Scottish Government
Riaghaltas na h-Alba
gov.scot

Assessing the status of Atlantic salmon (*Salmo salar*) from juvenile electrofishing data collected under the National Electrofishing Programme for Scotland (NEPS)

Scottish Marine and Freshwater Science Vol 10 No 2

I A Malcolm, K J Millidine, F L Jackson, R S Glover and R J Fryer

marine scotland

Assessing the status of Atlantic salmon (*Salmo salar)* from juvenile electrofishing data collected under the National Electrofishing Programme for Scotland (NEPS)

Scottish Marine and Freshwater Science Vol 10 No 2

I A Malcolm, K J Millidine, F L Jackson, R S Glover and R J Fryer

Published by Marine Scotland Science
ISSN: 2043-7722
DOI: 10.7489/12203-1

Marine Scotland is the directorate of the Scottish Government responsible for the integrated management of Scotland's seas. Marine Scotland Science (formerly Fisheries Research Services) provides expert scientific and technical advice on marine and fisheries issues. Scottish Marine and Freshwater Science is a series of reports that publishes results of research and monitoring carried out by Marine Scotland Science. It also publishes the results of marine and freshwater scientific work that has been carried out for Marine Scotland under external commission. These reports are not subject to formal external peer-review.

This report presents the results of marine and freshwater scientific work carried out by Marine Scotland Science.

Assessing the Status of Atlantic Salmon (*Salmo salar)* from Juvenile Electrofishing Data Collected Under the National Electrofishing Programme for Scotland (NEPS)

I A Malcolm, K J Millidine, F L Jackson, R S Glover and R J Fryer

Marine Scotland Science, Freshwater Fisheries Laboratory
Faskally, Pitlochry, PH16 5LB

Executive Summary

Atlantic salmon (*Salmo salar*) are a species of high cultural, conservation and economic importance that are worth ca. £80 million per annum to the Scottish economy. Quantitative and scientifically defensible assessments of population status are required to inform evidence based fisheries management across a range of spatial scales. Juvenile electrofishing data are one of the most commonly collected sources of information on the status of Atlantic salmon in Scotland. However, their interpretation is fraught with technical challenges that include the need to 1) estimate salmon densities from electrofishing count data 2) develop a suitable "benchmark" against which to compare observed densities 3) obtain appropriate (representative) annual monitoring data 4) develop approaches that allow site-wise estimates of observed and benchmark densities to be scaled to larger areas. This report presents an approach for assessing the status of Atlantic salmon in Scotland from juvenile electrofishing data. Observed salmon counts were obtained from the National Electrofishing Programme for Scotland (NEPS), an unequal probability Generalised Random Tessellation Stratified (GRTS) survey design with 27 strata (assessment regions). Capture probabilities were modelled from available multi-pass electrofishing data collected between 1997 and 2018 and used to predict densities of salmon fry and parr for 1-pass and 3-pass NEPS electrofishing sites. Observed abundances from NEPS were then compared to a recently published juvenile salmon density benchmark at site, catchment, regional and national scales to determine salmon performance and status. A rule based approach was used to classify regional electrofishing data into three grades based on performance against the Regional Benchmark and uncertainty in the mean observed regional densities. Further work is required to investigate, and where possible harmonise, the outputs of this juvenile assessment approach with existing adult based assessment methods used to classify the status of Scotland’s salmon rivers under Conservation Regulations. A number of future developments are identified to improve models of capture probability and benchmark density. Future developments of NEPS should consider current and future monitoring requirements at national and local scales, alongside available resources to improve the overall survey design.

Introduction

Atlantic salmon (hereafter salmon) are a diadromous species of high economic, conservation and cultural importance that are protected by international management agreements (North Atlantic Salmon Conservation Organisation; NASCO) and legislation at national (The Conservation of Salmon (Scotland) Regulations) and international scales (The European Commission Habitats Directive, 92/43 EEC). Scotland is an important stronghold for wild salmon populations accounting for ca. 75% and 30% of UK and EU wild Atlantic salmon production respectively (ICES, 2016). These populations support recreational fisheries estimated to be worth ca. £80 million per annum to the Scottish economy (PACEC, 2017).

The abundance of salmon returning to home waters has declined across much of the species range over the last 50 years (Chaput, 2012; ICES, 2018). Early reductions in abundance were at least partially offset by reductions in exploitation from coastal, estuarine and in-river fisheries (e.g. Gurney et al., 2015). However, adult numbers have continued to decline in recent years raising concerns that this could affect current and future salmon productivity without further management action.

Evidenced based fisheries management requires defensible, quantitative assessments of population status. Electrofishing data are one of the most commonly collected sources of information on the status of salmon with the potential to provide assessments at nested spatial scales ranging from individual sites, to sub-catchments, catchments, regions or whole countries. However, these data are more frequently used to illustrate trends in abundance than status. Status assessments are associated with a number of technical challenges including 1) estimation of total salmon abundance from electrofishing data 2) development of a suitable “benchmark” for expected densities, against which observed densities can be compared 3) design and implementation of an appropriate (spatially balanced, unbiased, representative) monitoring programme to determine salmon numbers 4) development of approaches that allow site-wise estimates of abundance and the benchmark to be scaled to larger areas i.e. catchment, region or whole country

These technical challenges are addressed in the current report, which presents an approach for assessing the status of salmon populations at nested spatial scales by comparing data collected during the first year of the National Electrofishing Programme for Scotland (NEPS) with a recently published juvenile salmon benchmark (Malcolm et al., 2019). The specific objectives of the report are to:

- Describe the NEPS survey design method
- Present NEPS data in the context of hydrological and climatological conditions observed during summer 2018
- Model capture probability for the electrofishing dataset using historical and contemporary data
- Estimate salmon densities from single and multi-pass electrofishing data collected under the NEPS programme
- Scale-up estimates of juvenile abundance from site to regional and national scales
- Compare observed juvenile densities to benchmark densities at site, regional, catchment and national scales
- Outline a 3-level grading system that would combine assessments of fry and parr, potentially allowing juvenile electrofishing data to complement the existing adult based assessment in determining Conservation Status
- Discuss future work requirements

Materials and Methods

The National Electrofishing Programme for Scotland (NEPS)

In common with many large-scale long-term monitoring datasets, Scotland's historical electrofishing data have evolved over time, been collected for a variety of reasons and not typically been generated using any formal sample design. As such these data suffer from major limitations that constrain their usefulness in assessing the current status of salmon populations. These constraints are concisely articulated by Dobbie e*t al* (2008):

"Methods for sampling environmental resources have often been fairly ad hoc. Convenience sampling has often been used, and appeals to expert knowledge to choose sample locations with easy access or that may be originally useful for other purposes. A key complication of convenience sampling that arises is that the relationship between the sample data and population characteristics of interests is not known, and the basis for extrapolation and inference is therefore necessarily unclear".

Put simply, it is unclear how to relate ad-hoc samples to the wider population of interest and thus whether the data obtained from these sites can be considered more broadly representative. This determines that in the case of ad-hoc sampling it is not possible to reliably extrapolate from a group of sites (e.g. electrofishing sites) to the wider population (e.g. the river as a whole). In contrast, NEPS was designed by scientists at Marine Scotland to provide a well-defined, representative sampling scheme that allows for unbiased estimation of juvenile salmon density at nested spatial scales.

NEPS uses a Generalised Random Tessellation Stratified (GRTS) survey design, an approach developed in support of the United States' Environmental Monitoring and Assessment Program (US EMAP). In recent years, improvements in spatial data, computing power and particularly software (Kincaid *et al.,* 2018), have facilitated the use of GRTS for survey design on river networks, allowing for design-based analysis of the resulting data. GRTS designs provide spatial balance with a stochastic component, i.e. the samples cover the region of interest, but also incorporate randomness in the site selection, thereby striking a balance between systematic and random sampling. GRTS sample designs also allow for dynamic adjustment to sample sizes (it is possible to increase or decrease sample sizes while maintaining design integrity), variable inclusion probability (can increase probability of sampling particular locations), stratified sampling (sample intensity can vary between strata e.g. regions) and the ability to replace sites that cannot be sampled (non-response) with oversamples to maintain an overall target sample size.

The first stage in sample design involves specifying the “sample frame”. This is a spatial representation of the population of interest, in this case Scottish rivers which contain a fishery for salmon (that are assessed for Conservation Regulations) and are possible to sample by wading and electrofishing. In an ideal world the sample frame would be an exact spatial representation of the target population. This might be possible if there were detailed spatial data on river depths and velocities and a complete map of impassable barriers to fish migration. However, such information is not currently available for Scotland. As such, it was necessary to define the sample frame as accurately as possible given available national spatial datasets. Consequently, the sample frame resulted in both under (e.g. rivers that could be sampled but are excluded) and over coverage (e.g. rivers that appear in the design but are not possible to sample). A summary of the GRTS survey design process, including delineation of the sample frame is illustrated in Figure 1. The sample frame was defined using the following approach:

1. Spatial polygons representing the outline of river catchments assessed under the Conservation Regulations (i.e. those containing a fishery for salmon) were overlain onto the digital river network (DRN). Only rivers inside these polygons were retained
2. Smaller Hydrometric Areas (HA: single large rivers or groups of smaller rivers) were combined into larger spatially continuous units until there were no areas < 950km^2. This resulted in 27 GRTS Regions that would form strata for the sample design (see below)

3. Strahler river order one rivers were removed as they often dry up during summer months and very rarely contain salmon
4. River orders 5 and above were removed as they are often > 25m wide, beyond which electrofishing is considered to be extremely challenging
5. Any rivers identified as above impassable barriers (Obstacles to fish migration dataset; SEPA 2019) were removed as these rivers would be inaccessible to salmon
6. Lochs were removed
7. Having defined the sample frame, density predictions were made for each river node (the junction between river lines e.g. confluences) using the national juvenile salmon density benchmark model (Malcolm *et al.,* 2019). These could be used to weight sample selection in the survey design alongside other potential weighting variables such as river width
8. Finally, the R package "spsurvey" (Kincaid *et al.,* 2018) was used to generate the survey design. The final design was a stratified unequal probability GRTS design for survey over time with an oversample. The 27 GRTS regions formed the strata for the design with an equal number (but not density) of samples in each region. A variety of weightings were explored including fish density, river width and juvenile production (density * width). Unfortunately, the river width data proved to be too unreliable to provide a useful weighting. This was due to spatial differences in the scale of data capture that resulted in river polygons becoming line features at different minimum widths, and the presence of lochs within or close to the DRN that confused channel width estimates. These data limitations resulted in particular sections of river receiving inappropriately high or low weightings that would have negatively impacted the overall survey design. Consequently, only fish density predictions were used to weight the final design

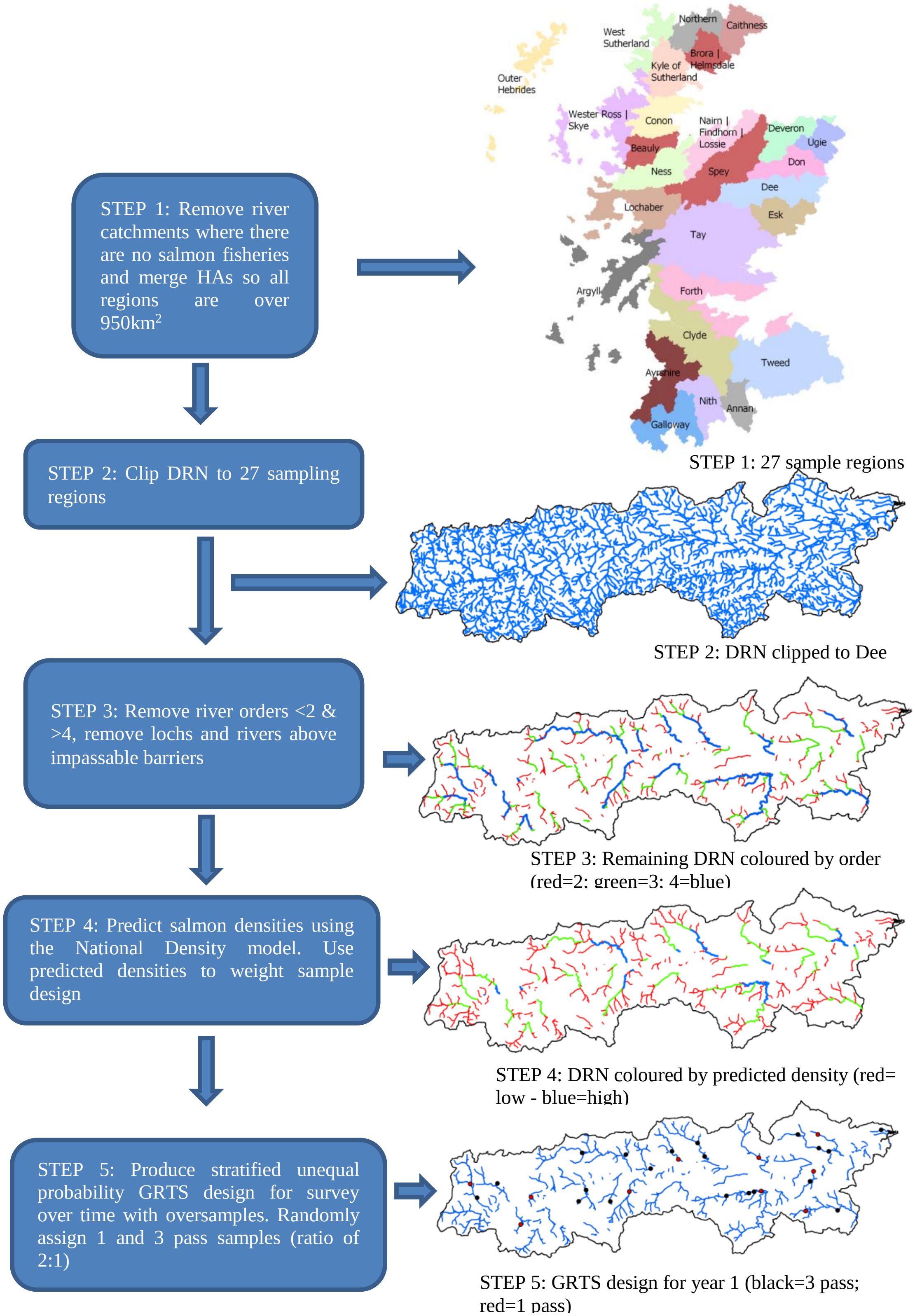


Figure 1 Schematic illustrating the GRTS design process

The NEPS survey was designed to operate over a period of up to 9 years and to strike a balance between spatial coverage and trend detection. It consisted of three "panels" (annual, 3 year, 9 year), with each panel containing 10 samples per year (30 samples for each GRTS region in each year). The annual sample panel was designed to be repeated every year (the same 10 sites are fished every year). The 3 year panel (containing 30 samples) was designed to rotate on a three year return interval, with the first 10 samples sampled in year one, the second 10 samples in year two and the third 10 samples in year three. In year four, the first 10 samples would then be sampled again and so on. The 9 year panel (90 samples) functioned in the same way as the 3 year panel, but over a period of 9 years. Where desired, local biologists could fish > 30 sites by bringing additional panels into the sample, although in practice this did not occur.

Electrofishing data (2018)

Funding for data collection was provided by Marine Scotland (£205K), SEPA (£66K) and SNH (£63K). Electrofishing was undertaken by local fisheries managers (see Marine Scotland, 2019a) following standard operating procedures developed by Marine Scotland Science in consultation with the Scottish Fisheries Coordination Centre (SFCC). All electrofishing data were area delimited. In each region, ten of the 30 sites were randomly selected to be fished using a 3-pass (depletion or quantitative) protocol, while the remaining 20 sites were fished using a single pass method. The effort expended on the first pass of the multi-pass electrofishing and the single pass electrofishing was expected to be the same. It was intended that sampling should be completed between 01 July and 30 September, with data entry and QC completed by the end of October. This was considered to provide a large enough window for data collection, while at the same time minimising the effects of temporally varying survival and thus densities. Such time scales were also intended to allow for analysis and reporting of data by the end of March 2019.

Full details of the data collection protocols are provided in Appendix 1. However, in brief, electrofishing was carried out in an upstream direction working methodically from bank to bank covering the whole wetted area with equal effort. Electrofishing was performed with a minimum team size of two people. Where rivers were <10m there was a requirement to use stop nets for 3-pass electrofishing sites. Where rivers were >10m wide the use of stop nets was optional depending on practical considerations. The minimum size of electrofishing sites was $100m^2$ or 50m in length (for small streams). In the event that sites were inaccessible or too deep to fish, field teams were permitted to move up to 50m in an up or downstream direction until the first suitable location. This reduced the risk of traveling long distances to a site that was not fishable (low resource efficiency), while also minimising risks of introducing biases in site selection towards more favourable locations, a problem with traditional electrofishing data. The number of fish caught on each run was recorded. Salmonid fry (0+) and parr (>0+) life stages were visually assessed in the field based on size. The fork length of all parr were measured to the nearest mm, a sample of up to 50 fry per run were also measured. Some data providers chose to measure all salmonids. Scale samples were taken from all parr, or where there was uncertainty over life-stage allocation. Genetic samples were obtained from up to 30 parr at each of the multi-pass electrofishing sites to assess genetic introgression (not reported here). All fish were returned to the reach after electrofishing was completed. Basic habitat data were also recorded at each site (% substrate and flow type) and water quality samples were taken to allow future improvements to capture probability and benchmark density models. These data are not reported at this time. Data were stored in both the SFCC and Marine Scotland Fish Observation (FishObs) databases.

Fish Data Processing

Unfortunately the SFCC database was not capable of unambiguously storing the electrofishing data. Nor was it possible to obtain direct access to the database for bespoke queries and pre-programmed queries were incapable of generating suitable outputs. It was therefore necessary to develop R scripts to reformat raw data exports (individual fish) into appropriate data summaries for analysis (see Appendix 2 for details). An R script was also written to re-format data from FishObs into a common format that matched the restructured SFCC data and met the data structure requirements of capture probability and juvenile density modelling. However, this process was considerably simpler given the structure of the FishObs database and the ability to write bespoke export queries.

Generation of covariates for electrofishing sites

GIS proxies for habitat (gradient, altitude, river distance to sea, % conifer in riparian zone) are required as predictor variables for both the capture probability and benchmark models (Malcolm *et al.,* 2019). Covariates were generated using an in-house R package (FFL GIS) for every node on the GRTS DRN and for all electrofishing sites following the methods described by Jackson *et al.* (2017) and Malcolm *et al.* (2019) where further details can be found.

Estimating capture probability

Capture probability was estimated following the methods described by Millar *et al.* (2016) where full details can be found. The capture probability model described by Malcolm *et al.* (2019) was re-fitted to a combined dataset that included all multi-pass electrofishing data collected across Scotland between 1997- 2015 and the new data collected as part of NEPS in 2018. In brief, capture probability was modelled as a logistic function of covariates representative of people and equipment (Organisation), fish size and behaviour (life-stage and electrofishing pass / run), time (Year and Day of the Year, DoY), habitat (Upstream Catchment Area, UCA; River Distance to Sea, RDS and Gradient) and geographical region (Hydrometric Area, HA). In contrast to previous analyses, Organisation was further divided into time periods to reflect major changes in staffing within organisations. These staff changes were identified from a rapid visual assessment of staff names / abbreviations identified in the SFCC database. Unfortunately it was not possible to undertake a more automated analysis of staff changes due to the various different ways in which the same individuals were recorded in the database (e.g. abbreviated name, full name, capitalisation, etc.) that would have required significant time to harmonise.

Estimating site-wise (observed) salmon densities

Fish densities were estimated for each of the electrofishing sites following the methods described by Glover *et al.,* (2018) and Malcolm *et al.*, (2019) where further details can be found. However, in brief:

$$Estimated\ density = \frac{\sum count_{pass\ n}}{site\ area * Pcum}$$

where

$\sum count_{pass\ n}$ is the total fish counts across all passes

and

$$Pcum = 1 - (1 - P_1) * (1 - P_2) * (1 - P_3)$$

is the cumulative capture probability across all passes (in the example above 3 passes) and P_n denotes the fitted capture probability for pass n (where n can be pass 1,2,3).

Site-wise benchmark densities

Site-wise assessments of status are useful for local fisheries management because they can be used to identify spatial variability in performance that can be used to guide management e.g. through a fisheries management planning process.

Benchmark densities were calculated for each electrofishing site using GIS derived habitat proxies (see covariate generation above) and the national juvenile salmon density benchmark model reported by Malcolm *et al.* (2019) where further details can be found. In brief, the national juvenile salmon density model was based on >3800 electrofishing observations collected between 1997 and 2015. In broad terms the Benchmark predictions represent the average expected density for a particular site given its GIS derived "habitat characteristics" and the underlying salmon density dataset. However, in more detail, the benchmark model excludes purely spatial effects (which can reduce expectations in the urbanised central belt of Scotland) and negative effects of conifer woodland (thought to relate to commercial conifer plantations). As such, the benchmark densities reported here are similar in concept to "intrinsic habitat potential" reported elsewhere (e.g. Burnett *et al*., 2007) and could be thought of as the salmon densities that you would expect to see on average in a "healthy" river catchment , given good levels of egg deposition, in the absence of major anthropogenic pressures. Benchmark densities were calculated separately for fry and parr life-stages.

Scaling benchmark densities to region

Several approaches were explored for scaling benchmark performance indicators from sites to larger spatial scales. In principle, if reliable and spatially consistent river width data were available and it was possible to scale between field observed wetted areas and GIS derived river widths, it would be possible to obtain an estimate of total juvenile salmon fry and parr production for the sample frame (i.e. river orders 2-4, below impassable barriers). However, spatially consistent GIS derived river width data were not available (see NEPS above) and it was not possible to readily define appropriate scaling factors to convert between observed wetted widths and GIS derived widths. It was therefore concluded that mean density per unit length of sample frame would provide the most appropriate benchmark that could be directly compared with field observed data.

The regional scaled benchmark was estimated as:

$$Regional\ Benchmark = \frac{\sum exp\left(\frac{USN + DSN}{2}\right) * edgelength}{\sum edgelength}$$

where USN and DSN are the log density estimates for the benchmark at the upstream and downstream end (node) of each river line feature (edge) in the DRN and edgelength is the length of each line feature (m).

Scaling site-wise observed densities to region

The R package “spsurvey” was used to both design and analyse data from the NEPS monitoring programme. Sample weights were adjusted to reflect the final list of sampled locations (i.e. removing sites that were not sampled and including replacement oversamples). Analysis was conducted using the “cont.analysis” function for continuous data. Separate analyses were performed for fry and parr. The response variable was the site-wise observed densities (n m^{-2} wetted area). Wetted area densities were chosen as these provided greatest consistency with the benchmark. The “cont.analysis” function estimates the mean observed density (per unit length) in each strata (GRTS region) and at the national scale, together with associated 95% confidence bounds.

Generating regional status assessments (grades)

Since 2016, Scottish rivers have received one of three grades during the Conservation Status Assessment. These grades are based on the probability of meeting a spatially varying egg deposition target indicative of maximum sustainable yield (Conservation Limit). Results are averaged over a 5 year period to prevent any single poor year from bringing down the status of the river (Marine

Scotland 2019b). The grades are associated with particular management advice (Table 1). Importantly category 3 rivers (the poorest grading) are associated with compulsory catch and release.

Category	Advice
1	Exploitation is sustainable therefore no additional management action is currently required. This recognises the effectiveness of existing non-statutory local management interventions.
2	Management action is necessary to reduce exploitation: catch and release should be promoted strongly in the first instance. The need for mandatory catch and release will be reviewed annually.
3	Exploitation is unsustainable therefore management actions required to reduce exploitation for 1 year i.e. mandatory catch and release (all methods).

Table 1 Conservation grades and associated advice

It is similarly possible to obtain status assessments for both fry and parr juvenile life-stages by comparing the regional estimates of mean salmon density (per unit length) obtained from the GRTS sampling, with the benchmark regional densities scaled up from the DRN. There are many ways of defining the grades, but the following is a pragmatic approach. Firstly a grade is obtained for each life-stage using the following rules, which are also illustrated in Figure 2:

- Category 1: The mean observed density exceeds the benchmark and the lower 95% confidence limit does not include zero.
- Category 2: The mean observed density exceeds the benchmark, but the lower 95% confidence limit includes zero (mean observed density estimate is extremely uncertain), or the mean observed density is less than the benchmark but within the 95% confidence limits
- Category 3: The upper 95% confidence limit of the mean observed density is below the benchmark

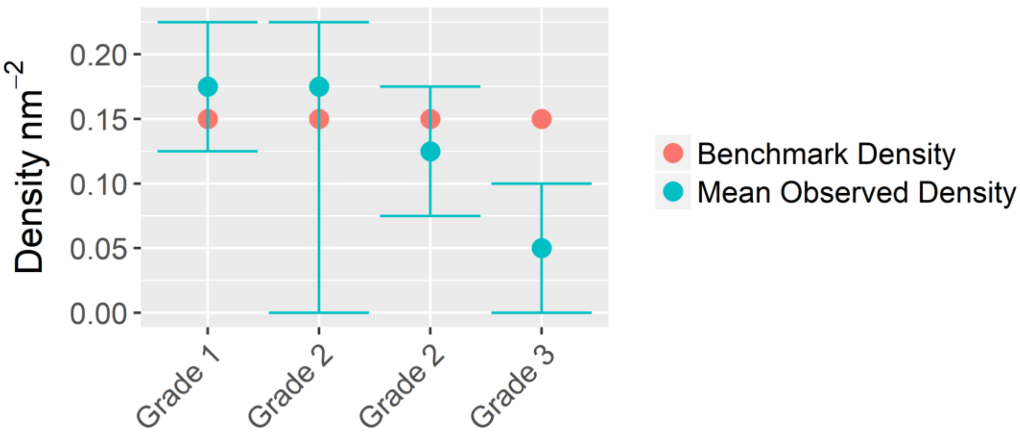


Figure 2 Theoretical scenarios under which a region would be classified as Grade 1, 2 or 3.

Next, the grades for the two life-stages are combined to provide a single grade for the juvenile assessment method. Given the desire to avoid status downgrades based on a single poor year of data, the combined status would favour the better of the two assessments (Fig. 3)

		Fry		
		1	**2**	**3**
Parr	**1**	1	1	2
	2	1	2	2
	3	2	2	3

Figure 3 Matrix showing the rule-based system for generating an overall juvenile status assessment (grading) from individual life-stage assessments. Fry grades run horizontally, parr grades run vertically.

Results

Meteorological and hydrological context

The summer of 2018 (June-August) was dominated by hot and dry conditions that ranked amongst the most extreme since records began in 1910 (CEH, 2018). Many areas experienced lower than average rainfall (Met Office, 2018), particularly the north and north/east of the country where rainfall was <50% of the 1981-2010 average (Fig. 4). This resulted in reduced river flows across Scotland with exceptionally low flows in northern rivers (CEH, 2018, Fig. 5). Rainfall was higher than average in the north and west during September, resulting in high river flows and challenging sampling conditions in the final month of the three month monitoring period.

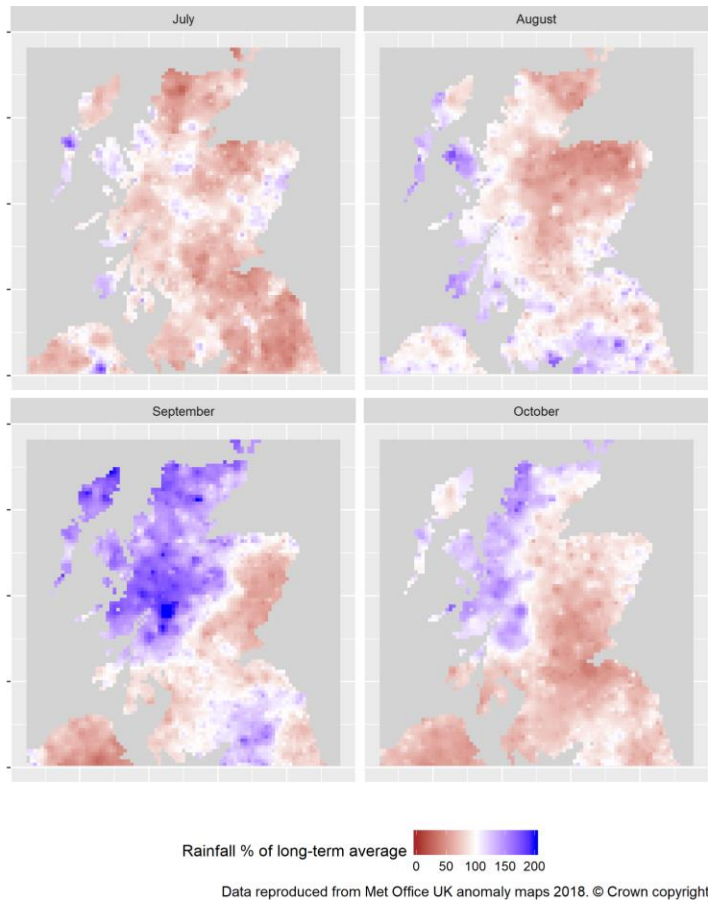
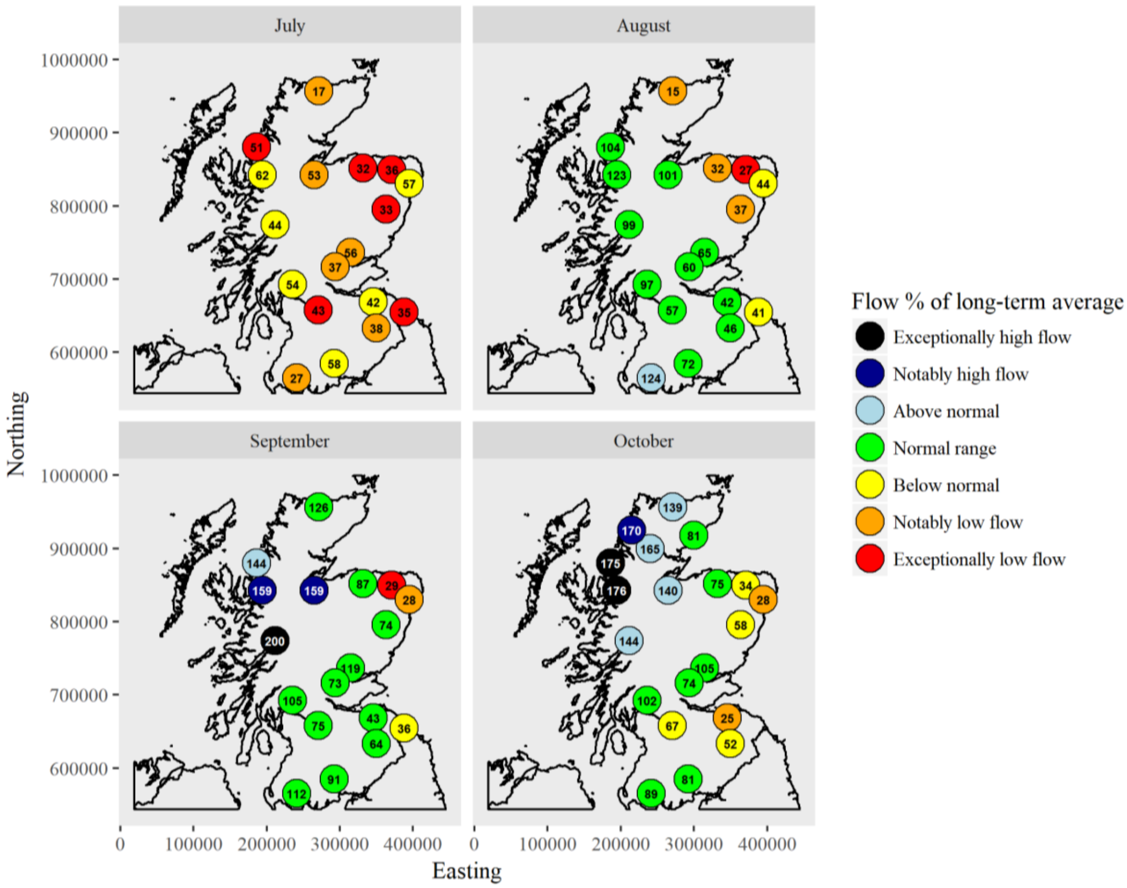


Figure 4 Percentage of long-term average rainfall for July-October 2018 when electrofishing was undertaken. Reproduced from MET Office (2018) UK actual and anomaly maps



Data reproduced from CEH Hydrological Summaries © NERC (CEH) 2018. © Crown copyright

Figure 5 River flows across Scotland during the electrofishing season compared to a 20 year baseline (1981-2010). Colours indicate the 2018 flow ranking relative to baseline years. Numbers indicate the % of baseline flows observed in each river and month. Reproduced from monthly reports produced by CEH (July, Barker *et al*., 2018; August, Hannaford *et al.,* 2018; September, Parry *et al.,* 2018a, and October, Muchan *et al*., 2018).

Electrofishing data collection

NEPS data providers were requested to electrofish between July and September 2018, and to enter data into the relevant databases by the end of October. The final site locations (Millidine *et al.,* 2018) and raw fish count data (Millidine *et al.,* 2019) are available as DOI datasets. Most data providers were able to complete electrofishing, but not always within the requested timeframes (Fig. 6). Although

July and August provided good conditions for electrofishing, September was associated with extremely high flows in the north-west of the country that severely constrained sampling during this period. It was not possible to complete all 30 NEPS electrofishing surveys in the Ness (25 sites completed), Lochaber (26), Wester Ross and Skye (27), Northern (28), Brora Helmsdale (29) or Argyll (29) regions. Additionally it was not possible to complete all the sampling in West Sutherland (20) due to landowner refusal to grant access to the River Dionard.

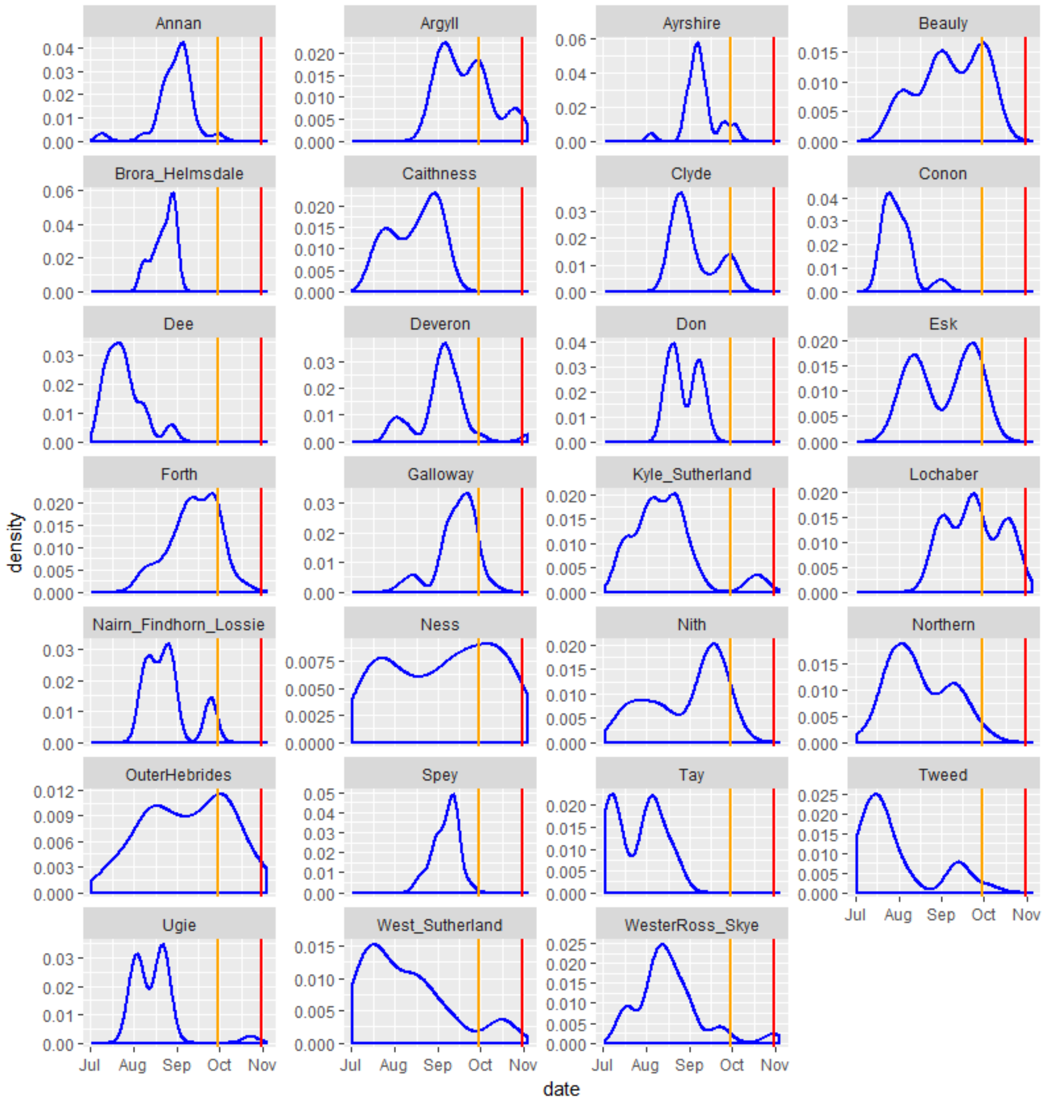


Figure 6 Probability density plots indicating when sites were fished in each of the GRTS regions. Orange line shows the cut-off date for electrofishing. Red vertical line shows the cut-off date for data entry.

Capture Probability

In common with previous studies (Millar *et al.,* 2016; Malcolm *et al.,* 2019), capture probability (*P*) was higher for parr than fry and higher on the first pass than subsequent passes. Capture probability decreased with UCA, RDS and Gradient and showed a modal relationship for DoY. In general, capture probability was lower in the south-west and higher in the north and east of the country. With the exception of 2005, which appears to be a substantial outlier, there is a suggestion of increasing capture probability over the last two decades.

In contrast to previous analyses, Organisation was not represented by a single factor level. Rather, capture probability was allowed to vary with different combinations of personnel and Organisation, i.e. a separate factor was created for each clear combination of Organisation and personnel identified from the SFCC database. Nevertheless, in most circumstances the differences in capture probability between different groups within the same organisation were small relative to differences between organisations e.g. Kyle of Sutherland (KoS) 01-15 vs. KoS 16-18 (Fig. 7A).

Although there were substantial differences in the partial effect of Organisation, care should be taken in interpreting these data as capture probability also depends on geographic region (HA). With the exception of Marine Scotland and SEPA, few Organisations routinely work outside their local area of responsibility. This limits contrast in the dataset and makes it challenging to separate these effects. To address this issue Figure 8 combines the effects of Organisation and HA to provide an overall perspective.

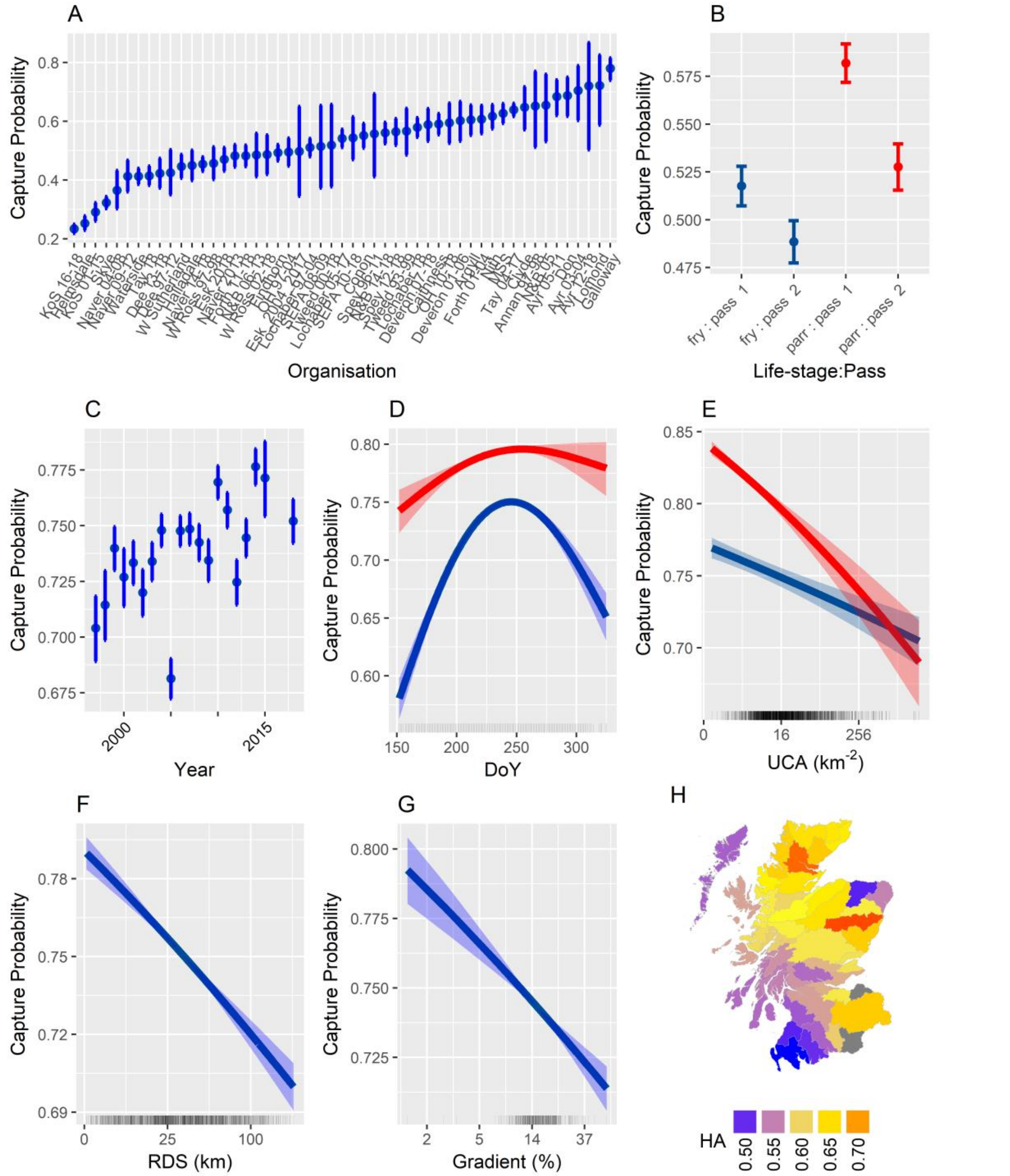


Figure 7 The effects of Organisation (A), Life-stage and Pass (B), Year (C), Day of the Year and Life-stage (D), Upstream Catchment Area and Life-stage (E), River Distance to Sea (F), Gradient (G) and Hydrometric Area (H) on capture probability. Where effects differed with Life-stage they are plotted separately for fry (blue) and parr (red). All effects are scaled to the mean fitted first pass capture probability. Organisation names have been abbreviated. Approximate 95% pointwise confidence intervals are shown as shaded areas or vertical lines. A rug indicates the distribution of the data on the x-axis.

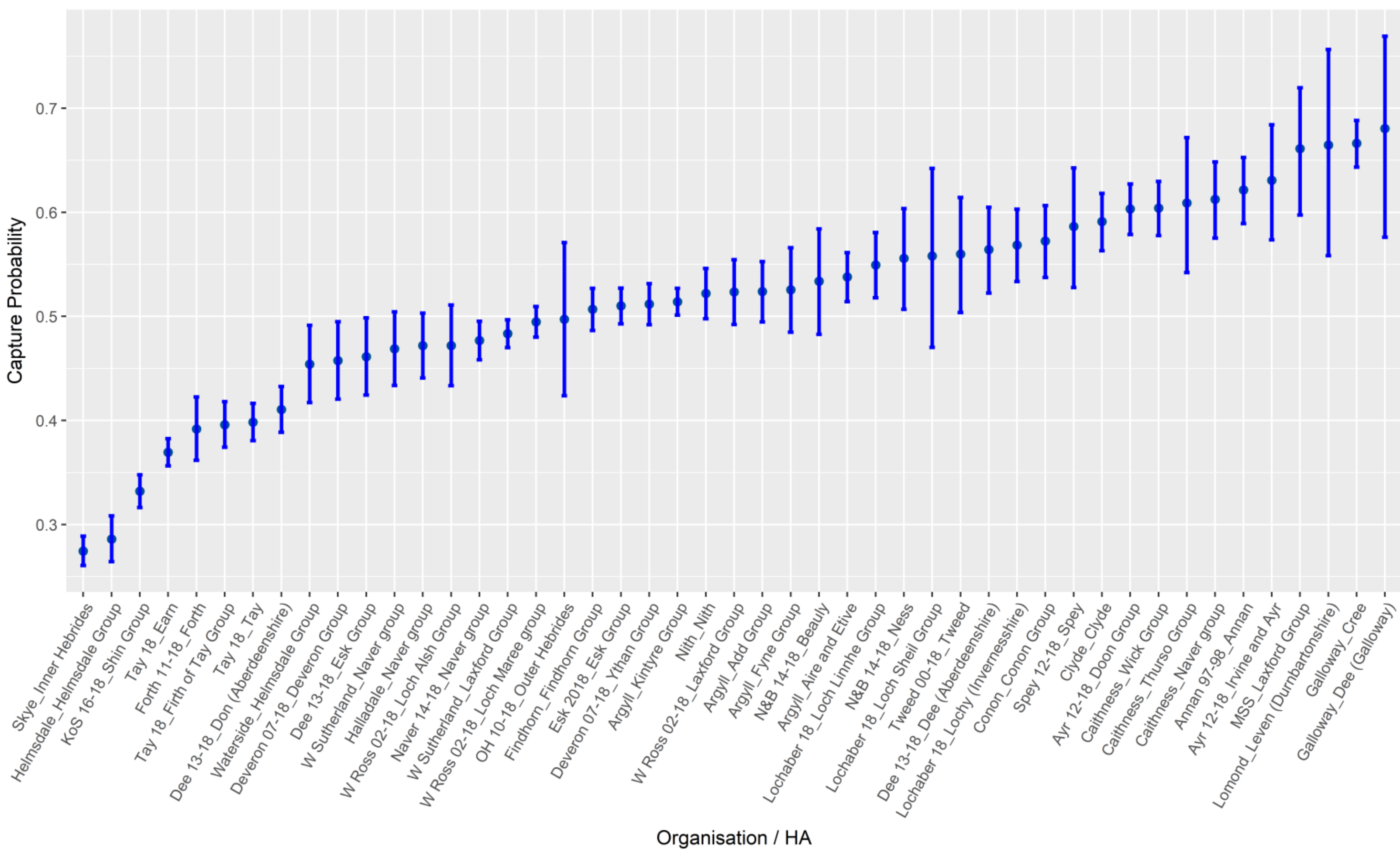


Figure 8 Combined partial effect of Organisation and HA on capture probability. All effects are scaled to the mean fitted first pass capture probability. Approximate 95% pointwise confidence intervals are shown as shaded areas or vertical lines. Abbreviated organisation and team combinations are shown on the x-axis.

The range of cumulative capture probabilities predicted for the 3-pass sites fished by each Organisation contributing to NEPS in 2018 are illustrated in Figure 9. While the overall level of the predicted capture probabilities is strongly influenced by Organisation, the spread of values within organisation reflects the geographical (HA where organisations fish in >1 HA) and environmental range (UCA, RDS, Altitude) of electrofishing sites, and the date on which they were sampled (DoY).

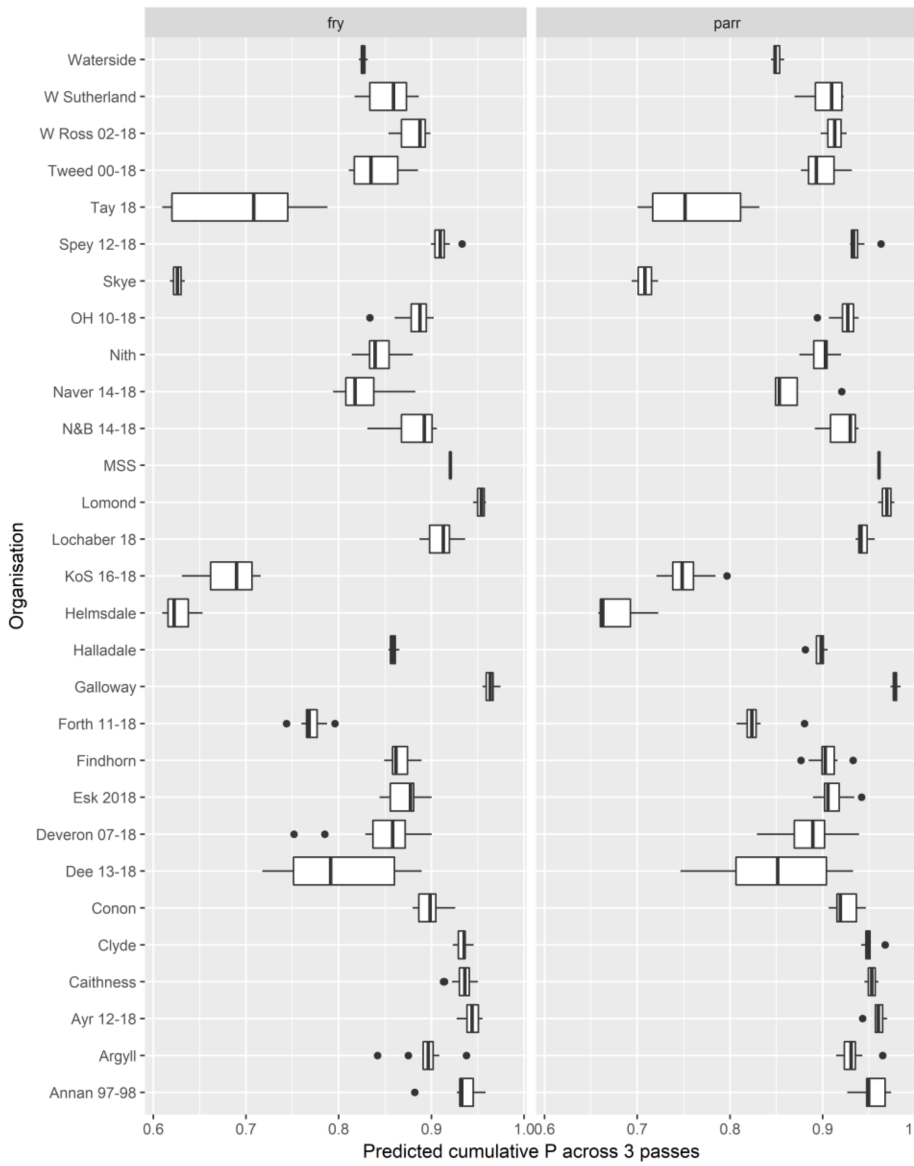


Figure 9 Box and Whiskers plots showing the distribution of fitted cumulative capture probabilities for 3-pass electrofishing sites surveyed by NEPS data providers.

Site-wise assessment of electrofishing data

Site-wise assessments of status are arguably more useful for local than National management, providing information on spatial variability in performance within catchments and regions. Nevertheless, they also provide an early insight into the NEPS data. There was considerable inter-site variability in densities both within and between GRTS regions (Fig. 10, A, B). As expected, fry numbers (Fig. 10A) were more variable than those of parr (Fig. 10B) and there were a greater number of sites with no fry (252, black points Fig. 10A) than parr (217, Fig. 10B). In general, densities were highest in the north and north east of the country.

Not all sites are expected to produce the same densities of fish due to spatial variability in habitat quality. The site-wise benchmark is the expected juvenile salmon density at a particular site, assuming adequate egg deposition and in the absence of major anthropogenic impacts. The performance of individual sites can therefore be assessed through comparison with the benchmark. Figures 10C and D show the observed densities as a percentage of the benchmark. Yellow-Red colours indicate where the sites are producing less fish than expected (<100%), Green-Purple colours indicate where sites are producing more fish than expected. Where a region is meeting the benchmark a mixture of well performing and poorly performing sites should be expected, which would on average, meet the benchmark density. However, where all sites in an area are below the benchmark this would indicate that rivers are not in good status and would merit further investigation. These plots again suggest that the north and north east of Scotland are performing particularly well against the benchmark.

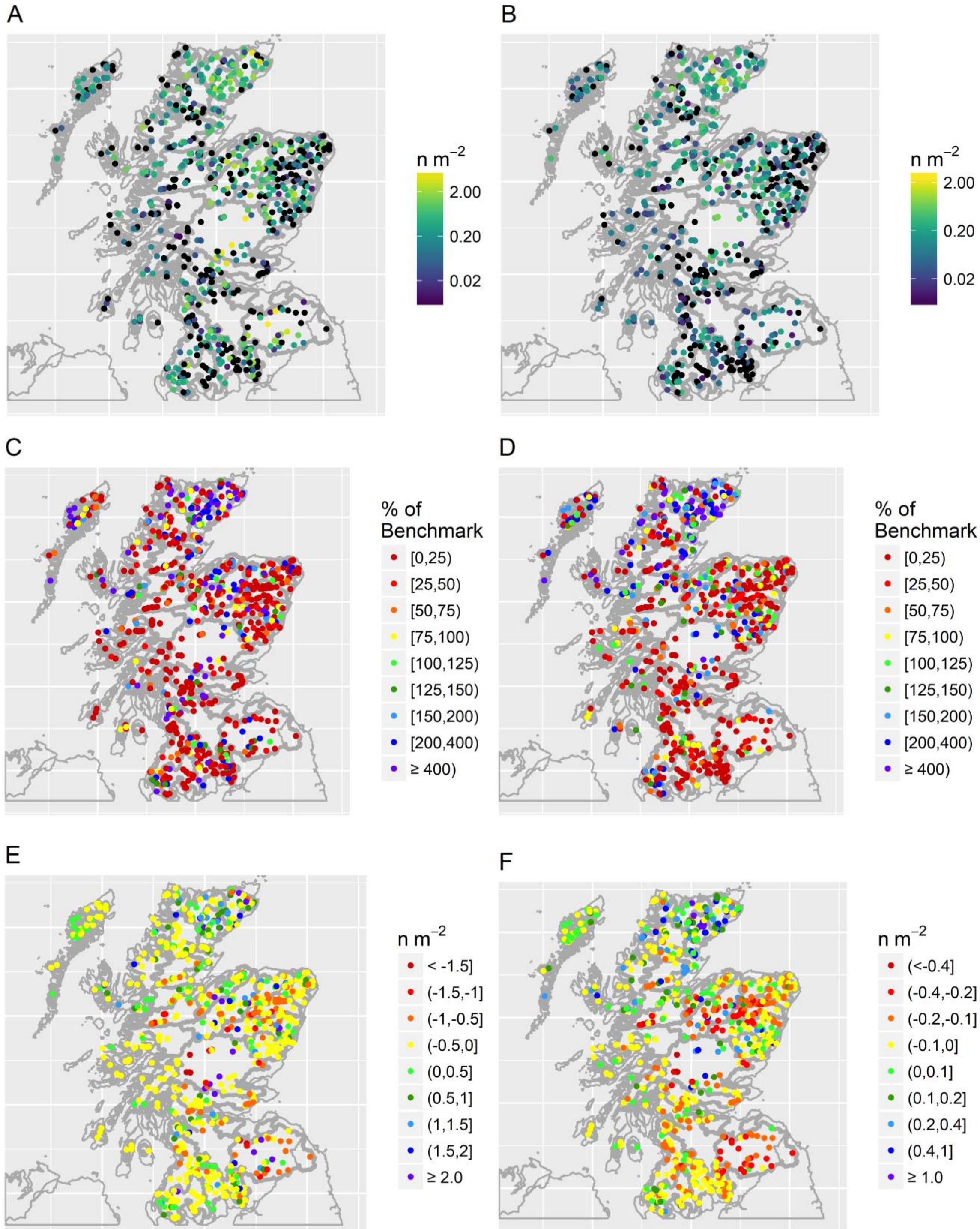


Figure 10. Maps showing spatial variability in observed salmon densities (A, B) together with their percentage (C, D), and absolute (E, F) performance against benchmark. Panels A, C and E show the results for fry. Panels B, D and F show results for parr. Black points indicate sites where no fish (of the relevant life-stage) were caught.

Although the percentage plots provide a useful indication of the status of sites, they do not differentiate between poorly performing unproductive sites and poorly performing productive ones. From a fisheries management perspective, the latter is arguably of more concern. Figures 10E and F show differences between observed and benchmark densities (Observed - Benchmark) for fry and parr respectively. Yellow colours indicate small negative differences between observations and the benchmark, while red colours indicate large differences. Similarly green, blue and purple colours indicate higher than expected densities. These maps suggest that many of the under-performing sites only result in small reductions in density (i.e. yellow in colour). The north and north east of the country again appear to be associated with a high number of well performing sites where densities are substantially above the benchmark.

Regional Benchmarks

The Regional Benchmark densities are the mean expected densities of salmon fry or parr per unit length of sample frame (i.e. Strahler river orders 2-4 below impassable barriers, see Materials and Methods for further details). It is important that this benchmark is interpreted appropriately and is thus explained further at this stage. High values of the Regional Benchmark do not necessarily indicate that a region is expected to produce the greatest numbers of salmon. This is because (1) the benchmark only reflects mean densities (per unit length) of salmon in the sample frame, rather than the entire river system, specifically it does not include larger rivers or standing waters (2) salmon production (total numbers of salmon produced by the river) reflects not only the expected salmon densities, but also river length and area, which in turn relate to the physical structure and characteristics of river systems.

These issues are illustrated in Figure 11 which summarises the characteristics of the sample frame in the GRTS regions. Although the River Tay has the greatest catchment area in Scotland, it is the River Tweed that has the greatest length of river in the sample frame (Fig. 11A). Nevertheless, the River Tay has the greatest overall river area (setting aside problems of estimating river widths from GIS data), reflecting generally wider river channels within the Tay sample frame compared to the Tweed (Fig. 11B). By multiplying the GIS derived river length, river width and predicted salmon densities from the benchmark model (Malcolm *et al*., 2019) it is possible to get an approximate estimate of the total numbers of salmon fry (Fig. 11C) and parr (Fig. 11D) that would be produced within the sample frame for the GRTS regions under benchmark conditions. As expected, the large salmon producing regions such as the Tweed, Tay, Dee and Spey are predicted to produce the greatest overall numbers of salmon. However, high salmon production does not necessarily correlate with high Regional Benchmarks (Figs 11 E, F), which only reflect the mean predicted density (per unit length of river) from the benchmark model. This is a function of the physical characteristics of the rivers within the sample frame in each region, but is not a function of the river area. For example, the rivers Don and Dee are adjacent regions in Aberdeenshire. The Dee has a greater river length, river area and predicted salmon production than the Don, but a lower Regional Benchmark (Fig. 11).

This can be further illustrated by focussing on two regions with strongly contrasting Regional Benchmarks (Fig. 12); Don (high; 0.42 nm^{-2} for fry, 0.17 nm^{-2} for parr) and Galloway (low; 0.15 nm^{-2} for fry, 0.06 nm^{-2} for parr). In the Don sample frame rivers are characterised by a wide range of benchmark densities for both fry (Fig. 12A) and parr (Fig. 12B). In contrast, the Galloway sample frame has considerably lower and more uniform expected densities (Fig. 12C, D). These differences reflect differences in the physical characteristics of the rivers within the two regional sample frames (Fig. 12 E-G). Under the benchmark model (Malcolm *et al*., 2019) juvenile salmon densities are predicted to decrease with Altitude, to increase with Upstream Catchment Area and to exhibit a modal response to River Distance to Sea (with maximum densities observed at ca. 100km). The sample frame within the Don region is characterised by rivers with generally higher upstream catchment areas and greater river distances to sea than Galloway, that override any negative effects of generally higher altitudes, resulting in higher average predicted densities (per unit length).

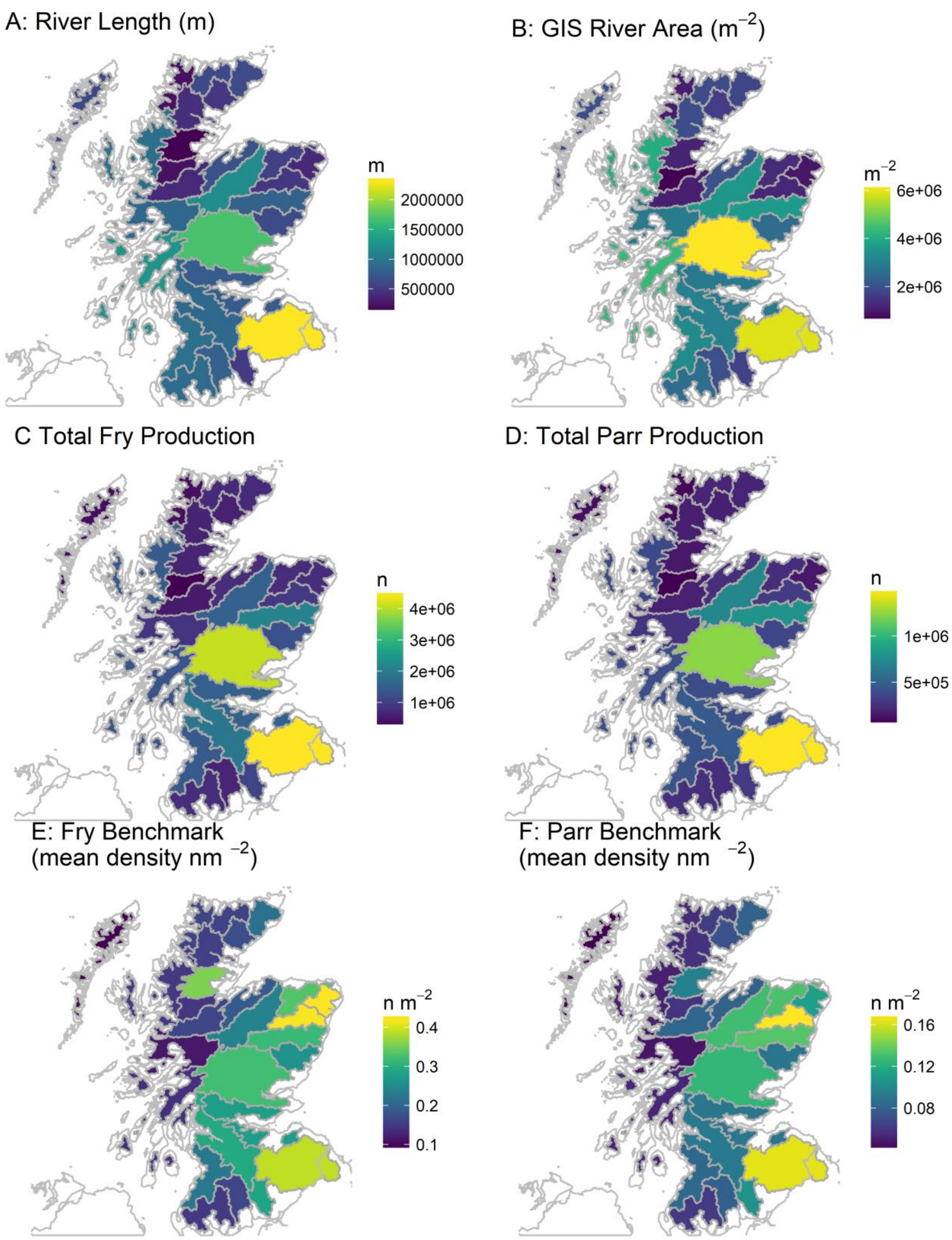


Figure 11. Regional variability in river length (A), area (B), fry (C) and parr (D) production and Regional Benchmark densities. Values apply only to the sample frame (Strahler river orders 2-4 below impassable barriers and excluding standing waters). Note that high Regional Benchmarks are not necessarily associated with high juvenile salmon productivity even within the sample frame.

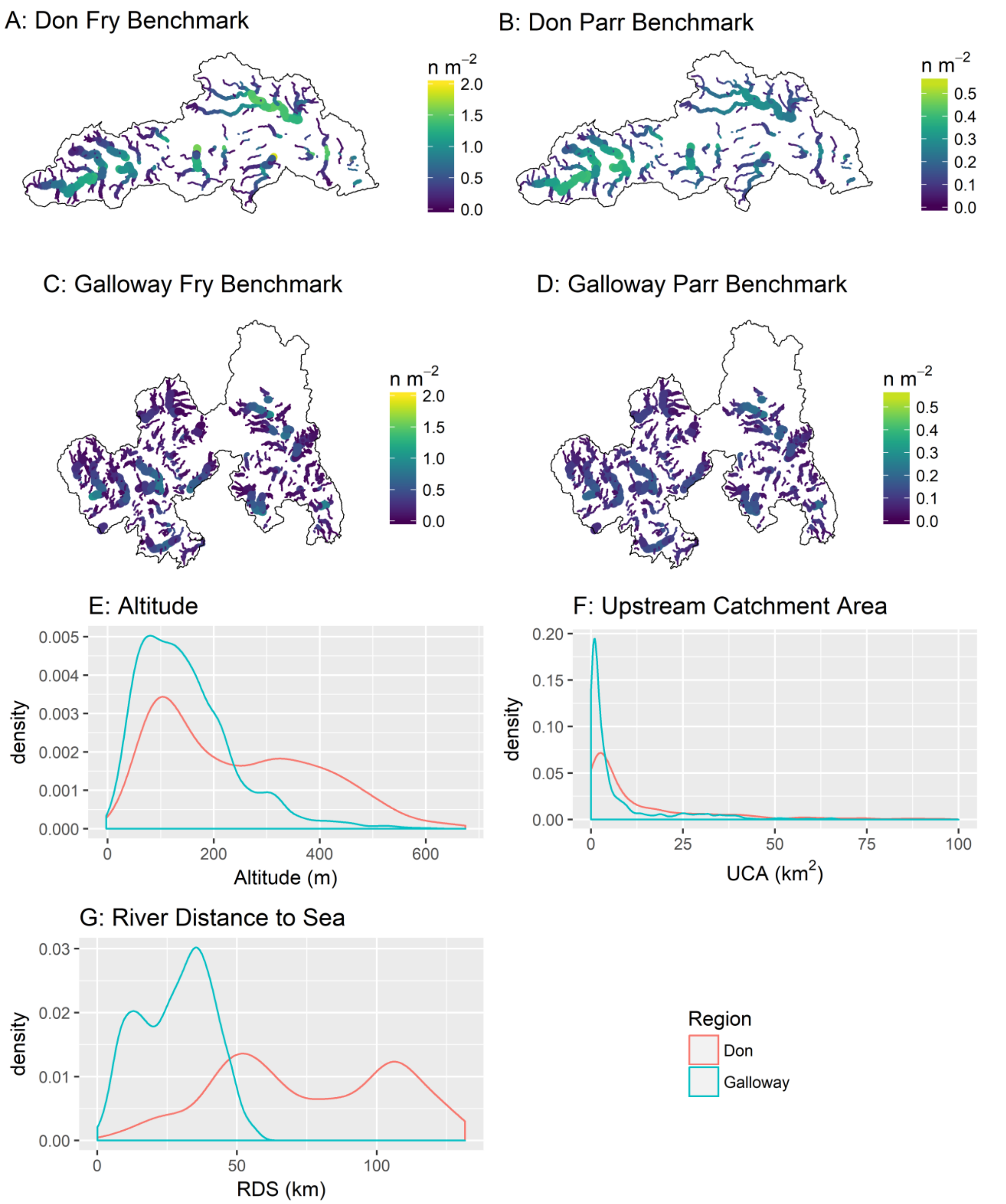


Figure 12. Spatial variability in benchmark densities for fry and parr in the Don (A, B) and Galloway (C, D) regions together with associated differences in the physical characteristics of rivers within the sample frames (E-G). Note that probability density functions (E-G) are only indicative and do not consider differences in the length of individual line segments.

Regional Assessment of Electrofishing data

Regional mean observed densities (Fig. 13C, D) were considerably more spatially variable than benchmark densities (Fig. 13A, B). The highest densities were observed in the east and particularly north-east. Low fry densities were observed in Lochaber and to a lesser extent the Ness, Kyle of Sutherland, Don and Ugie. Low parr densities were observed in the Annan, Galloway, Clyde, Forth, Argyll, Lochaber, Ugie and Don regions.

There was also considerable variability in regional performance against the benchmark (Fig. 14). Beauly, Brora Helmsdale, Caithness and Northern regions substantially exceeded the benchmark for both fry and parr such that the lower 95% confidence bound was above the benchmark. In contrast, Annan, Argyll, Clyde, Conon, Don, Esk, Kyle of Sutherland, Lochaber, Ness and Ugie were all characterised by low fry densities where the upper 95% confidence bounds were below the benchmark.

A relatively large number of regions were characterised by low mean parr densities where the upper 95% confidence bounds were below the benchmark including Annan, Argyll, Clyde, Dee, Deveron, Don, Esk, Forth, Galloway, Ness, Nith, Tweed and Ugie. In the case of the Tweed, and potentially other southern, low altitude and productive rivers, this could be due to the emigration of 1-year-old parr as smolts before the electrofishing season. If this is the case then there could be an argument for assessing the Tweed (or other similar rivers) using densities of fry alone, providing that there were good independent data to support this hypothesis e.g. smolt trapping data where scale ageing revealed a large proportion of smolts emigrating at 1-year-old.

Combining the data in Figure 14, with the rule based classification and combination system in Figures 2 and 3 generated a grading for each region and lifestage that considers the status of rivers and uncertainty in the mean density estimates from the GRTS probability survey (Fig. 15).

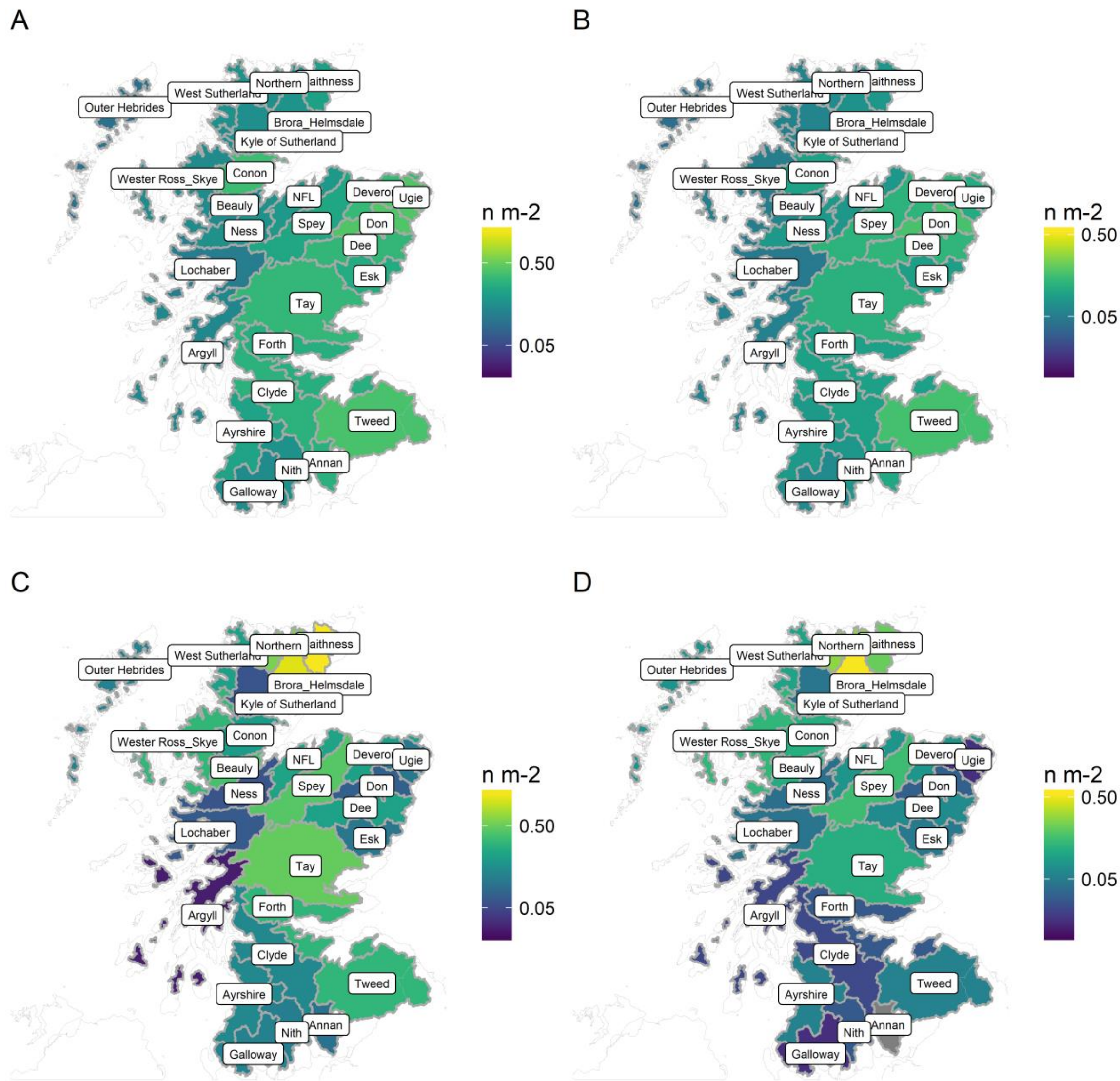


Figure 13 Regional benchmark (A, B) and mean observed densities (C, D) of salmon fry (A, C) and parr (B, D). The mean observed densities are estimated from the analysis of the GRTS survey data. The Regional Benchmark densities are based on the national juvenile benchmark model for Scotland (Malcolm *et al.,* 2019) scaled to regional levels using the digital river network.

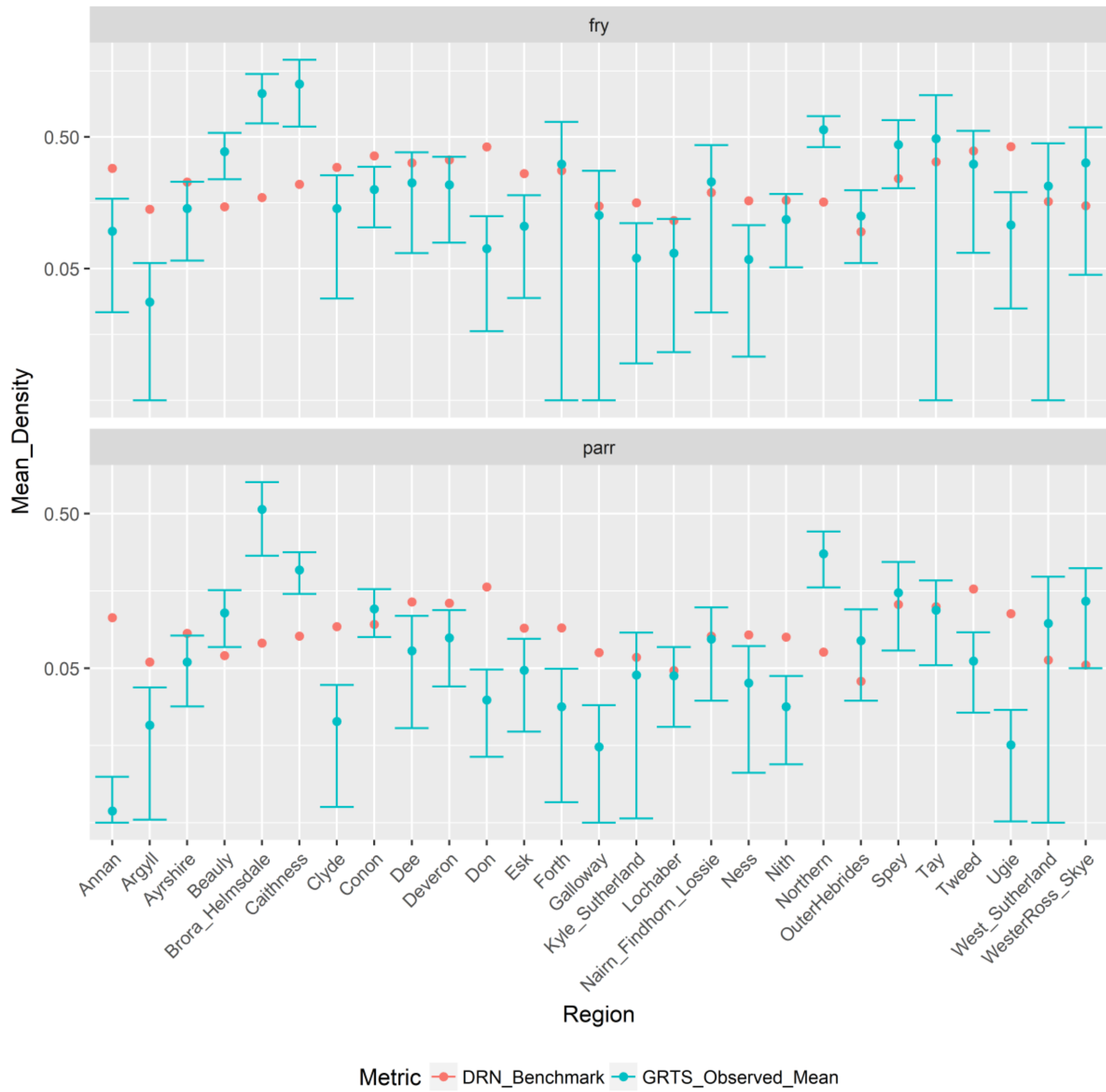


Figure 14 Comparison of the Regional Benchmark densities (scaled up from the national benchmark using the DRN) with the mean observed densities (estimated from the GRTS sample). Vertical bars indicate 95% confidence bounds about the mean observed densities. Note that the y axis is on a log scale and zero values for the lower 95% confidence bounds have been assigned a value of 0.009 for plotting.

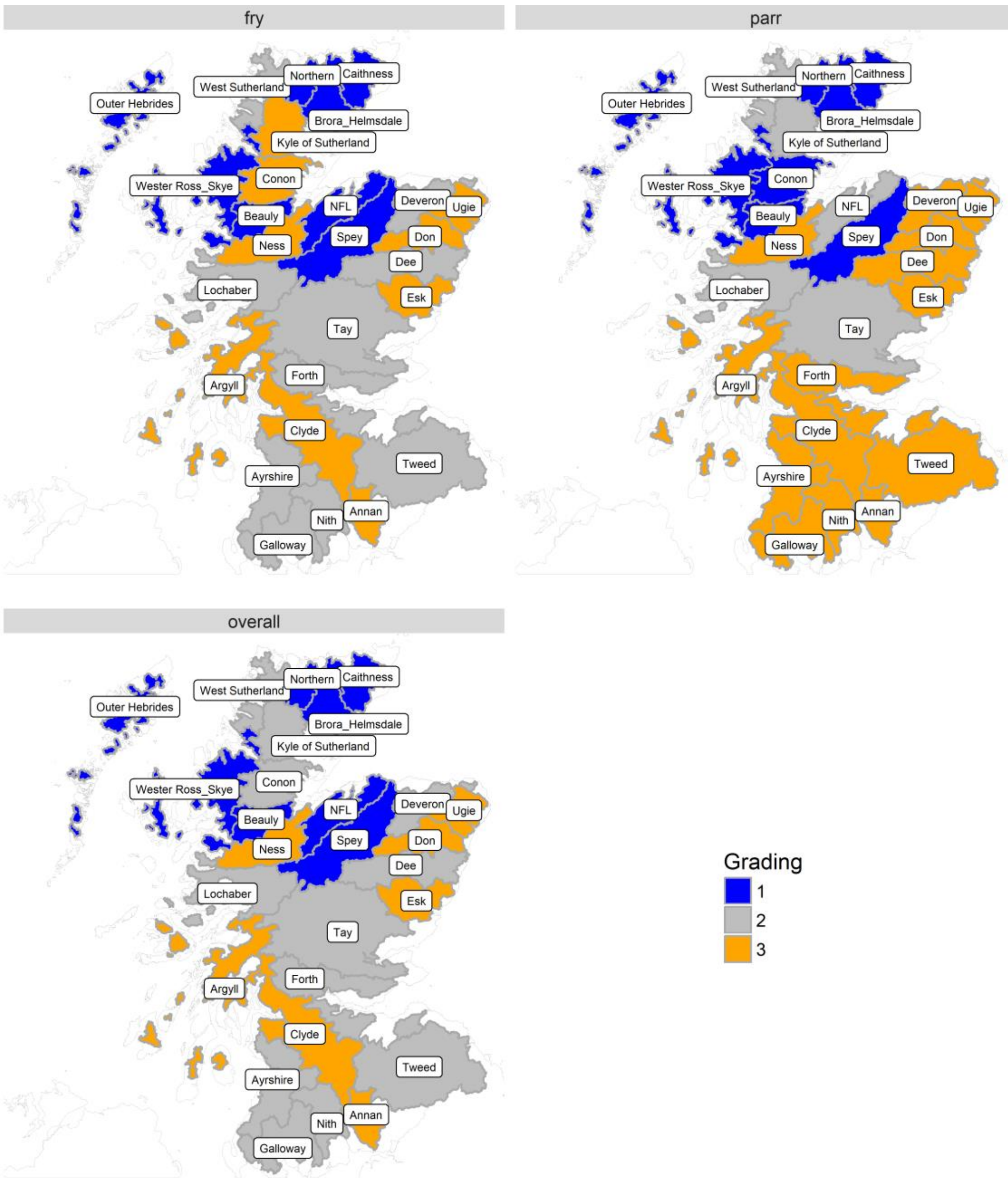


Figure 15 Maps showing potential regional grades for fry, parr and both life-stages (overall).

Within Region Variability (Post Stratification)

Ideally juvenile assessments would be performed at the scale of individual catchments to allow for differences in performance within regions. However, this would require a very large sampling resource. The decision to design NEPS and analyse data at regional scales reflected the availability of resources and thus potential sample sizes. Post-stratification of the NEPS regional data into constituent river catchments is possible, but often results in sample sizes that are too small to provide a useful estimate of mean observed density. Additionally, variance estimates will be negatively biased compared to a GRTS design where individual catchments formed the base strata. Nevertheless, post-stratification may be desirable in some circumstances. To illustrate this process Figure 16 shows the result of a post-stratified analysis of the status of rivers within the Esk region; the North Esk (n = 14), South Esk (n = 10) and Bervie (n = 6). There was great uncertainty in the mean density estimates from the Bervie, although the point estimate was above the benchmark for both fry and parr. Mean density estimates were most precise for the North Esk (greatest sample size) and suggested that the benchmark was not being met for either fry or parr, although the upper 95% confidence bound for parr was only slightly below the benchmark. The upper 95% confidence bounds for the mean density estimates for fry and parr in the South Esk were also below the benchmark.

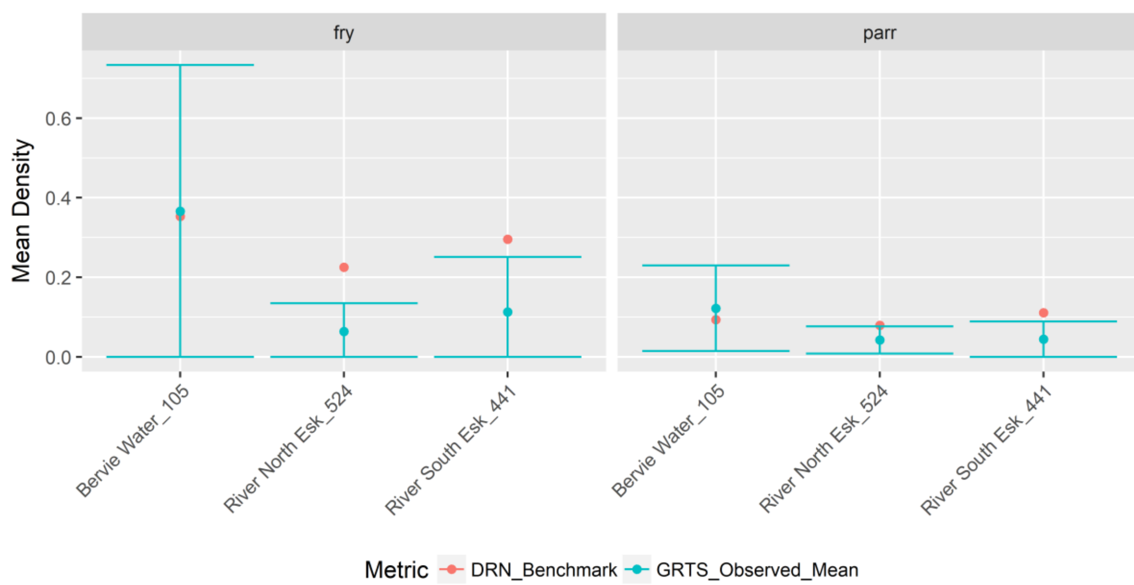


Figure 16. Post-stratification analysis of GRTS data collected in the Esk region to provide individual catchment assessments.

National Assessment of Electrofishing data

A national scale assessment of Atlantic salmon is useful to determine the overall status of the resource and to investigate year to year variability and temporal trends. Data from the GRTS design can be scaled to provide a national assessment of the status of salmon (Fig. 17).This suggests that on average Scotland's salmon populations are reasonably healthy. The GRTS estimate of mean fry density was 117% of the benchmark, while the estimate for parr was 89%, with the benchmark within the 95% confidence limits in both cases. If the same status classification that was applied to the regional data was applied to the national data then this would result in Grade 1 status.

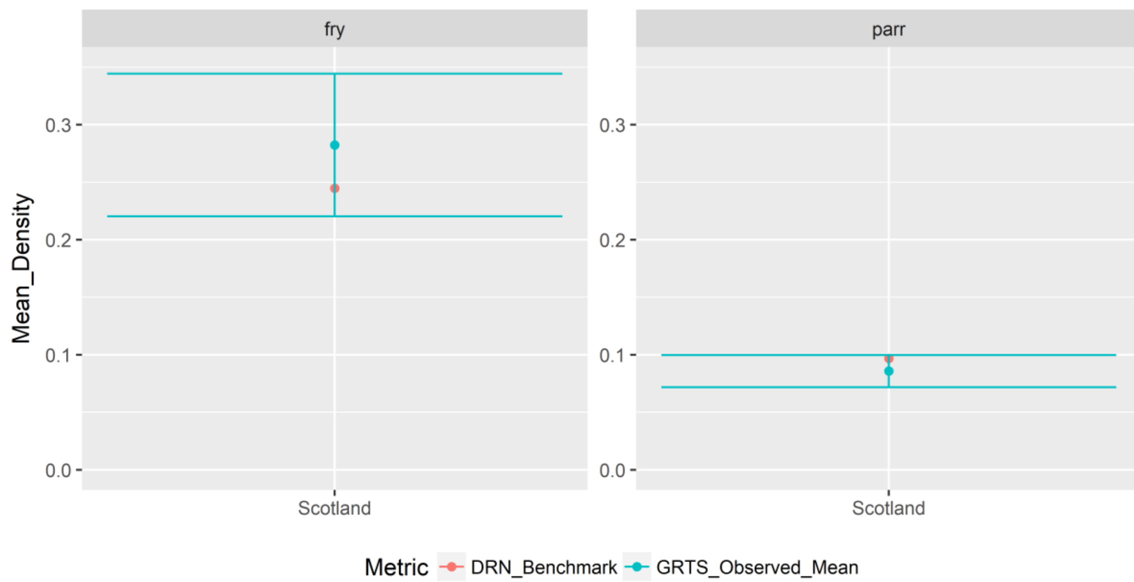


Figure 17. National assessment of the status of salmon for Scotland's rivers.

Discussion and Future Research

A defensible juvenile assessment for salmon requires 1) an approach for estimating total salmon abundance from electrofishing data 2) a spatially variable "benchmark" indicative of healthy populations for assessing performance against 3) an appropriate (representative, spatially balanced) monitoring programme 4) approaches for upscaling site-wise estimates of abundance and the benchmark to larger areas e.g. catchment, regional or national scales.

This report outlined how these challenges were addressed to develop a scalable juvenile salmon assessment method to inform local and national salmon management in Scotland. The resulting approach, that incorporates the National Electrofishing Programme for Scotland (NEPS), is able to identify within catchment variability in the performance of individual electrofishing sites or provide catchment, regional or national scale assessments of performance from multiple electrofishing sites. Over time this approach could also provide an assessment of trends in fish abundance or population status providing that a national survey was completed each year according to a common design, standards and protocols.

Despite the substantial progress that has been made in the development of juvenile assessment methods in Scotland in recent years, a number of issues warrant further investigation and these are discussed in further detail below.

Capture Probability

Capture probability varied substantially between Organisations, habitat, region and date of sampling. The current national capture probability model for Scotland developed by Malcolm *et al*. (2019) was constrained by the diversity of available multi-pass electrofishing data and consistency of recording across the dataset. NEPS data were collected according to a common set of standards that generated information on equipment, team composition (if more than one team per organisation), effort (sampling time per unit area and for each pass), fish sizes and ages (scale samples), in-stream habitat (flow type and substrate) and water quality (samples collected and returned to MSS-FFL for analysis). It is likely that these additional data will result in an improved capture probability model that is better able to separate the effects of region, organisation, fish size and sampling date with consequent benefits for density estimates from both 1-pass and 3-pass data. Over time, the strength of this dataset will increase, allowing for the development of an improved capture probability model for

Scotland. A more detailed analysis of the current NEPS dataset will be explored in the coming year.

If Organisations (other than MSS and SEPA) were to fish in other regions of Scotland and sufficient sites were fished according to standardised multi-pass protocols, then this could further strengthen the capture probability dataset and improve the appropriate attribution of region and organisational effects. Strategic exchange of equipment could also elucidate the relative importance of personnel and equipment within the current “Organisation” effect. Such a programme of work would need to be carefully planned and considered to ensure that it delivered an appropriate dataset.

Plots of the “Year” effect on capture probability suggest trends over time. Although such trends have been observed in other long-term datasets (e.g. Glover *et al*., 2018; Dauphin *et al.,* 2018) it was perhaps surprising to see trends emerging in the Scottish electrofishing data given the relatively short time series (21 years) and the spatially and temporally unbalanced nature of data availability across the country. Trends in capture probability can have substantial consequences for assessing trends in salmon abundance from timed or un-calibrated electrofishing data. Specifically, they bias the estimates of trends, with the strength and direction of the bias depending on the true trend in abundance, the trend in capture probability and the typical capture probability level (Glover *et al*., *submitted*).

NEPS uses a combination of 1-pass and 3-pass area-delimited electrofishing data to strike a balance between sample size (the number of sites that can be fished with a given resource) and the precision of the resulting density estimates. Through this approach it is possible to obtain an annual estimate of capture probability that can be used to provide a relatively unbiased estimate of fish abundance at both 1-pass and 3-pass sites that avoids temporal bias. Failure to carry out appropriate annual assessments of capture probability and to calibrate electrofishing data appropriately could result in misleading status assessments.

Wetted area

The choice of "survey area" could influence observed and benchmark juvenile salmon densities. The benchmark densities used in the current analysis were based on a model that used wetted areas measured at the time of electrofishing (Malcolm *et al.,* 2019). Consequently, the benchmark densities should reflect typical wetted areas, averaged over years. Such an approach was required because not all electrofishing data in the national electrofishing dataset (1997-2015) contained site-length measurements (some data were wetted areas alone). For consistency, NEPS densities for 2018 were therefore also calculated using wetted area. Nevertheless, this is worthy of further discussion.

Where fish counts are scaled to wetted area, observed fish densities could vary between days and years depending on the response of fish to prevailing flow conditions. If total fish production (numbers per unit length or river) is unaffected by flow conditions, then low flows will result in higher densities as fish are constrained to smaller wetted areas. However, if fish require some minimum territory size or food resource then declining flows could result in greater mortality of juveniles, and observed densities could remain similar across flow conditions, although overall juvenile production would decrease under lower flows. The consequence of these potential effects is that discharge could theoretically affect observed densities independent of total juvenile production, i.e. higher densities would not always indicate higher production.

These uncertainties can be overcome by scaling observed counts by the product of the electrofishing survey length and a more static measures of channel width e.g. active (non-vegetated) channel, bankfull width or GIS derived width obtained from spatial data (e.g. Glover *et al.,* 2018). Under such circumstances higher densities would be consistent with higher total production. However, only GIS derived widths would allow for upscaling of the benchmark (a spatially continuous measure of width would be required) and this would require that the benchmark model be re-fitted using a sub-set of the available baseline data where site length data are available. This would be a significant challenge and would result in the loss of information on spatiotemporal variability in salmon abundance from the larger dataset. Furthermore, GIS derived widths are associated with their own particular challenges as discussed here and elsewhere (Malcolm *et al.,* 2019).

Although inter-annual variability in flow conditions could affect observed densities, it is important to note that for practical reasons electrofishing is usually performed under low flow conditions even in years with higher flows thereby constraining the range of potential wetted widths. Furthermore, accurate estimates of true wetted area (river area under water) which can be obtained from image analysis or 2D hydraulic modelling (e.g. Fabris *et al.,* 2017) are almost impossible to obtain from simple length and "wetted width" transects. Specifically, the location of transects can substantially affect estimates (especially with few measurements) and wetted width measurements typically include the maximum channel width where any water is observed. This determines that relatively large changes in discharge can have small effects on measured wetted width due to the variable prominence of exposed boulders within transects (i.e. the area of exposed boulders is not typically subtracted from total wetted width). Of course the temporal variability in field recorded wetted measurements (width, area) will depend on a range of channel characteristics including gradient, substrate and channel morphology. However, it is interesting to note that for eight sites in the Girnock Burn which were delineated using fixed markers and fished over a four-fold range of low flow summer discharges, mean field recorded wetted widths only changed by between ca. 0 and 16%. This suggests that although variability in discharge could theoretically affect density estimates, with consequences for performance assessment, in reality the effects of varying base flow discharges are likely to be rather small.

Juvenile Abundance Benchmark

The national juvenile salmon density model presented by Malcolm *et al.,* (2019) provides the basis for the juvenile assessment benchmark used in this report. Because of the need to upscale the benchmark to catchment, region and national scales it is not possible to incorporate local site specific habitat data (e.g., substrate, flow type) into these larger scale assessments. However, it would be possible to include these predictor variables in site-wise assessments of performance for use by local managers, potentially improving assessments of status.

Water quality is a critical control on juvenile salmon, directly (Malcolm *et al.,* 2014) or indirectly affecting abundance through effects on in-stream productivity and food availability (Williams *et al.,* 2009). Water quality is not included in the current national juvenile salmon density model (Malcolm *et al.,* 2019), however it is a potentially important predictor that could further explain within and between catchment differences in salmon abundance. Water quality data were collected as part of the NEPS survey to allow further investigation of these effects and could be incorporated into future assessments, providing that large scale models of water quality could also be developed (e.g. Smart *et al.,* 2001; Monteith *et al.,* 2015). Furthermore, where fish densities were observed to respond to anthropogenically driven gradients in water chemistry, and appropriate "natural" chemical concentrations could be determined, this could provide a basis for attributing impacts to particular environmental pressures e.g. acidification.

The relative importance of site specific measurements (e.g. substrate), GIS derived habitat covariates (e.g. altitude, upstream catchment area) and water quality for predicting juvenile salmon production will be investigated using the data collected during NEPS. This will help to inform fisheries managers of where most value is gained during data collection. Furthermore, in circumstances where site specific variables provided useful additional explanatory power, this could be incorporated into Site-wise (although not regional or national) level assessments of performance. This could be valuable for local management.

Further research will also be carried out to develop approaches for predicting water quality from GIS derived covariates using spatial statistical river network models (Jackson *et al*., 2018). Such approaches have the potential to allow hydrochemistry and river temperature to be included in future juvenile density models and thus to inform refined benchmarks.

NEPS survey design

Although MSS staff investigated and trialled a variety of survey design options over recent years, the national scale application of a GRTS design through NEPS was implemented very rapidly over a period of < 6 months. Consequently there are a number of areas where improvements or changes could be made to the design before it is fixed for any extended period. Although such changes could not be made before the 2019 electrofishing season, it may be possible to explore potential changes before 2020, were future surveys to proceed.

One of the greatest challenges in the initial survey design was defining the sample frame, i.e. rivers that could be sampled by wading and electrofishing. Until such time as new standard methods are developed for obtaining quantitative and comparable estimates of salmon in deeper rivers, the refinement of the sample frame will continue to be a challenge. Poorly defined sample frames result in under coverage (i.e. rivers that could be fished by wading do not appear in the design) or over coverage (i.e. sample contains sites that cannot be fished). In the context of NEPS, over coverage can be a substantial resource problem as it is often unclear whether sites can be sampled before they are visited even with aerial imagery or other resources providing a coarse screening tool. It is possible that other measures of river order (Shreve rather than Strahler) could provide an improved assessment of the rivers that are likely to be fishable. It is also possible that other proxies for river size could be considered e.g.

upstream catchment area (UCA), potentially combined with channel gradient. A list of sites (and their associated GIS derived covariates) where fishing was and was not possible in 2018 may provide a suitable dataset for exploring improvements to the delineation of the sample frame. Alternatively, where there is very detailed local knowledge of rivers it may be possible to define river reaches where sampling is not possible (due to depth or velocity considerations). These different options should be considered while at the same time recognising the need to avoid spatial bias in site selection that would reduce the value of the GRTS sample design.

Rivers above impassable barriers to fish migration were removed from the sample frame (SEPA, 2019). However, NEPS sampling highlighted many previously unrecorded barriers (particularly natural barriers) meaning that oversamples were required. This barriers information has been fed back to SEPA so that the Obstacles to Fish Migration dataset can be updated. Continued updates and improvements to this dataset, alongside improved information on the fish species to which the passability classification refers to (e.g. salmon vs eels) will allow further refinements to the sampling frame to reduce over coverage. Similarly, as barriers are removed from catchments (and this information added to the barriers dataset) it will be possible to include previously inaccessible areas into the sample frame.

NEPS used a stratified sample design. This allowed the number of samples to be fixed in each region (strata) providing good spatial coverage while also reducing logistical and management challenges e.g. if a site cannot be sampled, then over-samples (replacement sites) are provided from the same region rather than from a Scotland sample as a whole. Given the number of rivers in Scotland that contain fisheries and are assessed for salmon under the Conservation Regulations (220), it would not be possible or sensible to have strata for individual rivers as this would require sampling effort that was beyond the available resources. However, it is possible that the current strata are too coarse and that some medium-large rivers should have their own strata. While it is possible to post-stratify existing regions (e.g. Esk above), this process can result in under-estimates of variance. Prior to future changes to NEPS it would be desirable to discuss and agree the structure of strata between national and local fisheries managers to reflect resource availability and any local management units for which independent assessments are desired.

The sample sizes used in the NEPS 2018 survey design reflected a balance between the desirable and the possible, given available resources. The data that have been collected should now be used to inform future sample sizes. Specifically, the data should be used to simulate the levels of precision that could be obtained for different sample sizes given variable levels of environmental variability and catchment size. Future work should also investigate approaches for combining data across years to improve understanding of population status.

In 2018 the NEPS programme was supplemented by electrofishing in Special Areas of Conservation (SACs; not reported here). These samples were obtained in rivers that would typically obtain very few samples under a regional NEPS design due to their small size, or rivers that are not assessed under Conservation Regulations (do not contain salmon fisheries). The location of these additional samples was determined using an independent GRTS sample design. Similarly, there is increasing interest in developing detailed local monitoring programmes for particular regions / rivers in Scotland. Further investigation is required to determine how to combine data from multiple different GRTS survey designs into a single analysis. Alternatively, given financial and other resource constraints on fisheries management in Scotland, future NEPS designs should consider known monitoring requirements and incorporate these where possible through appropriate choice of strata and sample sizes that reflect available resources. This would allow for a more straightforward analysis of available data without the need for post-stratification, weight adjustment or other complex approaches for post-hoc combinations of different survey designs.

Status Assessment

The primary driver for NEPS was the delivery of a juvenile assessment method that could complement the existing adult based assessment method and inform river grades under Conservation Regulations. This report presents an approach for juvenile assessment, but further work is required to compare the results of the two assessment approaches and harmonise where possible before further decisions are made. Harmonisation of the adult and juvenile assessments may be possible through adjustment to one or other of the benchmarks e.g. using a percentage of the benchmark (Malcolm *et al*., 2019) in circumstances where one approach is shown to be consistently more or less conservative than the other. Further consideration should also be given to the assessment of juveniles in circumstances where evidence shows that fry grow very quickly and emigrate as 1-year-old parr before the electrofishing season. In these circumstances it would be possible to base the juvenile assessment on fry densities alone, providing there were good independent data to show this to be the case e.g. scale aged smolt data from main-stem smolt wheels that could integrate across the catchment.

Despite a desire to harmonise adult and juvenile assessments, complete agreement should not to be expected given the major differences in underlying principles, data, assumptions and implementation. For example, adult based assessments average status over 5 years, whereas the juvenile assessment approach presented here combines two status assessments (fry and parr), typically integrating over a period over 2-3 years depending the age distribution of parr.

In addition, the benchmark for the adult assessment is an egg target derived from estimates of maximum sustainable yield (MSY) taken from Scottish (ova-ova) stock-recruitment relationships, that varies spatially between rivers depending on their position around the coast and their catch per unit area. In contrast, the benchmark for juvenile assessment is based on the average numbers of fry or parr that would be expected in a particular site in the absence of anthropogenic pressures assuming sufficient ova to substantially stock available habitat. This benchmark was not derived from stock-recruitment relationships, given the very few catchments with both reliable ova and juvenile data, but rather on electrofishing observations (Malcolm *et al*., 2019). The latter approach results in spatially varying benchmark expectations within catchments, while the former results in spatially varying benchmarks between catchments.

The spatial scales of assessment also vary between approaches. Juvenile assessments are carried out across the entire catchment (sites are spatially balanced) but are constrained to sites where sampling is possible by wading. In practice this generally constrains electrofishing to large tributaries up to river order 4, although it is possible that sampling could be extended to larger rivers with favourable channel characteristics (i.e. wide and shallow rivers) or where electrofishing was undertaken by boat. In contrast adult based assessments integrate across entire catchments using rod-catch data to model ova deposition.

Given these conceptual and methodological differences between approaches, complete agreement between assessments is unlikely and both approaches have strengths and weaknesses. Nevertheless, where there is agreement between approaches, this is likely to provide greater confidence in the assessment outcomes than any single approach on its own. Future work should therefore look to compare the two approaches, harmonise where possible and consider options for combining assessments in a strength of evidence framework.

Acknowledgements

NEPS was supported by funding from the Scottish Government, SEPA and SNH.

The NEPS survey design, data analysis and reporting were delivered under Marine Scotland Science Service Level Agreement (SLA) FW02g.

We would like to acknowledge the valuable contributions of Simon Dryden to the NEPS programme, building support for the project, providing enthusiasm and liaison between MS and collaborators in the wild fisheries sector.

Staff at MSS Freshwater Laboratory are thanked for logistical support and for analysing water quality data, a valuable resource for future developments of juvenile assessment approaches.

We would like to acknowledge the assistance of Sean Dugan (SFCC) in supporting data entry and reporting from the SFCC database and for providing valuable comments on data entry SOPs.

The following collaborating organisations are thanked for their valuable efforts in facilitating or delivering data collection, without whom this work would not have been possible: West Sutherland Fisheries Trust; Northern District Salmon Fishery Board; Caithness District Salmon Fishery Board; Helmsdale District Salmon Fishery Board; Brora District Salmon Fishery Board; Kyle of Sutherland Fisheries Trust; Cromarty Firth Fisheries Trust; Ness and Beauly Fisheries Trust; Findhorn, Nairn and Lossie Trust; Spey Foundation; The Deveron, Bogie & Isla Rivers Charitable Trust; Ugie District Salmon Fishery Board; Ythan District Fishery Board; River Dee Trust; The Esk Rivers & Fisheries Trust; Tay District Salmon Fisheries Board; Forth Fisheries Trust; Tweed Foundation; The River Annan Trust; Nith Catchment Fisheries Trust; Galloway Fisheries Trust; Ayrshire Rivers Trust; Clyde River Foundation; Loch Lomond Fisheries Trust; Argyll Fisheries Trust; Lochaber Fisheries Trust; Skye & Wester Ross Fisheries Trust; Outer Hebrides Fisheries Trust; Waterside Ecology Independent Ecological Consultants.

Finally, we would like to thank staff at CEH, SEPA and the MET Office for providing discharge and rainfall data.

References

Barker, L. Mastrantonas, N. Lewis, M. Clemas, S. 2018. Hydrological summary for the United Kingdom: July 2018. Wallingford, UK, NERC/Centre for Ecology & Hydrology, 12pp. (CEH Project no. C04954) http://nora.nerc.ac.uk/id/eprint/520709/

Burnett KM, Reeves GH, Miller DJ, Clarke S, Vance-Borland K, Christiansen K. 2007. Distribution of salmon-habitat potential relative to landscape characteristics and implications for conservation. Ecological Applications 17 (1): 66–80 DOI: 10.1890/1051-0761(2007)017[0066:DOSPRT]2.0.CO;2

CEH Centre for Ecology and Hydrology. 2018. UK Hydrological Status Update – December 2018 https://www.ceh.ac.uk/news-and-media/blogs/uk-hydrological-status-update-december-2018#summer date updated 19/12/2018, date accessed 20/03/2019

Chaput G. 2012. Overview of the status of Atlantic salmon (Salmo salar) in the North Atlantic and trends in marine mortality. ICES Journal of Marine Science 69 (9): 1538–1548 DOI: 10.1093/icesjms/fss013

Dobbie, MJ, Henderson BL, Stevens, Jr DL. 2008. Sparse sampling: Spatial design for monitoring stream networks. Statistics Surveys 2 (0): 113–153 DOI: 10.1214/07-SS032

Fabris L, Malcolm IA, Buddendorf WB, Millidine KJ, Tetzlaff D, Soulsby C. 2017. Hydraulic modelling of the spatial and temporal variability in Atlantic salmon parr habitat availability in an upland stream. Science of the Total Environment 601–602 (December): 1046–1059 DOI: 10.1016/j.scitotenv.2017.05.112

Glover RS, Fryer RJ, Soulsby C, Bacon PJ, Malcolm IA. 2018. Incorporating estimates of capture probability and river network covariance in novel habitat - abundance models: assessing the effects of conservation stocking on catchment-scale production of juvenile Atlantic salmon (Salmo salar) from a long-term electrofishing dataset. Ecological Indicators 93 (February): 302–315 DOI: 10.1016/j.ecolind.2018.05.013

Gurney WSC, Bacon PJ, Malcolm IA, MacLean JC, Youngson A. 2015. The demography of a phenotypically mixed Atlantic salmon (Salmo salar) population as discerned for an eastern Scottish river DOI: 10.7489/1662-1

Hannaford, J. Turner, S. Lewis, M. Clemas, S. 2018 Hydrological summary for the United Kingdom: August 2018. Wallingford, UK, NERC/Centre for Ecology & Hydrology, 12pp. (CEH Project no. C04954) http://nora.nerc.ac.uk/id/eprint/520977/

ICES. 2016. Report of the Working Group on North Atlantic Salmon (WGNAS), 30 March–8 April 2016, Copenhagen, Denmark.

ICES. 2018. Report of the Working Group on North Atlantic Salmon (WGNAS) International. April 4–13. Woods Hole, MA, USA

Jackson FL, Fryer RJ, Hannah DM, Malcolm IA. 2017. Can spatial statistical river temperature models be transferred between catchments? Hydrology and Earth System Sciences 21 (9): 4727–4745 DOI: 10.5194/hess-21-4727-2017

Jackson FL, Fryer RJ, Hannah DM, Millar CP, Malcolm IA. 2018. A spatio-temporal statistical model of maximum daily river temperatures to inform the management of Scotland's Atlantic salmon rivers under climate change. Science of the Total Environment 612 DOI: 10.1016/j.scitotenv.2017.09.010

Kincaid T, Olsen T, Stevens D, Platt C, White D, Remington R. 2018. Package 'spsurvey' Spatial Survey Design and Analysis Available at: https://cran.r-project.org/web/packages/spsurvey/spsurvey.pdf

Malcolm IA, Bacon PJ, Middlemas SJ, Fryer RJ, Shilland EM, Collen P. 2014. Relationships between hydrochemistry and the presence of juvenile brown trout (Salmo trutta) in headwater streams recovering from acidification. Ecological Indicators 37 (PART B): 351–364 DOI: 10.1016/j.ecolind.2012.02.029

Malcolm IA, Millidine KJ, Glover RS, Jackson FL, Millar CP, Fryer RJ. 2019. Development of a large-scale juvenile density model to inform the assessment and management of Atlantic salmon (Salmo salar) populations in Scotland. Ecological Indicators 96: 303–316 DOI: 10.1016/J.ECOLIND.2018.09.005

Marine Scotland. 2019a. https://www2.gov.scot/Topics/marine/Salmon-Trout-Coarse/Freshwater/Monitoring/ElectrofishingProgramme/Collaborators date accessed 29/03/2019

Marine Scotland. 2019b. https://www2.gov.scot/Topics/marine/Salmon-Trout-Coarse/fishreform/licence/status date accessed 29/03/2019

Met Office. 2018. Summer 2018 UK Climate Summary https://www.metoffice.gov.uk/climate/uk/summaries/2018/summer, date updated 06/09/2018, date accessed 20/03/2019

Met Office. 2018. UK actual and anomaly maps https://www.metoffice.gov.uk/climate/uk/summaries/anomacts, date accessed 20/03/2019

Millar CP, Fryer RJ, Millidine KJ, Malcolm IA. 2016. Modelling capture probability of Atlantic salmon (Salmo salar) from a diverse national electrofishing dataset: Implications for the estimation of abundance. Fisheries Research 177 DOI: 10.1016/j.fishres.2016.01.001

Millidine, K. J., Fryer, R. J., Jackson, F. L., Glover, R. S., & Malcolm, I. A. 2018. Site locations for the National Electrofishing Programme for Scotland (NEPS) and west coast SAC rivers (2018). DOI: 10.7489/12112-2

Millidine, K.J., Jackson, F.L., Glover, R.S., Fryer, R.J. Malcolm, I.A. 2019. National Electrofishing Programme for Scotland Fish Counts. DOI: 10.7489/12201-1

Monteith DT, Henrys PA, Evans CD, Malcolm I, Shilland EM, Pereira MG. 2015. Spatial controls on dissolved organic carbon in upland waters inferred from a simple statistical model. Biogeochemistry 123 (3) DOI: 10.1007/s10533-015-0071-x

Muchan, K. Turner, S. Lewis, M. Clemas, S. 2018 Hydrological summary for the United Kingdom: October 2018. Wallingford, UK, NERC/Centre for Ecology & Hydrology, 12pp. (CEH Project no. C04954) http://nora.nerc.ac.uk/id/eprint/521522/

PACEC. 2017. An Analysis of the Value of Wild Fisheries in Scotland. (March) Available at: http://www.gov.scot/Topics/marine/Salmon-Trout-Coarse/fishreform/sectorvalue

Parry, S. Mastrantonas, N. Lewis, M. Clemas, S. 2018a. Hydrological summary for the United Kingdom: September 2018. Wallingford, UK, NERC/Centre for Ecology & Hydrology, 12pp. (CEH Project no. C04954) http://nora.nerc.ac.uk/id/eprint/521195/

SEPA. 2019. https://www.sepa.org.uk/environment/environmental-data/ , date accessed 20/03/2019

Smart RP, Soulsby C, Cresser MS, Wadec a J, Townend J, Billett MF, Langand S. 2001. Riparian zone influence on stream water chemistry atdifferent spatial scales: a GIS-based modellingapproach, an example for the Dee, NE Scotland. The Science of the Total Environment 280: 173–193 DOI: 10.1016/S0048-9697(01)00824-5

Williams KL, Griffiths SW, Nislow KH, McKelvey S, Armstrong JD. 2009. Response of juvenile Atlantic salmon, Salmo salar, to the introduction of salmon carcasses in upland streams. Fisheries Management and Ecology 16 (4): 290–297 DOI: 10.1111/j.1365-2400.2009.00673.x

Appendix 1

Standard Operating Procedures for NEPS Data Collection and Data Entry

National data collection protocols

National electrofishing sampling protocols

A new national electrofishing programme has been developed to assess and monitor the status of juvenile Atlantic salmon in Scottish rivers using a common set of standards. The protocols have been designed to collect as much information as possible to (1) explore opportunities for assessing the status of regions and rivers (2) improve existing fish density models (3) explore alternative measures of population health (e.g. biomass) (4) ensure that the collected data can support future developments in other areas e.g. National Eel Plan and Water Framework Directive.

Collection of genetic samples for a sub-set of locations will inform studies of genetic introgression. Water sampling will be used to assess the importance of water quality in controlling within and between catchment variability in fish abundance. Data on substrate and flow types will be used to improve characterisation of habitat using landscape proxies.

For queries on these protocols or in the case of a requirement for over-samples the first point of contact at FFL is XXXX. In the event that XXXX is on annual leave or absent on business an alternative point of contact will be available through the MSS-FFL main office.

Protocol: National multi-pass electrofishing

The national electrofishing programme uses a generalised random-tessellation stratified (GRTS) sample to ensure a representative, spatially balanced, unbiased, quantitative sample of juvenile numbers. To avoid the introduction of bias, it is important not to deviate from the electrofishing site locations provided. If sites are not ‘fishable’ (due to health and safety considerations) an oversample should be requested. Consistent recording of information on equipment and teams provides an opportunity to further develop capture probability models and thus should always be recorded.

- Sites should cover a minimum area of 100 m^2 or be 50m in length (for very narrow streams), whichever results in the shorter reach length.

- Proceed to the coordinates provided (**or river location nearest to coordinates**). This should be the bottom of the electrofishing site. If the electrofishing site is different from the provided location i.e. location does not fall exactly on the river, then record the adjusted location using GPS.
- If the sampling location falls on a braided section of river or the middle of a pool then move the shortest possible distance upstream to the nearest suitable (single thread / wadeable) starting point. However, do not move substantially (e.g. >50m) from the specified GPS coordinates.
- If the reach is too deep to fish and moving <50m does not allow access, then do not fish the site. Instead obtain an over-sample location. This is to avoid biasing sampling towards shallow habitats that are easier to sample and potentially associated with greater salmon fry densities.
- Where possible set the upstream extent of the site to coincide with a natural constriction (e.g. shallow area). Do not finish sections in the middle of a pool.
- Record the site length, if on a bend record site length on both banks. Record 5 equally distributed wetted and bankfull widths (in metres). Note the distance along the length that each width measurement is taken.
- Fish with a minimum team size of two people. Note that the person using the EF equipment must hold a valid electrofishing license.
- For sites ≤ 10m wide stop nets should be used
- For sites >10m wide aim to start and stop the site at physical barriers (e.g. shallow water) where possible
- Always conduct three electrofishing passes
- Record team members, specify who is on the anode, record equipment (make, model, bank-based / backpack), presence of stop nets and use of banner net if applicable. If possible also record electrical conductivity at the site and equipment settings.
- Use the same effort for each pass and systematically fish the entire river width working from downstream to upstream
- Record the total time taken for each pass and where possible (as equipment allows) the time the electrode was active (button depressed).

Protocol: National single-pass electrofishing

Where one pass electrofishing data is collected according to the same standards as the first pass of three pass data, in the same year of sampling, it is possible to get a quantitative estimate of density using the capture probability model.

- Follow the above protocol, with the following modifications
- The use of stop-nets is not compulsory but information on which (if any) stop nets are used **must** be recorded. The use of stop nets is recommended for simple habitats (e.g. canalised rivers with sand or fine gravel beds). These may be identifiable, prior to electrofishing, by inspecting satellite images of the site from Zoom Earth, Google Earth or Bing.

Protocol: fish processing

It is important to record the pass on which **all** fish were caught to inform the capture probability model for different species and life stages. Measuring and scaling all parr will allow for an accurate assessment of population demographics, size at age and of age at smolting. Consequently, it is very important to record information that allows individual salmonids to be linked to associated scale packets and samples.

- Process fish at the end of each run and be sure to record the run number on which fish were caught.
- For salmonids, assign all fish as “fry (0+)” or “parr (>0+)” at the time of sampling based on size observations.
- Measure the fork length of **all** “parr” to the nearest mm.
- Where there are ≤50 fry per run, measure all fry
- Where there > 50 fry per run measure **at least** a sample of 50, again to nearest mm and then record a count of the remaining fry that have NOT been measured. Alternatively, you can measure all fry.
- Size based aging of lifestage (i.e. fry versus parr) is normally fairly reliable, but there can be large overlaps in the sizes of different parr age classes. Therefore scale samples should be taken from **all** salmonid parr. Where there is any uncertainty over lifestage, scale samples should also be taken. Scales should be stored in provided Salmon (white) / Trout (brown) scale packets including **information on Sample Site, Date, length and processing number** (from DPU OR the row number in the field data sheet) thereby allowing scale ages to be related back to individual fish records.

- For eels process as per salmonids (individuals with length), recording sizes of up to 50 fish per run.
- For all other species, obtain a count of individuals **per pass**
- Take at least one photograph of the electrofishing site that incorporates landscape context.
- Place fish in a holding box if further runs are to be undertaken
- Release all fish back into the bottom of the reach after recovering from anaesthetic

Protocol: genetics samples

Genetics samples will be utilised as part of a Scottish Government funded three year study that seeks to quantify levels of introgression of genetic material of fish of non-native origin into wild Scottish Atlantic salmon populations. The samples collected will be genetically screened and levels of introgression determined at an individual/site/river and regional level. An additional £15 per site will be provided for collecting these samples.

- Tissue samples should only be taken from up to 30 parr for the sites sampled using multi-pass electrofishing.
- Using scissors take a ~2mm^2 clip of the caudal fin while the fish is under anaesthetic and place into a numbered ethanol filled tube.
- Clean scissors by wiping with a damp rag/towel between each sample collection.
- **Note the genetics sample tube number**, so that genetics samples can be related back to individual fish records.
- Collect tissue samples from all parr until either 30 samples have been obtained or all parr available have been sampled.

Protocol: habitat

Consistent recording of habitat provides the opportunity to improve the representation of habitat using landscape covariates.

- Record the percentage cover of each substrate class in the electrofishing reach (Wentworth scale)
- Record the percentage flow type in each reach (based on simplified SFCC descriptions)

Protocol: water quality

Water samples are required to assess whether broad scale patterns of hydrochemical variability can substantially improve predictions of fish abundance. The samples will be analysed and the resulting data included in future iterations of the juvenile density modelling. MSS has a system in place to collect these samples from you and return them to MSS-FFL. The following describes the protocols for sample collection and postage.

- Take a water sample at all electrofishing sites
- Rinse the bottle and cap provided 3 times in the river
- Facing upstream submerge the bottle completely until filled – ensure there is no air space within the bottle
- Replace lid and note the bottle number on your datasheet
- Complete the water sample datasheet provided
- Refrigerate the sample until collection, if possible
- Boxes for samples will be provided with bubble wrap for padding. Each box will hold up to 4 samples.
- Once 4 samples have been collected and the associated datasheet completed, ensure both the water samples **AND** record sheet are placed in one of the boxes provided. Next, call the MSS-FFL office and request the collection of your samples. **Do not wait until you have completed all of your electrofishing; instead request the collection each time you have 4 samples.**

Required Equipment

Essential equipment for data providers:

- GPS (or smart phone with app to collect location information)
- Maps (or smart phone with mapping app)
- Camera (or smart phone with camera)
- Stop watch
- Waders
- Electrofishing equipment
- Field laptop with DPU installed **or** field data sheets and pencil
- Tape measure
- Measuring board
- Anaesthetic

- Knife for taking scales
- Buckets
- Hand nets / dip nets / banner nets (if applicable)
- Stop nets (for multi-pass electrofishing <10m wide)
- Sediment size guide and flow type guide
- Holding box (for multi-pass electrofishing)
- Battery powered aerator

Essential equipment provided by MSS:

- Scissors for taking fin clips (multi-pass sites)
- Tweezers
- J-cloth (for wiping scissors between samples)
- Labelled tubes of ethanol for genetic sampling (multi-pass sites)
- Scale packets (salmon and trout)
- Labelled water sample bottles
- Water sample datasheet
- Water sample boxes
- Habitat substrate definitions

Optional equipment provided by data providers and potentially useful resources:

- Electrical conductivity meter (if available)
- Mapping and satellite image webpages: Zoom Earth (https://zoom.earth/) Google Earth or Bing
- Smart phone apps for mapping: OS Maps, GB Outdoors, Backcountry navigator
    - Note that these can be associated with a cost if you want to use certain OS Maps offline
- Smart phone apps for grid references: Locate (from OS), OS Maps, UK Grid Reference Finder, Grid Reference

National electrofishing data entry protocol: SFCC database

This protocol describes the data entry requirements for entering data from the national electrofishing programme into the SFCC Electrofishing Database. The SFCC database can be accessed remotely by any SFCC member or data collection organisation for the purposes of this work. Fish data entry protocols vary with species and lifestage because of the requirements of the SFCC database to enter different types of data (e.g. individual fish, versus counts of fish) into the database using different data entry screens. Example field datasheets have been produced, which can be used to record this data in field and ensure that all necessary data is recorded. Where possible the field datasheets replicate the different data entry screens, within the SFCC database. This results in 5 field datasheets recording information on; site, habitat, individually measured fry (using a tally system), individually measured parr (including scales and genetics information) and other species.

In this protocol the bold headings refer to the window that should be clicked on in the SFCC database. The relevant field datasheet is noted in brackets. Text in italics refers to boxes or sub tabs on the data entry pages. Any **Optional** fields are **NOT** part of the national electrofishing protocol and are thus not included on the provided field data sheets. Further information can also be found in the SFCC Database User Manual, and in 3 short training videos here: https://vimeo.com/92220223 . For queries and general data entry support relating to the SFCC database the first point of contact is XXXX. For queries relating specifically to the data entry protocol contact XXXX.

Log ins note: Make sure you are logged in as the organisation that has completed the electrofishing (this is important for the capture probably model) for example if the Dee Trust fish the Don they will be logged in as the Dee inputting data for sites on the Don. Additional logins can be provided by XXXX on request. If you are not an existing SFCC member then please contact XXXX to discuss obtaining a login and the entry of sites.

View and Edit My Sites (Site and team datasheet)

- Complete the necessary site information
- From the home page click **View and Edit My Sites**
    - *Site Code*: Enter the Site Code provided by MSS, copying all formatting exactly including all underbars, capitalisation and using no spaces.
    - *Date registered:* Enter the date on which you added the site to the database
    - *Salmon Fishery District:* Select the relevant district from the dropdown list
    - *Catchment:* Select the relevant catchment from the dropdown list

- *Altitude (m):* Enter the altitude (optional)
- *Easting*: Enter the easting of the site to 6 numerical figures
- *Northing*: Enter the northing of the site to 6 numerical figures (click View site on Streetmap to check it is in exactly the correct river location).
- *River Order 1*: Select the mainstem river relevant to your site (mandatory field)
- *River Order 1*-6: Select sequential river orders where available (optional)
- *Access/Permission/ Site Situation*: Optional
- To SAVE click the green tick icon in the top left of the screen.

Add/Edit Events (Site and habitat datasheets)

- Complete the necessary information
- From the home page click **View Incomplete Events**
    - *Date:* Enter the date on which the fishing took place
    - *Site Code*: Select the site code you previously added from the dropdown menu or using the Search box.
    - *Fishing Type* : select 'Quantitative (1mm)'
    - *Historical*? : DO NOT tick the Historical? box
    - *Number of runs*: select the relevant number of runs
    - *Instream Cover*: record information on instream cover (optional)
    - *Target Species*: Select Atlantic Salmon (Salmo salar)
    - *Other fish species present*: Please select Yes
    - *Purpose*: select the relevant type from 'National Assessment (1 Run Sampling)' or 'National Assessment (3 Run Sampling)'
    - *Habitat Type:* select General
    - *No. Of Points Used*: select 5
    - *Site Fishing/Notes:* Include an relevant site or fishing notes that you wish (optional)
    - *Click the green tick icon in the top left to Save.*
- ***Dimensions**:*
    - *Site length (m)*: Click on the *Dimensions* tab and input the average of your two measured lengths. Click *save*.

- Widths: Scroll to the bottom of the screen and click *Edit* in the Measurements (General) window. Enter site dimensions in metres using the tab key to move between fields. Click *Done* when complete.
- The Wet, Bed and Bank Width Area (m^2) fields should now auto calculate.

- ***Instream:*** Click on *Instream*, the click *edit* to enter basic habitat information
- ***Flow:*** Click on *Flow*, the click *edit* to enter basic flow information
- ***Bank:*** Enter bank information if you wish (optional)
- ***Other:*** Complete all required equipment and team information including:
  - *Team Leader:* should be the person on the electrode (names should always be entered in the following consistent format of first and last names capitalised, underscored and with no spaces e.g. Joe_Blogs
  - *Number of staff*: record the number of people on the electrofishing team
  - *Equipment type:* record 'Generator' or 'Backpack'
  - *Manufacturer:* record the equipment manufacturer
  - *Model:* record the equipment model
    - Please contact XXXX if your specific model is not in the dropdown list and it can be added
  - *Volts:* record the EF voltage used
  - *Stop Net:* record if stop nets were used
  - *Time electrode was active:* if your equipment can record this, report this in *Survey Notes* this should be entered in the following consistent format of anpass_time (minutes and seconds) separated by | e.g. anpass1_60.32|anpass2_20.00|anpass3_15.50
  - *Time per pass:* report the total time taken for each pass in the *Survey Notes* this should be entered in the following consistent format of totpass_time (minutes and seconds) separated by | e.g. totpass1_60.32|totpass2_20.00|totpass3_15.50
  - Photos of the site should be uploaded

<u>Input of individually measured salmon and trout FRY</u>

Fish Entry Wizard / Fish Count Entry (Salmonid Fry Datasheets (tally))

- From the event page click **Fish Entry Wizard**
- *Select Species:* select the species you wish to add data for
- Click ***Fish Count Entry****:*

    - Add counts of fry, of each length, for each run
    - Data entered are saved automatically. When complete close the Fish Count Entry sheet.
    - Note: if the fry has been scaled record using the *Fish Entry Wizard / Fish Measurement* and **DO NOT** duplicate data in the tally sheet.
    - Close the window
- Ensure the species of interest is still selected in the Fish Entry Wizard page and click ***Age Allocation***
    - Select 'Coarse' from the 'Age Allocation Class' field
    - Add the fry/parr breakpoint to the nearest mm, assuming that only fry appear in the tally system this number should be the maximum observed fish size
    - Tick confident
    - Click 'Reload Graph' and check the breakpoint has been entered correctly
    - Close the window
- Repeat for all other species

<u>Input of salmon and trout PARR and eels > 249mm</u>

Fish Entry Wizard / Fish Measurement (Salmon/Trout Parr and Eel Datasheets)

- From the event page click **Fish Entry Wizard**
- *Select Species:* select the species you wish to add data for
- Click ***Fish Measurement*** *Entry:*
    - Within the individual Fish measurement screen click ***Add New****.*
    - *Run:* select the run the individual was caught on
    - *Length:* select length of the individual
    - *Weight:* leave blank
    - *Sex:* leave blank
    - *Scales Taken:* check box for salmon and trout, leave blank for eels
    - *Scales Read:* leave blank unless / until scales have been read
    - *Actual Age:* enter either a 'guessed age' based on the fish size, or 4++
        - Unfortunately 'Actual Age' is a mandatory field in the SFCC database and cannot be left bank. We acknowledge that entering any age information here is very misleading given that the scales have not

        been read. It is therefore critical that the ‘scales read’ box is **NOT** ticked when adding in these false ages.

        - When scales have been read the ‘Actual Age’ for each fish should be updated to the correct age and the ‘Scales Read’ box ticked
        - Please note that age is not included in MSS’s current modelling framework (only lifestage which will be determined from the location of data entry and coarse age assignments). MSS will not undertake any analysis using age until accurate ages have been determined, via scale reading, and records updated within the database.
    - *Scale Packet Number:* enter scale packet number (DAYPROCESSINGNUMBER)
    - *Genetic Sample Number:* enter genetics sample tube number, following this format TUBECODE e.g. Z1234
        - Note: you will only have genetics samples for 3 run electrofishings
    - *Tag Type:* leave blank
    - *Tag Number:* leave blank
    - *Fin clip:* check box if genetic samples were taken, otherwise leave blank.
    - *Fish Notes:* record any additional information about the fish here

- Click  Save then Add another record, then enter next individual fish
- To save time use the tab key to jump between fields and the up / down arrows and letter keys where fields are drop-down menus.
- If you make a mistake and wish to delete a fish record click the red delete button 
- Close the screen then return to the main Fish Entry Wizard screen to repeat for all remaining species

Input of counts of other species

Other Fish Species Count (anything other than salmon, trout or eels). Only counts per pass are needed (Other Fish Species Datasheets)

- From the main Event page click the **Other Fish Species Count** tab and click **Add New**
- *Species:* select species from dropdown menu
- *Run number:* select run number

- *Count:* enter count of individuals caught in that run
- Repeat for all remaining species and runs

<u>Input of counts per pass where only a sample of fish are measured (e.g. salmonid fry, eels)</u>

In situations of high abundance it is acceptable to measure a sample:

- Where there are ≤50 fry per run, measure all fry
- Where there > 50 fry per run measure at least a sample of 50, again to nearest mm and then record a count of the remaining fry that have NOT been measured. Alternatively, you can measure all fry if desired.
- For eels process as per salmonids (individuals with length), recording sizes of up to 50 fish per run.

Other Fish Species Count (Salmon/Trout Parr and Eel Datasheets)

- From the main Event page click the **Other Fish Species Count** tab and click **Add New**
- *Species:* select species from dropdown menu
- *Run number:* select run number
- *Count:* enter count of individuals caught in that run
- Repeat for all remaining species and runs

National electrofishing data entry protocol: FishObs DPU

This protocol describes data entry using the Data Processing Utility (DPU) for the MSS FishObs database, with the 'FishObs DPU v30 User Guide' giving detailed worked examples of data entry via the DPU. The DPU can be used on a laptop in the field, alternatively field datasheets have been produced which replicate the tabs within the DPU to allow paper data recording in the field. In this protocol the bold headings refer to tabs in the DPU, with the associated field datasheets in brackets, text in italics refers to the relevant DPU box to complete. For queries on this protocol the first point of contact at FFL isXXXX. In the event that XXXX in on annual leave or absent on business an alternative point of contact will be available through the MSS-FFL main office, request to speak to someone about data entry for the National Electrofishing Programme.

Site Visit (Site & Team Datasheet)

Site Visit Information

- *Start Date:* Enter start date and time
- *End Date:* Enter end date and time
- *Group*: Select your Organisation from the dropdown menu
- *Comments:* Add the Eastings and Northings recorded at the site
    - You can also use the comments box to enter any general information you wish to record, which cannot be stored elsewhere e.g. relevant weather and flow conditions.

Site Information

- Select the relevant site from the Dropdown list
    - Note that if you start typing the site name it will jump to the site in the list
- Alternatively, you can click 'Advanced Site Selection' and 'Filter By Sepa Catchment' and 'Select Site' from a reduced list

Proj / Camp / Proto / Contact (Site & Team Datasheet)

Campaigns

- *Select a Campaign:* Select **'**Nat.Juv.EF' from the dropdown menu and click 'Use this Campaign'
    - Note that the campaign list is not in alphabetical order

Projects

- *Select a Project:* Select 'FWO2G' from the dropdown menu and click 'Use this Project'
  - Note that the project list is not in alphabetical order

Protocols

- *Select a protocol:* Select relevant electrofishing protocol either "National multi-pass electrofishing" or "National single-pass electrofishing" and click 'Use this Protocol'
  - Note that you can uncheck the 'Protocol Met?' box if for any reason the protocol has not followed (e.g. only fished a 50m^2 site and not the minimum 100m^2 included in the protocol).
- *Select a protocol:* Select relevant fish processing protocol: "National fish processing" and click 'Use this Protocol'

Contacts (Team section in the Site & Team Datasheet)

- *Select a Contact:* Select a team member from the dropdown list
- *Select a Contact type:* Select the relevant role from the dropdown list
- Click *Add this contact*
- Repeat the above for all team members /roles if possible
  - Note that at minimum this should record the name of the team member on the electrode.
  - If other team members are not available in the dropdown list record their name and role in the 'site visit comments'

Habitat (Habitat Datasheet)

- Add percentages for each substrate and flow type
  - Note that these must add up to 100 and that hovering over a substrate or flow type will show the description

Equipment (Site & Team Datasheet)

- Click on *'Change Fields'* and place a tick in the following boxes, at minimum (you can record more detailed information if you wish): EquipmentNo, Equipment_Type, EFcond, EFpass, EF-volts, EquipmentDescription, ElectrodeTime, PassTime, StopNets

- Add the relevant information to the columns for each pass.
    - The number of rows in this window should be the number of electrofishing passes. The ‘EquipmentNo’ field should match the ‘EquipmentLink’ field on the ‘Fish’ tab to associate fish with a particular electrofishing pass. E.g. for 3-pass fishing, ‘EquipmentNo’ will be 1, 2, or 3, referring to the first, second and third pass. Fish caught on the first pass will have ‘EquipmentLink’ 1 in the Fish tab to match up with the first row in this tab.

Fish (Fish Datasheet and Site & Team Datasheet)

- Untick ‘No Fish Caught’ unless no fish were caught
- Click on ‘*Change Fields’* and place a tick in the following boxes, at minimum (you can record more detailed information if you wish): DayProcNo, EquipmentLink, DateCaptured, DateProcessed, Species, LifeCycleStageID, SedatedID, Length, ScaledID , Count, Comments, ScalePacketID (if different to the day processing number), ScalePacketStorageLocation, TissueSampleLink (lets you jump to tissue sample screen)
- Complete one row for each row on the fish datasheet
    - Note that once you have completed your first entry (row), you can use ‘sticky’ tabs for things which are the same for every fish e.g. Date, SedatedID
    - You can then hide these unchanging fields by unticking them in *‘Change Fields’* and the information will still be saved. You can then hide the ‘*Change Fields*’ menu to give you more space to view the DPU.
- If you have taken a tissue sample (for genetics) click ‘TissueSample’ so you create a Tissue Sample field. You can then fill in the tissue sample information (see section Tissue Sample)

Tissue Sample (Fish Datasheet)

- Click on ‘*Change Fields’* and place a tick in the following boxes: TissueSampleID, DayProcNo, TissueSampleNumber, TissueType, TissueBoxNumber
- Enter the information in each columns for each fish where a tissue sample was taken (rows with a Tissue sample tube number)

Site Measures (Site & Team Datasheet)

- Click on '*Change Fields'* and place a tick in the following boxes: MeasurementId, Measurement, MeasurementType, Units, MeasurmentNumber, DistanceAlong, MeasuredAlong
- Enter the information in each columns for each site measurement

Options – SAVING ALL YOUR DATA

- Click on '*Save File'* and save the file as a .xml with the filename being "sitename_fishingdate"
- Email the .xml file to XXXX

Appendix 2

NEPS Data Restructuring

NEPS data were stored in both the SFCC and MSS-FFL FishObs databases. These databases have different structures and export capabilities. Consequently, substantial data manipulation and restructuring was required to harmonise exported datasets in a common format.

It was also necessary to ensure that this format met subsequent requirements for modelling capture probability and density (summarised in Table A2.1). Specifically, the data need to be in a ‘long format’, where each row in the data frame is a count of fish for each Visit/Pass/Species/Lifestage combination.

Table A2.1 Information required for current (C) and future (F) analysis

Require information (columns)	Description	Analysis stage
Site name	Unique site identifier	C & F
Easting	Site Easting	C & F
Northing	Site Northing	C & F
Date	Date of electrofishing event	C & F
DoY	Day of the year of electrofishing event	C & F
Year	Year of electrofishing event	C & F
Data source	Name of the database data came from	C & F
Date uploaded	Date that data was uploaded to the database	C & F
Organisation	The organisation/team which completed the electrofishing.	C & F
Number of EF passes	Number of electrofishing passes (1 or 3)	C & F
Visit ID	Unique identifier for the electrofishing event	C & F
Site ID	Unique identifier for the electrofishing site	C & F
Site length	Electrofishing site length (m)	C & F
Wetted area	Electrofishing site wetted area	C & F
Bankfull area	Electrofishing site bankfull area	C & F
Column for each habitat type	Percentages of each habitat type in the electrofishing site: HO_Organic, SI_Silt, SA_Sand, GR_Gravel, PE_Pebble, CO_Cobble, BO_Boulder, BE_Bedrock	F
Column for each flow type	Percentages of each flow type in the electrofishing site: SM_StillMarginal, DP_DeepPool, SP_ShallowPool, DG_DeepGlide, SG_ShallowGlide, RU_Run, RI_Riffle, TO_Torrent	F
Stocking information	Information on if the area is stocked	F
Electrofishing	Electrofishing equipment, recorded in ‘Ef.Equip’	C & F

equipment		
Stop net information	If stop nets were used or not	F
Stop nets description	Any further details on stop nets	F
Pass time	Amount of time taken to fish each pass	F
Pass number	The electrofishing pass the fish was caught on	C & F
Species	The fish species	C & F
Lifestage	The fish lifestage	C & F
Sample ID	Unique identifier of the visitID, species, lifestage	C & F
Sample ID factor	Unique identifier of the visitID, species, lifestage as a number	C & F
Count	Count of fish for the event, pass, species, lifestage	C & F

All restructuring was undertaken using bespoke functions written in R (not provided here). A brief summary of this process is provided in this appendix, where the initial exported data structure, restructuring process and final restructured datasets are described. Once data from each database had been restructured into a common format it could then be combined to create a full NEPS dataset for analysis.

FishObs data restructuring

For a small number of approved users, working on Scottish Government computing systems, direct querying access is available for FishObs via the ‘Business Objects’ software. This allows the production of bespoke queries to generate datasets that can be rapidly analysed and reported with limited pre-processing. For NEPS two data exports were required and appropriate queries written to produce these (coloured in blue in Fig. A2.1):

1. A dataset containing the fish data (counts of each fish species and lifestage per event, pass)
2. A dataset containing the electrofishing event information (number of passes, habitat and equipment information)

Quality control was undertaken on the Data Processing Utility (DPU) files prior to upload to FishObs. Consequently, although quality control checks were undertaken during initial data exploration, no further updates/corrections were required on these datasets. The restructuring of these exports was also relatively limited (summarised in Fig. A2.1).

The main step was to create the ‘0 counts’ i.e. those events with no fish caught at all. The FishObs database (and indeed databases more generally) do not export 0 count/null results, as there is fundamentally nothing (no fish) to export. It is therefore necessary to use the number of passes fished included in the event information to generate a data frame of the appropriate dimensions to which the fish data can be merged. For example, for NEPS a single pass electrofishing observation will have 5 rows (salmon fry, salmon parr, trout fry, trout parr, eels) and a 3 pass electrofishing would have 15 rows (see Event Processing box in Fig. A2.1).

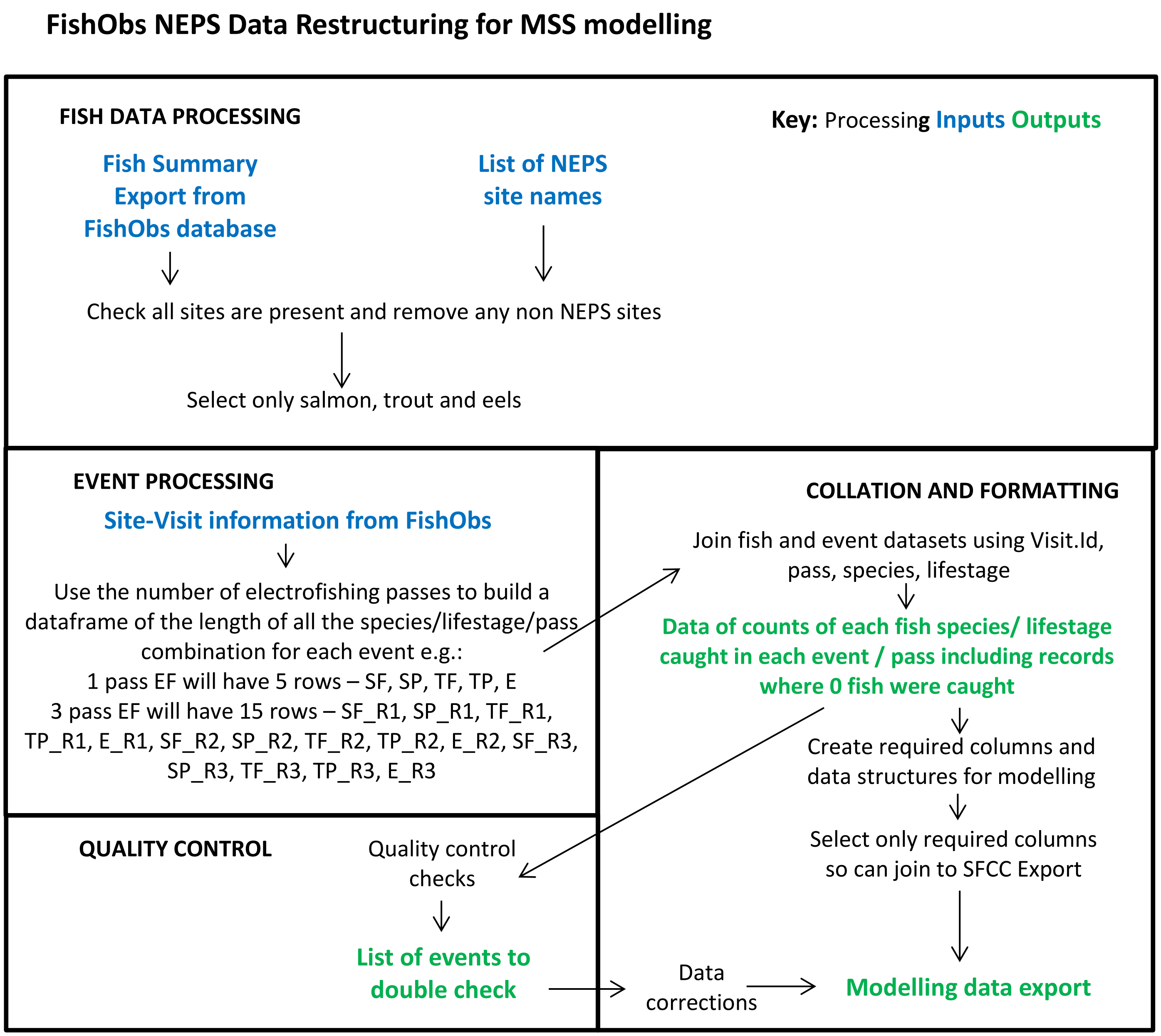


Figure A2.1 Flow diagram of the process followed to restructure data exported from the FishObs database prior to modelling.

Once this event/pass data frame was created the associated fish data could be joined (using common codes for visitID and pass number). Any rows where no fish data were added are those where no fish were caught and could thus have 0 added to the count field. Finally, the required columns for capture probability and juvenile density modelling could be produced (Table A2.2). These have predetermined structures and names to allow them to be joined to the SFCC dataset.

SFCC data export restructuring

In 2018 changes were made to the SFCC database to allow NEPS data to be stored. However, at present, updates have not been made to the database export and querying functionality to allow the generation of datasets that can be rapidly analysed and reported without substantial data manipulation. Further, the existing queries which generate summary exports (as provided by FishObs) were not suitable for exporting NEPS data as individually recorded fish (i.e. all parr) were not included in these standard summary exports. Consequently, it was necessary to work with the individual fish export using the 'Fish Profiler' tool in the SFCC database. For NEPS three data exports were required which used both the 'Fish Profiler' and 'Event Profiler' tools (coloured in blue in Fig. A2.2):

1. A dataset containing fish data (in this case, individual fish export where each row is a fish caught)
2. Other fish species counts export (for circumstances of high abundance where counts of fry were recorded after the first 50 were measured)
3. A dataset containing the electrofishing event information (number of passes, habitat and equipment information)

Unfortunately, due to the numbers of fish exported, and the inability to select only NEPS events to export, it was necessary to undertake multiple individual fish exports to prevent timing out of the SFCC database. This resulted in 5 separate exports (below), which had to be combined to create a single dataframe ('all individual fish caught').

1. Salmon from 1 pass electrofishing,
2. Salmon from 3 pass electrofishing,
3. Trout from 1 pass electrofishing,
4. Trout from 3 pass electrofishing
5. Eels from both 1 and 3 pass electrofishing

After the individual fish exports were combined into a single dataset and any sites that were not part of NEPS were removed, it was possible to begin the relatively complex restructuring process (summarised in Figs. A2.2) using R.

Quality control was undertaken throughout data entry and numerous corrections made. In addition, a suite of quality control checks (Table A2.3) were built into the restructuring function based on commonly observed issues. Further checks were then done during initial data exploration and additional corrections made in the database. This resulted in numerous updated exports from the database to ensure the most reliable data was used - a final quality controlled dataset was available for analysis on 17/12/2019.

Table A2.3 Quality control information generated

Object	Description*
sites_missing	Any sites in the data in the target_sites_vector which are not in the data
no_fish_sites	Sites without any data in the individual fish species export, e.g. those which have not been fished, data not entered, included but with typos or sites with no fish
fishing_type	Should only be "Quantitative (1mm)" – anything else needs to be checked
habitat_type	Should only be "General" – anything else needs to be checked
only_counts	Vector of sites which only have data in the 'OTHERExport' and not individual fish – only fish counts have been added. This should only be used for fry when >50 caught in a pass so double check data entry; no salmon and trout caught but some other species recorded.
no_fry_events	Paste of the SFCC EventID and SiteCode for any events which have no fry caught in any pass (i.e. for the entire fishing). These should be double checked in the SFCC database to ensure that the 0 fry is real and not that the 'coarse age' allocation (to give an 'Assigned.Age') is missing. It would be reasonable to expect that if forgotten this would have been forgotten for both species
no_salmon_fry_events	Paste of the SFCC EventID and SiteCode for any events which have no salmon fry caught in any pass. Same justification as above.
no_trout_fry_events	Paste of the SFCC EventID and SiteCode for any events which have no trout fry caught in any pass. Same justification as above.
no_fish_events	Paste of the SFCC EventID and SiteCode for any events which have no fish for any species or lifestage
areas_missing	NA in the wetted areas
areas_too_big	Wetted areas > $200m^2$
areas_too_small	Wetted areas < $75m^2$

*Where vectors are returned of sites to check this is a paste of the SFCC EventID and SiteCode as the EventID is a unique identifier but the SiteCode is useful for knowing the region/site for contacting trusts. The "." Is used as a separator so

they can be split for querying if needed, where x is the QC vector:
```
as.data.frame(do.call(rbind, strsplit(x, split="|", fixed=T)))
```

The first stage of the restructuring was to generate counts for each combination of event, pass, species, and lifestage from the individual fish dataset. As the SFCC database does not contain a field for lifestage, it was necessary to assign lifestage information using the information contained in the ‘assigned age’ and ‘actual age’ columns. In brief, a fish has a ‘assigned age’ if it is added using the ‘fish count entry’ wizard and the age given using coarse or fine age allocation. In the case of NEPS this relates to all fry. A fish has an ‘actual age’ if it has been added individually using the ‘fish measurement’ wizard. In the case of NEPS this relates to all parr.

Once the lifestage was assigned for all fish, they could then be aggregated into the required summary information of counts per event, pass, species and lifestage. Any additional counts of fry added as ‘other fish species’ (in circumstances of high abundance) could then be added onto the counts.

Next it was necessary to create ‘0 counts’ i.e. those events with no fish caught at all. The same process was followed as for FishObs (see Event Processing box in Fig. A2.2). Once this event/pass data frame had been created the associated fish data were attached (using the EventID and pass number). Any rows where no fish data were added were those where no fish were caught and could thus have 0 added to the count field.

Finally, the required columns for capture probability and juvenile density modelling were produced (Table A2.4). These have predetermined structures and names to also allow joining to the FishObs dataset.

SFCC NEPS Data Restructuring for MSS modelling

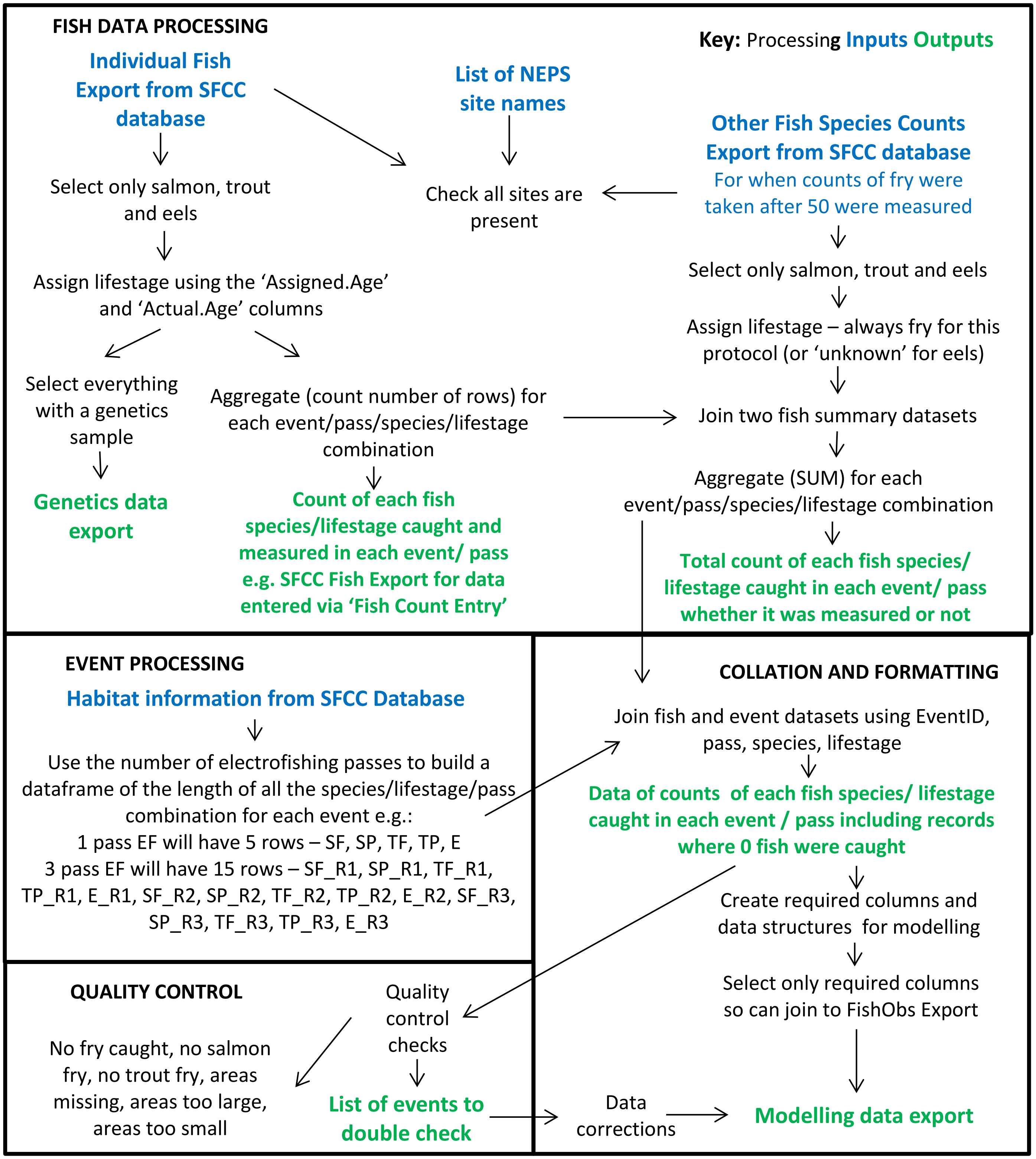


Figure A2.2 Flow diagram of the process followed to restructure data exported from the SFCC database prior to modelling.

Marine Scotland Science
Freshwater Fisheries Laboratory
Faskally
Pitlochry
PH16 5LB

Copies of this report are available from the Marine Scotland website at
www.gov.scot/marinescotland