to near zero and observe the outcome. It is also possible following a period (~30 years) of sustained high mortality in the sea and also changes in climate over about 20 years, that the propensity for migration to the sea has changed in the Burrishoole with fish "realising" the cost-benefit of such migration – a similar scenario to that observed by Sandlund & Jonsson (2014).

The smaller rivers, the Åvaån, Shimna and the Bresle, had the highest ova deposition per unit area and produced the highest smolt production rates. The Ricker-type model best fitted these data, probably indicating that space/available habitat is limiting and density-dependent mortality is more important, especially at higher stock levels, leading to a more pronounced effect in smaller rivers.

Some of the models in Figure 6 (Ricker) illustrate the “problem” with the Ricker model – high recruitment from low or medium stocks will pull the curve up, thereby giving the curve more of a dome shape than the recruitment for higher stock levels would indicate.

Ricker and Beverton-Holt models are really special cases of the Shepherd model (i.e. not three different models) so there is probably no need to discuss model differences too extensively. So, an alternative approach to that taken here, and for future investigation, would be to fit Shepherd models, or more pragmatically, fit a hockey-stick model. These models might give more reasonable survival estimates at low stock levels, especially where data are lacking. Caution should also be taken where an excessive dome-shape appears, i.e. too large a penalty for large Stock values.

It should be noted that in some of these rivers, even though model fit may appear bad at first, the data are worth protecting and working with, similar in fact to many salmon datasets. With such a complex and flexible species as trout and some uncertainty in the S/R data, and possibly large environmental stochasticity generating variance around the S/R curve, we may not expect much better. It can be hard to get managers to accept that this is as good as it gets, but a similar approach has proven to work in Norway for salmon, where abundances have increase after some years of spawning target management. As an illustration, a robust population with a surplus of spawners (always above the CL) would yield S/R data with R^2 close to zero – meaning that for a Beverton-Holt model we would just have “random” variation around the asymptote.

In other words, a relatively stable Stock and Recruit situation, possibly as observed here in the Bresle, Shimna, Tamar and Lune examples, may not fit well into S/R models, but the data may well indicate a steady state CL or other reference point suitable to set a management target/limit.

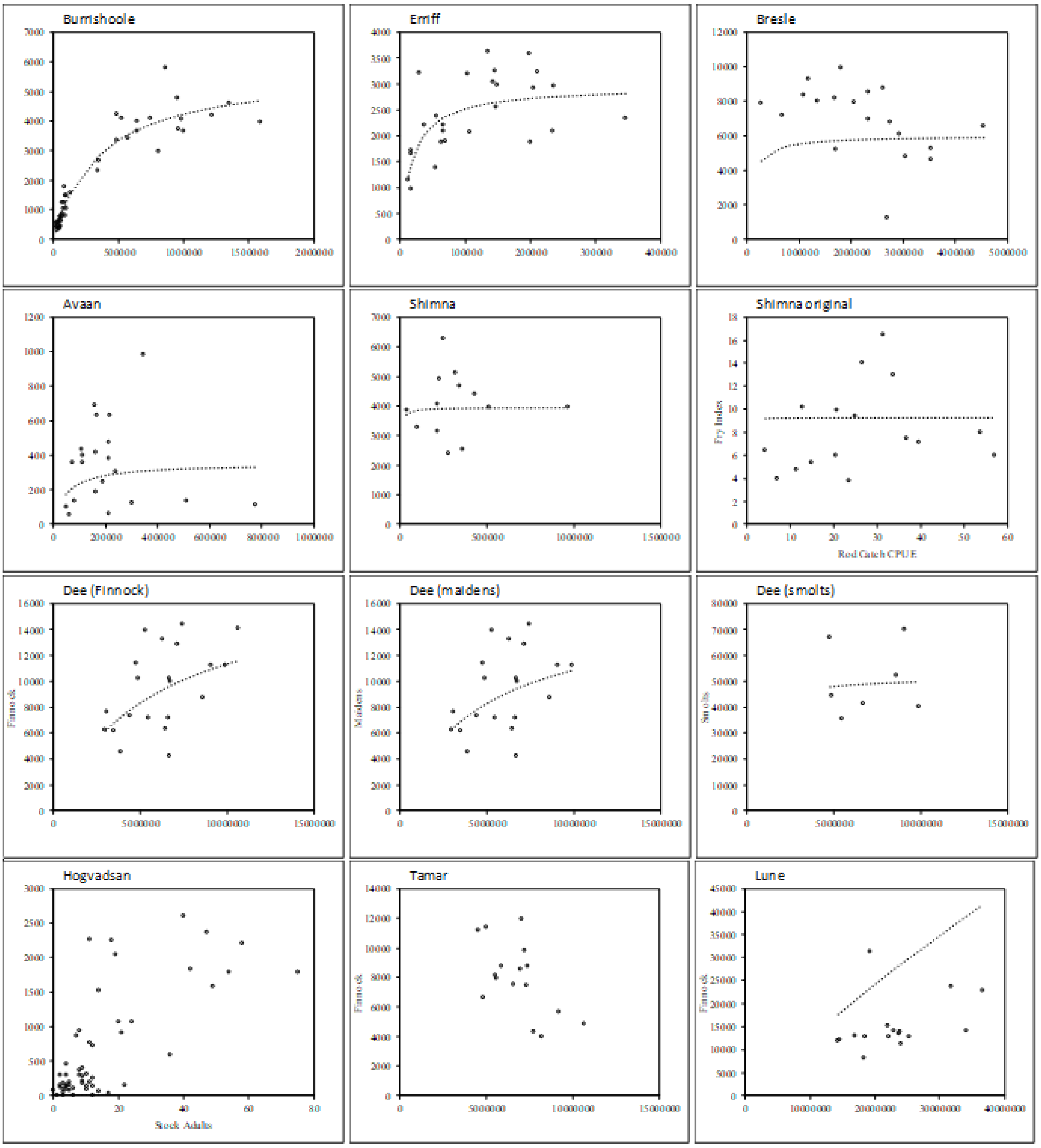


Figure 6. Beverton-Holt stock recruitment plots for the 12 datasets. Unless otherwise stated, the x-axes are ova deposited and the Y axes are smolts. Note the three y-axis recruitment options for the Dee, the Adults fish count for the Stock (x-axis) in the Hogvadsen, and the two datasets for the Shimna.

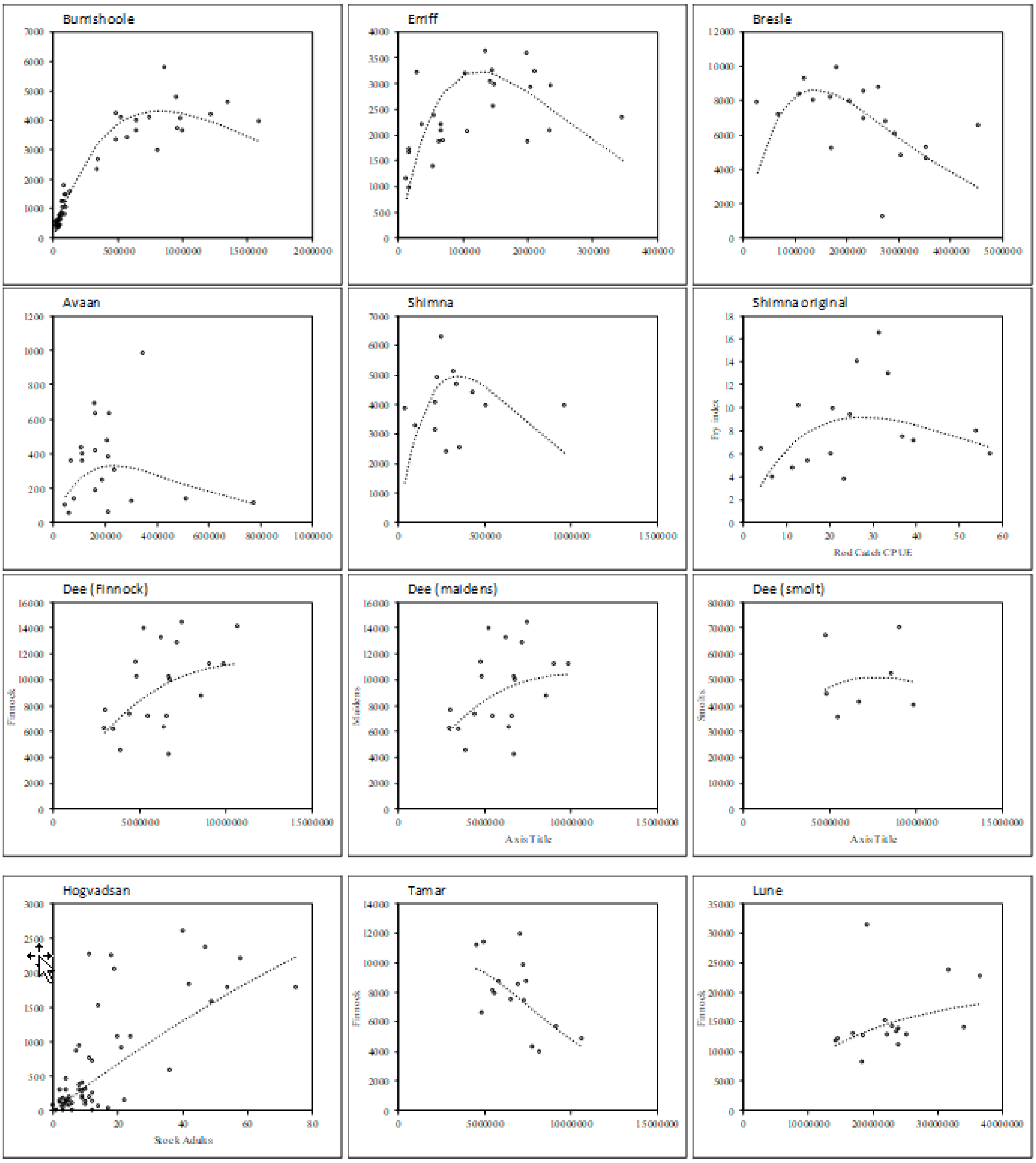


Figure 7. Ricker stock recruitment plots for the 12 datasets. Unless otherwise stated, the x-axes are ova deposited and the y-axes are smolts. Note the three y-axis recruitment options for the Dee, the Adults fish count for the Stock (x-axis) in the Hogvadsån, and the two datasets for the Shimna.

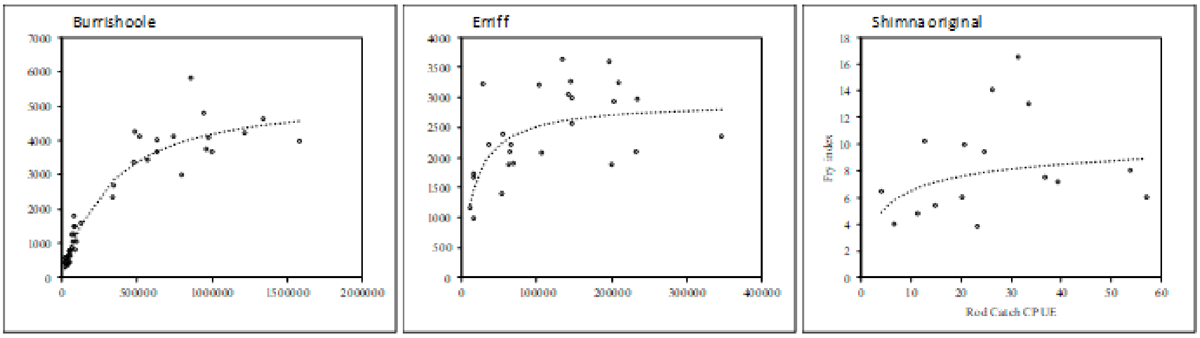


Figure 8. Shepherd stock recruitment plots for three datasets. Unless otherwise stated, the x-axes are ova deposited and the y-axes are smolts.

Table 3. Outputs from the Beverton-Holt models. The unshaded rows are for ova to smolt, whereas the shaded rows are for other types of data. RA = Replacement Abundance.

Country	River	Main Habitat Type	Input Var Stck Type	Input Var Recruit Type	Beverton-Holt					
					a	b	r^2	RA Stck	RA Smolt	AIC
Ireland	Burrishoole	Lake	Total Stck eggs	Smolt	$1.60E^{-02}$	$2.79E^{-06}$	0.92	353195	2848	11.60
Ireland	Erriff	Lake	Total Stck eggs	Smolt	$1.73E^{-01}$	$5.86E^{-05}$	0.41	14103	1335	5.69
France	Bresle	River	Total Stck eggs	Smolt	$6.70E^{-02}$	$1.11E^{-05}$	0.02	84090	2913	28.02
Sweden	Avaan	River	Total Stck eggs	Smolt	$7.09E^{-03}$	$2.01E^{-05}$	0.03	49473	176	54.30
Sweden	Hogvadsen	River	Trap count Adults	Smolt	No fit					
UK NI	Shimna	River	Total Stck Adults	Smolt	$1.41E^{+00}$	$3.56E^{-04}$	0.004	1159	-2788	8.32
UK NI	Shimna	River	CPUE Proxy Stck	Fry Index	$2.31E^{+02}$	$2.48E^{+01}$	$3.38E^{-05}$	9.2	9	21.73
UK Wales	Dee	River	Total Stck eggs	Finnock 0+	$3.18E^{-03}$	$1.80E^{-07}$	0.24	5528460	8792	16.60
UK Wales	Dee	River	Total Stck eggs	Maiden 0+ & 1+	$3.54E^{-03}$	$2.25E^{-07}$	0.18	4433363	7852	16.60
UK Wales	Dee	River	Total Stck eggs	Smolt	$1.37E^{-01}$	$2.65E^{-06}$	0.003	325936	23908	5.96
UK ENG	Tamar	River	Total Stck eggs	Finnock 0+	No fit					
UK ENG	Tamar	River	Total Stck eggs	Finnock 0+	No fit					
UK ENG	Lune	River	Total Stck eggs	Finnock 0+	$1.32E^{-03}$	$4.59E^{-08}$	0.11	21742673	14370	11.40

Table 4. Outputs from the Ricker models. The unshaded rows are for ova to smolt, whereas the shaded rows are for other types of data. RA = Replacement Abundance. Rmax = Maximum Recruitment and SMax = Stock the maximises recruitment.

Country	River	Main Habitat Type	Input Var Stck Type	Input Var Recruit Type	Ricker							
					a	b	r^2	RA Stck	RA Smolt	Rmax	S max	AIC
Ireland	Burrishoole	Lake	Total Stck eggs	Smolt	0.014	1.21E-06	0.99	350130	3262	4,318	802564	14.68
Ireland	Erriff	Lake	Total Stck eggs	Smolt	0.071	8.07E-06	1.12	32725	1789	3,245	134624	20.52
France	Bresle	River	Total Stck eggs	Smolt	0.017	7.23E-07	0.71	563409	6364	8,635	1354248	31.72
Sweden	Avaan	River	Total Stck eggs	Smolt	0.004	4.29E-06	0.08	129566	287	331	237701	49.91
Sweden	Hogvadsen	River	Trap count Adults	Smolt	35.993	2.57E-03	0.17	139	7183	5,151	389	
UK NI	Shimna	River	Total Stck Adults	Smolt	0.039	2.88E-06	1.20	112814	3164	4,954	346972	22.18
UK NI	Shimna	River	CPUE Proxy Stck	Fry Index	0.907	3.63E-02	0.22			9.2	27.7	22.42
UK Wales	Dee	River	Total Stck eggs	Finnock 0+	0.003	8.18E-08	0.26	7313097	10170	11,377	12229296	16.89
UK Wales	Dee	River	Total Stck eggs	Maiden 0+ & 1+	0.003	9.65E-08	0.19	6119811	9260	10,414	10366922	16.69
UK Wales	Dee	River	Total Stck eggs	Smolt	0.018	1.31E-07	0.02	3059390	37161	50,912	7629899	6.25
UK ENG	Tamar	River	Total Stck eggs	Finnock 0+	0.007	2.70E-07	0.36	1824606	8018	9,791	3697982	7.42
UK ENG	Tamar	River	Total Stck eggs	Finnock 0+	No fit							
UK ENG	Lune	River	Total Stck eggs	Finnock 0+	0.001	2.01E-08	0.13	34154824	17693	18,825	49659925	11.65

Table 5. Outputs from the Shepherd models. The unshaded rows are for ova to smolt, whereas the shaded rows are for other types of data.

Country	River	Main Habitat Type	Input Var Stck Type	Input Var Recruit Type	Shepherd							
					a	b	c	r^2	RA Smolt	Rmax	S max	AIC
Ireland	Burrishoole	Lake	Total Stck eggs	Smolt	0.016	$2.59E^{-06}$	1.052	0.91				13.58
Ireland	Erriff	Lake	Total Stck eggs	Smolt	0.173	$5.85E^{-05}$	1.001	0.4				7.68
Sweden	Hogvadsen	River	Trap count Adults	Smolt	no fit							
UK NI	Shimna	River	CPUE Proxy Stck	Fry Index	3.46	$4.97E^{-01}$	0.912	0.09				23.72
UK ENG	Tamar	River	Total Stck eggs	Finnock 0+	no fit							

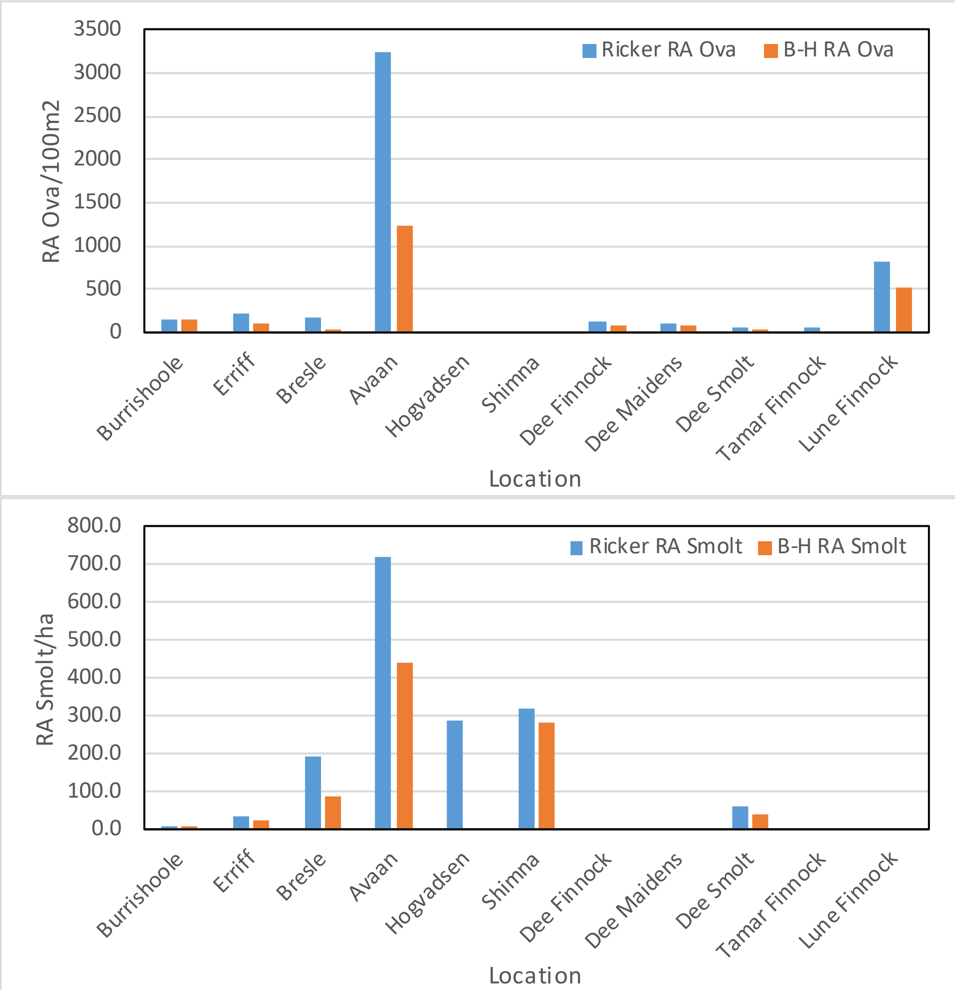


Figure 9. Replacement abundances in ova per 100m² and smolts per hectare for Beverton-Holt and Ricker models.

Table 6. Commentary on the data and Stock/Recruit models displayed in Figures 3 to 5.

Location	Stock Data	Recruit Data	Beverton-Holt (see Figure 3)	Ricker (see Figure 4)
Bur-rishoole	Ova	Smolt	Best fit model, Shepherd similar. Data includes pre- and post-stock collapse.	Quite a good fit. Data includes pre- and post-stock collapse.
Erriff	Ova	Smolt	Best fit model, Shepherd similar	Not such a good fit, although similar Smolt Replacement abundances. Model quite sensi-tive to the higher data values, es-pecially stock.
Bresle	Ova	Smolt	Not a good fit, possibly indicating a steady stock state and not enough extreme data to force the model	Better fit, giving a very different Replacement Abundance. Fringe points in the data are hav-ing a large influence on the shape of the model

Location	Stock Data	Recruit Data	Beverton-Holt (see Figure 3)	Ricker (see Figure 4)
Åvaån	Ova	Smolt	Not a good fit. It's a small river with hugely variable data. Extremes in output descriptors for smolts and ova deposition rates.	Slightly better fit, but extreme values still overly influencing the shape of the model. Three low smolt outputs for high spawning stock may be related to pollution fish kill events.
Hogvad-sen	Adults	Smolt	Hugely variable dataset, possibly with non-stationarity over the time period. Dataset not reliable. Model did not fit.	Model did not fit.
Shimna	Adults	Smolt	Model did not fit well - had an "a" value >1. Possibly indicating a steady stock state and not enough extreme data to force the model.	Model did not fit well, two extreme data values influenced the shape of the outer half of the curve, similar to the Åvaån.
Shimna Original	Rod CPUE	0+ Fry	Model did not fit well - had an "a" value >1. The Shepherd model gave a better fit than the BH	While the AIC values were similar, the Ricker curve appeared to represent the data more appropriately. Difficult to compare outputs due to the input data types (Rod CPUE and 0+ fry)
Dee Fin-nock	Ova	Fin-nock 0+	Data clustered without extremes of stock, possibly indicating a relatively stable state. Little difference between models	Ricker less suitable? Influence of a big habitat.
Dee Maid-ens	Ova	Maiden 0+ & 1+	Data clustered without extremes of stock, possibly indicating a relatively stable state. Little difference between models	Ricker less suitable? Influence of a big habitat
Dee Smolt	Ova	Smolt	Not enough data to produce a suitable model.	Not enough data to produce a suitable model.
Tamar Finnock	Ova	Fin-nock 0+	Model did not fit	Model fitted but data were clustered and not enough distribution in stock levels to give a reliable picture.
Lune Fin-nock	Ova	Fin-nock 0+	Model did not fit well	Model did not fit well

5.5 Discussion

Thornton (2008) provides a discussion of the merits and drawback of using S/R relationships for the setting of BRPs for trout and much of this discussion draws on that report.

5.5.1 Salmon management

Because stock-recruitment (S/R) relationships are not available for most rivers, the procedures used to set CL for salmon in many areas are based, in part, on parameters derived from an estimated S/R relationship in a neighbouring, more intensively monitored, river (e.g. 'index' rivers) where population census data are available (Crozier *et al.* 2003; White *et al.* 2106). Modelling procedures are often used to 'transport' S/R relationships from data-rich to data-poor rivers; for example, in E&W these include habitat models to predict the height of the S/R curve (or carrying capacity) based on river-specific data (Wyatt and Barnard, 1997; Environment Agency, 2003). The replacement line (representing survival from smolt output to adult return) is also adjusted according to river-specific estimates of sea age composition and sex ratio (e.g. Wyatt and Barnard, 1997; Environment Agency 2003). In the Irish case, S/R transportation models are related to river habitat characteristics, including wetted area (McGinnity *et al.* 2003, 2012, White *et al.* 2016).

Stock status is assessed annually in relation to the CL, with spawner numbers usually derived from rod catches and assumed exploitation rates (in the absence of trap or counter-based run estimates).

5.5.2 Sea Trout Management

Given that an established method exists for setting river-specific CL for salmon, it would seem logical to apply a similar method to sea trout management, especially since the sea trout's lifecycle is similar in many respects to that of salmon. The methodology developed for salmon, however, involves the transport of known S/R relationships from index rivers to other rivers where less data are available, and this process is based on the underlying assumption that the population dynamics of each stock are similar and that differences in river-specific production occur as a result of differences in carrying capacity. Applying such a method to sea trout would therefore require a S/R relationship for at least one 'typical' sea trout river and a method by which to transport this relationship to other rivers (Walker *et al.* 2006).

Few studies have described the relationship between stock and recruitment for sea trout, and S/R relationships for trout populations that include the anadromous form remain largely unexamined. The complex life history of the trout, its aptitude for multiple spawning and lack of understanding of the relationships between resident and anadromous populations within the same catchment means that, on the few rivers where appropriate census data exist, there is greater uncertainty as to what any empirical S/R relationship represents in terms of this complexity (Poole *et al.* 2006).

5.5.3 Comparisons between rivers

The biological reference points derived from S/R models fitted to trout population are presented in Tables 3–5. The reference points derived from these models are based on different measures of recruitment (eggs, smolts, finnock or all maidens) and use different definitions of 'productive' area. It is thus difficult to compare reference points for sea trout in each system.

The river systems differed considerably in their physical characteristics and the life-history characteristics of the sea trout they produce. The Åvaån, for instance, is a very small stream whereas the Dee is a large river system with considerable areas of salmon habitat. Work carried out on the Burrishoole and the Bresle, in contrast, has allowed the examination of catchment-scale stock-recruitment relationships – one for a lake-river system (the Burrishoole) and one for a river-only system (the Bresle). In both of these cases, the authors drew attention to the difficulties in considering the effects of non-anadromous trout and other fish species (principally salmon) (Milner *et al.* 2006). In the case of the Shimna River, Kennedy *et al.* (2017) did attempt an estimate of potential egg deposition from resident trout, but still cautioned their use due to the unknown levels of residency and anadromy in the respective offspring.

5.5.4 Freshwater production

Relatively few data exist detailing time series of smolt production values from individual rivers. There was a range in values presented and correcting for wetted area, or available habitat, did not yield a consistent value that could be applied between rivers. Likely factors influencing the level of smolt production per unit area are:

- Amount of available habitat, small habitats tend to have higher production per area. Lower rates are typical of catchments with large areas of deep lakes or rivers with a lot of typical salmon habitat such as the Dee.
- The abundance and relationship with non-anadromous “freshwater resident” trout.
- Differences in life history characteristics of trout.

5.5.5 Stock recruitment models

Three stock recruitment models were applied to the data from nine rivers across Europe. However, not all the rivers had the same data available. For example:

- Only three rivers had time series of total smolt counts (Burrishoole, Erriff, Bresle)
- Four rivers had partial smolt counts (Högvadsån, Åvaån, Dee, Tamar)
- Two rivers had smolt numbers estimated from other data such as fry abundance (Shimna, Lune).
- The data for the Högvadsån did not include adult size or fecundity so there was no estimate of ova deposition, this dataset was subsequently deemed unreliable.
- The data for the Åvaån which is a small stream, included years following significant fish kills. This likely led to unusually low smolt production data seta against relatively high spawning stock in at least three or four years.
- The River Dee data included annual estimates of ova deposition, and recruitment as 0+ sea age maidens (finnock), and total maidens (.0+ & .1+ sea ages) as proxies for smolt production. To estimate actual smolt production from these relationships would require knowledge of the rates of marine return from smolt output on an annual basis.
- Two datasets were available for the Shimna river. The data ova-to-smolt were derived from counter, rod catch and electrofishing estimates and were deemed less reliable than those using rod catch CPUE as a proxy for stock and density of 0+ fry as a measure of recruitment.

It seems likely that while the data for individual rivers can be modelled to provide a benchmark for that river against which targets and CL could be set for that river, it is a more complex process, for which the data may not be currently available to support, to establish a multiple river system of transferring BRPs from “donor” index rivers to “recipient” data poor systems in a similar fashion to that of salmon. However, even within the salmon world there appears at least a 10-fold variation in egg deposition rates at MSY – see White *et al.* (2017) and S/R transportation models have been developed around that variation.

Care should be taken to check for Allee effects at low Stock levels and non-stationarity in the data. Temporal variation in the data often occurs with changes in habitat and environment over time. This can lead to different survival rates from Stock to Recruit and will generate "spurious" model outputs. For example, the capacity of a catchment to produce smolts may change with the introduction of commercial forestry, acidification and/or enrichment. Liming, for example, was introduced on the Högvadsån and smolt production rates changed from an average of 7.7 smolts/ha to 65.4 smolts/ha.

A further problem is caused if major events cause specific traumas in the data. For example, a number of fish kills of adults took place on the Åvaån and the corresponding smolt cohorts were "unusually" low in at least three or four years.

5.5.6 Other approaches

The collection of high quality stock and recruit data consistently and on a continual long-term annual basis is difficult and expensive and it is therefore unlikely that many more datasets will become available to support full S/R type setting of BRPs. As we have seen, even with good data collection over considerable time-periods, the models may not be particularly good at fitting the range of data available and the output reference points may be quite localised in their applicability. Therefore, managers have to learn to live with large uncertainties in data and models, and with relying on some degree of expert judgement. A diverse tool kit is needed depending on what kind of data that is available.

Much more feasible is the collection of exploitation data (rod catch, net catch, effort) and index juvenile data and these may prove invaluable in supporting management and conservation of trout, and sea trout in particular. A number of approaches are discussed throughout this report with Trout habitat and juvenile densities (section 4.3), pseudo-stock recruitment based on rod catch (section 5.1; Davidson *et al.* 2017) and Length-Based Indicators, combined with some measure of abundance (Shephard *et al.* 2019; section 4.2).

Sea trout stock characteristics vary between rivers and regions and this diversity poses challenges to developing and applying one or a few models/assessments across the range. A 'one-size-fits-all' option is highly unlikely, but a suite of tools is more promising, especially if they can be targeted towards a relatively small number of sea trout stock groupings. One such grouping has been proposed for 16 sea trout stocks in England and Wales, based on growth rates (fast vs slow) and longevity (short vs long). Such groupings might be used as the basis for focussing stock recruitment or other model approaches, and/or to make recommendations on selecting index rivers.

5.6 Use of genetics in sea trout stock assessment

5.6.1 Use of a genetic database and assignment analysis to explore patterns of straying and potential mixed-stock fisheries: an example from the River Tamar, southern England

Since the late 1990s, DNA markers have been increasingly used in fisheries research as an alternative to traditional tagging studies, and extensive DNA microsatellite databases now exist as baselines for genetic stock identification of Atlantic salmon (e.g. Griffiths *et al.* 2010; Gilbey *et al.*

2018). DNA approaches have potential advantages over traditional physical tagging studies, in that all fish can potentially be included, as any captured fish can be screened for the genetic markers being used. However, molecular approaches do also have drawbacks and the success of DNA-based assignment is dependent on a number of key factors including the number of genetic loci used and their levels of polymorphism, and underlying levels of genetic differentiation between populations (Hansen *et al.* 2001). Additionally, owing to the meta-population structure of many salmonid species, assignment is usually more successful to regional groupings of rivers than to a single river of origin (e.g. Beacham *et al.* 2006). Despite these potential drawbacks, DNA-based approaches have become the method of choice in mixed-stock fishery studies (Ensing *et al.* 2013). To date, however, relatively few studies have been undertaken on European (Koljonen *et al.* 2014; Olafsson *et al.* 2016) and UK fisheries (Griffiths *et al.* 2010; Ikediashi *et al.* 2012; Ensing *et al.* 2013), with even less focusing on recreational, in-river fisheries (Warnock *et al.* 2011).

The River Tamar (southwest England) is one of three of the England Environment Agency's 'Index Rivers' and as such it is subject to intensive monitoring programmes to provide an understanding of salmonid stock and fishery processes, and to improve the wider management of sea trout and salmon. The Tamar monitoring programme includes extensive juvenile electrofishing surveys, the trapping and tagging of smolts during their spring migration and the trapping of returning adults in a trap immediately below a fish pass adjacent to a weir at the tidal limit of the river (Gunnislake). A detailed description of the rod-caught sea trout stock has been produced (Harris 2006) for the River Tamar, where sea trout typically smolt at age two years. The majority of the rod catch involves fish that have returned to the river in the same year that they smolted (known variously as peal, finnock or whitling). Of the repeat spawning fish, a few were found to have spawned up to four times, however, the vast majority had only a single spawning mark (Harris 2006). Temporal variation in the composition of the sea trout run (multiple-spawning fish enter the river early in the year, while peal start to return in July) was also reported.

In the genetic study (King *et al.* 2016) reviewed here, an extensive genetic baseline of microsatellite profiles from resident trout sampled from rivers across southwest England was employed (Figure 10) to address two key questions: 1) Do the rod and line fisheries within the rivers Tamar, Lynher and Tavy (which all flow into the same estuary: Plymouth Sound) represent a mixed-stock fishery, capturing straying fish from other rivers? And, 2) If strays are present, can they be distinguished as either transient/temporary or as potential spawners?

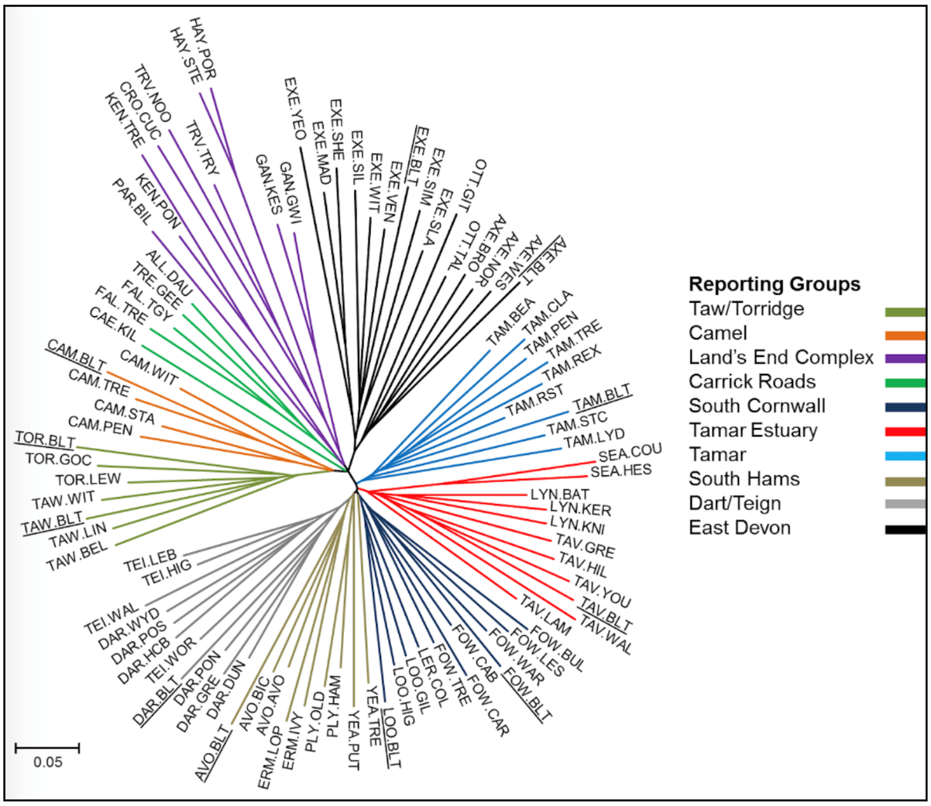


Figure 10. Genetic baseline for assignment analysis: phylogenetic analysis of microsatellite profiles of juvenile (parr) resident trout; sample sites coloured by reporting group.

What did the study find? Mixed-stock analysis of the genetic profiles of more than 1000 sea trout entering the Tamar and Tavy (King *et al.* 2016) showed that the fish constituted mixed stocks (Figure 11), and, as the non-natal fish sampled appear restricted to the lower catchment (Figure 11A, B; Table 7), straying appears to be temporary. While differences in straying rates between life history stages (peal and 1-SW sea trout) do not appear consistent between year classes (Table 11), overall straying rates were approximately equal over the four year-groups of samples analysed to date (peal 14.4%, 1-SW fish 15.4%). As well as providing insight into sea trout behaviour, this study also has important implications for the management of recreational rod and line fisheries.

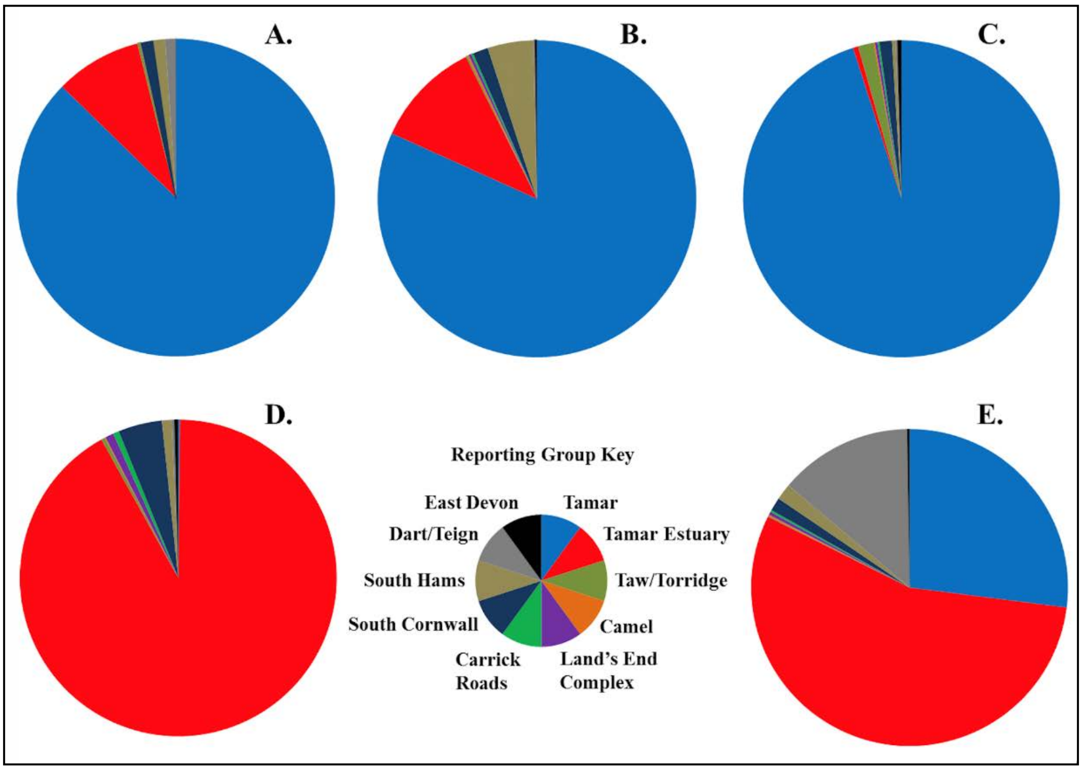


Figure 11. Mean estimated stock composition of sea trout caught in the River Tamar (blue), and the Tamar Estuary (Lynher and Tavy, red); fish were assigned to the reporting groups defined in by phylogenetic analysis (Figure 1). Pie charts show proportions of sea trout: A) trapped at a weir (Gunnislake) at the upper tidal limit (June – August, 2010 and 2011; B) caught in the lower Tamar rod fishery; C) caught in the upper Tamar rod fishery; D) caught in the Lynher rod fishery; and E) caught in the Tavy rod fishery.

Table 7. Total of 3164 fish sexed. All peal and repeat spawning fish genotyped at 19 genetic markers (microsatellite loci) and assigned to the southwest of England baseline (Figure 10).

Year	N_{smolt}	N_{peal}	Strays (%)	$N_{sea\ trout}$	Strays (%)
2010	-	187	27 (14.4%)	188	23 (12.3%)
2011	-	147	12 (8.2%)	105	18 (17.2%)
2015	300	192	22 (11.5%)	162	36 (22.3%)
2016	400	302	55 (18.3%)	97	11 (11.4%)
2017	400	193	31 (16.1%)	91	11 (12.1%)
2018	400	?	?	?	?
Total	1500	1021	147 (14.4%)	643	99 (15.4%)

In light of several recently published, detailed, broad spatial genetic studies of trout undertaken over the last 10 years (Atlantic Aquatic Resource Conservation project, Celtic Sea Trout Project, Living North Sea project, SAMARCH), we are confident that the suitably detailed genetic baselines essential for local genetic assignment analyses of returning sea trout are now available, and are sufficiently detailed to facilitate robust studies of straying rates in other European rivers.

5.6.2 Genetic sexing analysis of trout/sea trout

Accurate estimation of fish sex ratios is essential for the calculation of spawning targets and the biological reference points required for reliable management of salmonid fisheries. Reliable sexing of adult salmonids is generally possible only in the later stages of sexual maturity and is generally based on morphological features. However, use of a non-lethal genetic sexing test allows accurate determination of the sex of salmonid fish at all stages of their life history, from parr to multi-sea winter returning adults.

Ongoing research at the University of Exeter employs a molecular sexing test to estimate the sex ratios of sea trout from the rivers Tamar and Frome in southern England (Yano *et al.* 2013; King *et al.* 2019). Use of a PCR-based, easy to interpret, methodology has facilitated highly accurate determination of the sex of fish at all stages of their life history (Figure 12). Since 2015, molecular sexing of sea trout smolts and adults from the Tamar has enabled data on the sex ratio of trout to be collected (Figure 12). These data suggest female-biased mortality during the months these trout are at sea, with the difference being consistent over time between 2015–2018.

Additionally, samples of Atlantic salmon from the Tamar have been analysed over a similar time frame. These data indicate that the amount of time salmon spend at sea impacts the sex ratio of fish returning to the Tamar. Specifically, studies from 2015–2017 show that 1SW fish had approximately equal numbers of returning males and females, whereas 2SW fish returning to the Tamar showed significant female bias. With more extensive samples of trout from the Tamar, it will be interesting to see whether or not similar trends are apparent.

Looking ahead, additional samples of trout from the Tamar, including samples of returning sea trout from 2018 and smolt samples from spring 2019, will be available for genetic analysis. Furthermore, while currently not as extensive in terms of the life history stages sampled, tissue samples from trout sampled from the river Frome (between 2016–2018) have also been collected and are available for analysis.

Genetic sexing methodology – Molecular sexing is undertaken using a duplex Polymerase Chain Reaction (PCR) approach, using primers that amplify the male-specific sdY (sexually dimorphic on the Y-chromosome) gene along with primers that amplify the fatty acid-binding protein 6b (fabp6b) gene. The fabp6b gene acts as a positive control and is amplified in both male and female samples; fabp6b primers amplify products of ~450 base pairs (bp), whereas the sdY primer amplifies products of 713 bp in male fish only. The difference in length of these fragments allows products to be visualised and distinguished on ethidium bromide-stained 1.8% agarose gels. Typically, each group of amplifications includes a negative water-only control and two positive controls, one from a confirmed male and one from a confirmed female fish.

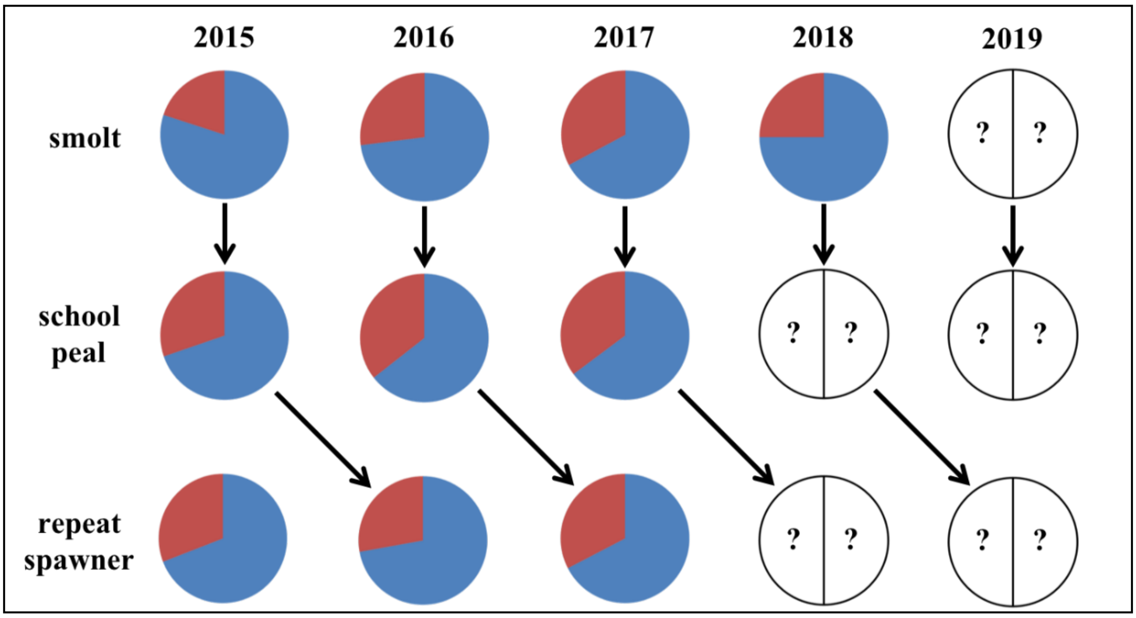


Figure 12.Changes in sex ratio for different cohorts of sea trout sampled from the River Tamar. Black arrows link different life history stages of the same cohort of fish. Blue sectors represent the proportion of female fish; red sectors represent the proportion of male fish. White sectors represent year groups for which samples have been acquired and which remain to be analysed.

5.6.3 Future genetic research applications

Genetic tools can be used for the assignment of fish sampled at sea to river of origin (requires detailed local genetic baseline); the estimation of age-specific straying rates (requires estimation of fish age and information on location of capture of adult sea trout); and, the analysis of mixed-stock fisheries for stock discrimination, although this requires info on location of capture and detailed local genetic baseline.

Sex ratio data can be used to enhance BRPs for trout/sea trout in target rivers that would be useful in management and conservation of trout stocks. This would require tissue samples from life history stages of interest. It could work with fresh tissues and, critically, also with dried scales, facilitating the estimation of historical sex ratio data, allowing time series analysis of changing sex ratios over time. By calculating sex ratios for different life history stages through time, one can provide insights into differential mortality between sexes, e.g. possible female-biased marine mortality of Tamar sea trout.

5.7 ToR summary

To summarize, S/R relationships using data counts, returning stock estimates, catches, and juvenile abundance surveys for sea trout populations within catchments were explored by applying several curve fitting approaches (including Beverton-Holt, Ricker, Hockey Stick). These relationships could potentially be used as a Biological Reference Points (BRP) for sea trout but no single model/curve was shown to be a universally good fit for all catchments; instead a suite of tools may be more promising, especially if they can be grouped around a relatively limited number of possible stock recruitment relationship. The challenges of developing and applying a BRP approach to sea trout throughout Europe is proposed to be a major task for the next WG term.

6 General Discussion

6.1 Future Work

The WG has developed a list of knowledge gaps and associated research requirements: these can be grouped under themes such as life history, assessment of state, management of impacts; climate change, ecosystem services and socio-economics.

The overview of S/R related data and models for sea trout stocks revealed a mix of different data types and reliabilities, and no one model appears to suit all. It is likely that suitable BRPs may be definable for individual stocks, often in conjunction with other methods, such as rod catch related pseudo S/R analysis. It seems less likely that a system transferrable from one river to the next, similar to salmon, will be easy to achieve.

A number of issues have been identified that may impact on the ability to set reliable BRPs and these are also discussed in Thornton (2008), Walker *et al.* (2006), Poole *et al.* (1996), ICES 2016 and elsewhere in this report.

One of the issues that is regularly raised in relation to setting a S/R relationship for trout in a catchment is the unknown interaction between anadromous and freshwater-resident forms. This is likely to be quite catchment-specific and depend largely on the proportion and size of the resident stock, and the size/fecundity of the resident fish. Pragmatically, it may be less of an issue on rivers with a strong sea trout component. For example, some simulations (Milner unpublished) indicated that resident trout, even in the most favourable scenarios, were likely to make a relatively minor contribution to total egg production in systems where sea trout were prominent.

The principal biological issue stems from the species having two broad life-history types – the anadromous sea trout and the freshwater resident trout. In fact, many authors would argue that life-history tactics cannot be classified solely as anadromous or fresh-water resident, but rather as a continuum of life-history tactics in space and time (Ferguson *et al.* 2017, 2019). This idea is based on the principle that migration is likely to be a trade-off between costs and benefits of the environment, regardless of the distance and environment travelled (Cucherousset *et al.* 2005). This results in considerable variability in life-history tactics among individuals and populations of trout, with a number of different migration patterns. Differences between the sexes occur, with males typically having a higher tendency to remain in the natal river, and females more likely to migrate to sea (Cucherousset *et al.* 2005). This indicates that large body size typically gives a larger fitness gain in females than males, although this varies among rivers as revealed by the large variation in sex ratio among the migratory and resident population components (Nevoux *et al.* 2019). The most fundamental difference among river systems appears to be the presence or absence of lakes. Lake habitat tends to offer more options for residency and possibly in some cases less incentive for marine migration because of improved growth opportunities along with reduced migration costs. This may also apply to larger, deeper rivers more typical of Atlantic salmon.

It is likely that a single BRP for trout is unlikely to meet all proposed management objectives, primarily because of the complexity of the trout's lifecycle, but also because of the way in which monitoring data are currently collected.

The data required to develop and use BRPs may not be matched by the current monitoring programmes. This review has highlighted a number of data shortfalls:

- Data on rod catches, or stock levels, of freshwater resident trout are largely lacking.
- Rod effort data are currently relatively crude and may be combined for salmon and sea trout, or missing altogether.
- Age data collected during routine juvenile surveys are limited, or missing, in many areas.
- Freshwater age structure of trout is likely to be a key factor in understanding the causes of anadromy and distribution of anadromy within individual catchments
- Different management systems for anadromous, and freshwater-resident trout, across Europe can lead to inconsistences in the data available for sea trout.

6.1.1 Future Research

The WG has identified the following future research requirements, noting that international collaboration should continue to be pursued in order to maximise opportunities and expertise:

- Establish an objective baseline of trout distribution (both resident trout and anadromous morphs) across Europe.
- Continue to promote collaborative research into the causes and relative incidence of anadromy. Understand the role of temperature, and implications of climate change on anadromy.
- Further understand genetic diversity of trout stocks.
- Investigate the possibility of developing regional versions of the HabScore models based on region-specific reference sites.
- Investigate historic time series of data for calibration sites used in the original HabScore models to determine whether these are truly representative of 'pristine' conditions.
- Investigate differences in mean smolt age and the suggested trend towards increased production of younger smolts. Link to implications of climate change.
- Investigate feasibility of developing a model to provide annual estimates of exploitation for sea trout.
- Provide ongoing data into the sea trout database on annual descriptors such as exploitation, marine survival, smolt production etc.
- Carry out further investigation of a wider set of river characteristics with the aim of de-fining a subset of variables accounting for the greatest between-rivers variance of sea trout catch.
- Carry out further analysis of index river data. For example, examine more closely the S/R models:
  - Transfer functions – what explains the S/R relationship and between-river variance. Both shape of S/R relationship and variance around it (degree of environmental stochasticity). What kind of variables, river or population characteristics, do we need to do this job well? Lakes, salmon or not, predators, smolt age distributions, proportion of residency, resource availability etc.
  - What type and amount of data are required for setting a BRP for a trout population?
  - Any (missing) info that would improve the reliability of our models, such as temporal variation in catch effort? Better and standardized reporting of catches, catch effort, size and age data, local fecundity data etc.

- What is the value of alternative, and cheaper, data sources? Any bias that may affect the BRP? See also Shephard *et al.* (2018a, 2019) and Davidson *et al.* (2017a)
- Alternative BRPs / management targets. Which to choose depends on data and knowledge.

- Review calibration methods for converting semi-quantitative data to quantitative data. Establish a consistent approach across Europe and consider the use of converted data within the HabScore model where population variance estimates are required.

6.1.2 Future data collection

The WG recommends the following data collections:

- Include stock and recruitment data from more rivers throughout the range. For example, data may already be available from rivers in Norway and Denmark.
- Investigate feasibility of introducing a national licence return system for recording rod catches of freshwater resident trout.
- Investigate feasibility of collecting data on rod effort for salmon and sea trout individually.
- Investigate feasibility of collecting trout length data on a consistent basis.
- Improve quality of age data collected during routine juvenile fisheries surveys.
- What are the key management objectives for sea trout fisheries in different regions; what do managers want the science to assess?
- Establish what level of risk is acceptable to fisheries managers in setting biological reference points for trout.

6.2 New term for WGTRUTTA

The WG wishes to continue this work throughout another 3-year term and has therefore drafted a resolution for this.

Key deliverables within this second term will include:

- The evolution of the sea trout database with data from all involved countries, and its preparation and inclusion as one of the official ICES databases.
- An assessment of stock status in relation to BRPs across Europe (on area or individual stock level).
- The creation of a unified and standardized protocol for sampling juvenile trout and characterizing the respective habitat across sea trout countries.

6.3 Cooperation with other Expert Groups

WGTRUTTA has members who are also members of other EGs addressing assessment and advisory roles for diadromous species, namely the Working Group on Baltic Salmon and Sea Trout (WGBAST), the Working Group on North Atlantic Salmon (WGNAS), the Working Group on Eel (WGEEL) and the WKLIFE. These connections ensure knowledge transfer and efficient use of resources.

The WGTRUTTA has also reported annual progress to the Working Group on Diadromous Species (WGDIAD) that oversees all diadromous fish elements in ICES.

6.4 Cooperation with Advisory structures

Outside of the ICES process, WG members also take part in national data collection activities under the EU's Data Collection Framework (DCF and EU MAP) and associated co-ordinating activities. This also ensures knowledge transfer and efficient use of resources.

6.5 Cooperation with other projects

SAMARCH is an EU-INTERREG France/England Program. The main objective is to inform and develop new policies and training for the managers of the future to improve the management of salmonids in estuaries and coastal waters. Several WG members are also taking part in SAMARCH and thereby ensuring effective knowledge exchange between the initiatives.

RETROUT is a 'Blue Growth' project funded by the EU-INTERREG Baltic Sea Region Program and Roslagens Sparbank Foundation. The main objective is to improve the potential for coastal fishing tourism in the Baltic Sea Region through improved ecological health of the rivers, strengthened governance for fishing tourism and the development of the fishing industry. The WG is working with this project to arrange data exchange.

COMPASS is an EU-INTERREG N. Ireland/Republic of Ireland/Scotland Program. The main objective is to develop a new regional marine monitoring network to investigate emerging areas of environmental concern. The project is also conducting telemetry research on sea trout in the Irish sea to detail regional migration patterns, behaviour, and mortality rates. Data from this project will be exchanged with WGTRUTTA community.

MARGEN II is an EU-INTERREG Sweden/Denmark/Norway Program focussing partly on the marine migratory routes of sea trout as well as their genetics.

6.6 Recommendations

- The WG has identified a range of knowledge gaps and associated research opportunities. The WG recommends developing a network of PhDs to research these topics, and an application within the Marie Curie ETN network action has been sent in to achieve this.
- The WG recommends that a scale reading workshop is convened to calibrate age reading between labs. This would link to the wider ICES workstream of improving data quality.

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Annex 2: WGTRUTTA resolution

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	6–8 February 15–19 October	Copenhagen, Denmark Lisbon, Portugal	Interim report by 1 November to SSGEPD	
Year 2019	25 February – 1 March	Dorchester, UK	Final report by 1 December to SCICOM	

ToR descriptors

	Description ToR	Background	Science Plan codes	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 outmigrating 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.	6.1; 6.2	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 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.	6.1; 6.2	Year 1-3	Evaluation of approaches / methods for modelling sea trout populations, with respect to assessment needs, availability of data, geographical 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).	6.1; 6.2	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.

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.
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 manars to assess the status of stocks and investigate the effects of management actions. 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 WGDIAD regarding diadromous fish stocks, life histories, threats and sustainable use of the resource.
Linkages to other committees or groups	Relevant to HAPISG and EOSG. 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

Annex 3: WGTRUTTA outputs

The WG has disseminated its results through a series of peer-reviewed papers in scientific journals, presentations to international conferences, and interim reports to ICES (published by ICES), as listed below.

Peer-reviewed papers

Shephard, S., Davidson, I. C., Walker, A. M., & Gargan, P. G. 2018. Length based indicators and reference points for assessing data-poor stocks of diadromous trout *Salmo trutta*. *Fisheries Research*, *199*, 36–43. https://doi.org/10.1016/j.fishres.2017.11.024.

Shephard, S., Josset, Q., Davidson, I., Kennedy, R., Magnusson, K., Gargan, P.G., Walker, A.M., Poole, R. 2019. Combining empirical indicators and expert knowledge for surveillance of data-limited sea trout stocks. *Ecological Indicators*, 104; 96–106. https://doi.org/10.1016/j.fishres.2017.11.024

Nevoux, M., Finstad, B., Davidsen J.G., Finlay, R., Josset, Q., Poole, R., Höjesjö, J., Aarestrup, K., Tolvanen, O. & Jonsson, B. (2019). Brown trout *Salmo trutta*: A review of ecological factors affecting abundance and life history of a partly anadromous fish. Fish and Fisheries 20:1051-1082, https://doi:10.1111/faf.12396

Reports

ICES, 2017. Interim Report of the Working Group with the Aim to Develop Assessment Models and Establish Biological Reference Points for Sea Trout (Anadromous *Salmo trutta*) Populations (WGTRUTTA), 24-26 April 2017, Gothenburg, Sweden. ICES CM 2017/SSGEPD:21. 8 pp. Available at: http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGEPD/2017/01%20WGTRUTTA%20-%20Report%20of%20the%20Working%20Group%20WGTRUTTA.pdf

ICES. 2019. Interim Report of the Working Group with the Aim to Develop Assessment Models and Establish Biological Reference Points for Sea Trout (Anadromous *Salmo trutta*) Populations WGTRUTTA), 6–8 February; 15–19 October 2018, Copenhagen, Denmark; Lisbon, Portugal. ICES CM 2018/EPDSG:21. 32 pp. Available at: http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/EPDSG/2018/01%20WGTRUTTA%20-%20Report%20of%20the%20Working%20Group%20with%20the%20Aim%20to%20Develop%20Assessment%20Models%20and%20Establish%20Biological%20Reference%20Points%20for%20Sea%20Trout%20(Anadromous%20Salmo%20trutta)%20Populations.pdf

Presentations

Walker, A.M. and Höjesjö, J. 2017. "WGTRUTTA" Working Group with the Aim to Develop Assessment models and Establish Biological Reference Points for Sea Trout (Anadromous *Salmo trutta*) Populations. Presentation for Session N: Diadromous Fish - Population status, Life histories, Ecology, Assessment, and Management of Poorly Understood Diadromous Fishes, ICES Annual Science Conference, Fort Lauderdale, Florida, USA, September 2017.

Samuel Shephard, Quentin Josset, Ian Davidson, Richard Kennedy, Katarina Magnusson, Patrick G. Gargan, Alan M. Walker, Russell Poole. 2019. Combining empirical indicators and expert knowledge for surveillance of data-limited sea trout stocks. Presentation for Session N: Advances in data-limited assessment methodologies for marine and diadromous stocks, ICES Annual Science Conference, Gothenburg, Sweden, September 2019.

Katarina Magnusson, Johan Höjesjö, Stig Pedersen, Richard Kennedy, Erik Degerman. 2019. Estimating carrying capacity for sea-trout (*Salmo trutta*) fry from electrofishing and habitat characteristics. Presentation for Session N: Advances in data-limited assessment methodologies for marine and diadromous stocks, ICES Annual Science Conference, Gothenburg, Sweden, September 2019.

Annex 4: Questionnaire for Database

QUESTIONNAIRE ON STANDARD SAMPLING METHODS FOR JUVENILE TROUT

One of the objectives of WGTRUTTA is to compile a database with environmental and bioecological information on sea trout rivers across the distribution area. To understand if compiled data is comparable, we first need to have information on regional variability of local standard protocols used for juvenile trout sampling and habitat characterization. For this purpose, we kindly ask you to answer this short questionnaire. We are in the process of finalizing the database this year so would appreciate your answer with 2 weeks. Thank you!

MEMBER NAME: **COUNTRY:**

1. FISH SAMPLING WITH ELECTROFISHING

SAMPLING METHOD: i) whole site [ ]; ii) selected habitats within site [ ]; iii) river sections [ ]

SAMPLING UNIT: i) by area [ ]; ii) by time [ ]; iii) other [ ] specify________________________________

Nº OF ELECTROFISHING PASSES: i) one [ ]; ii) two [ ]; iii) three [ ]; iv) more than three [ ]

USE OF STOP NETS: i) Yes [ ]; No [ ] SAMPLING TARGET: anadromous trout [ ]; resident trout [ ]; both [ ]

PREFERENTIAL SAMPLING SEASON: i) Spring [ ]; Summer [ ]; Autumn [ ]; Winter [ ]

PLEASE DESCRIBE BRIEFLY YOUR STANDARD TROUT SAMPLING PROTOCOL (PROVIDE INFORMATION ON LOCAL OFFICIAL SAMPLING PROTOCOLS (WEB PAGE) IF EXISTENT):

2. HABITAT CHARACTERIZATION

PLEASE PROVIDE INFORMATION ON THE METHODS AND UNITS USED FOR FIELD COLLECTION OF THE FOLLOWING ENVIRONMENTAL VARIABLES:

2.1. CURRENT VELOCITY: i) current meter [ ] units:______; ii) direct observation [ ] classes: _____________________________________; other [ ] specify_______________________________________

2.2. DEPTH: i) graduated pole or probe [ ] units:______; ii) direct observation [ ] classes:______________________________________; other [ ] specify________________________________

2.3. SUBSTRATE: i) granulometric analysis [ ] units:______; ii) direct observation [ ] classes/categories:____; other [ ] specify____

2.4. AQUATIC VEGETATION AND DEBRIS: i) aerial photograph [ ] Units:______; ii) direct observation [ ] classes:______________________________; other [ ] specify____

2.5. SHADE: i) densiometer [ ]; Units:______; ii) direct observation [ ] classes:____________________________________; other [ ] specify___________________________________

2.6. SLOPE – PLEASE DESCRIBE BRIEFLY HOW YOU CALCULATE/ESTIMATE SLOPE FOR YOU SAMPLING SITE: