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Scottish Marine and Freshwater Science Vol 11 No 9

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

The National Electrofishing Programme for Scotland (NEPS) 2019

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

Scotland's rivers support fish populations that are of high economic, conservation and cultural value. Evidenced based management of these important natural resources requires defensible, quantitative assessments of population status and trends. Electrofishing data are one of the most commonly collected sources of information on the status of salmon and other freshwater and diadromous fish populations providing status assessments at nested spatial scales ranging from individual sites (< 100m) to the whole of Scotland. In 2018 the National Electrofishing Programme for Scotland (NEPS) was established to provide unbiased quantitative data on the abundance of Atlantic salmon and other freshwater fish species in Scotland's rivers. When combined with a benchmark for expectation, this allowed assessment of the status of salmon stocks. In 2019, the survey was repeated. This report presents an analysis of the 2019 data, compares salmon abundance and status between years and reports on method developments since 2018. These include the introduction of a new capture probability model for trout, presentation of data on trout abundance and approaches for combining independent surveys within years, and repeat surveys between years. Climate conditions contrasted strongly between the NEPS survey years with 2018 recorded as one of the hottest and driest years on record, while 2019 was the second wettest summer ever recorded in Scotland. As a result wetted widths were on average 7-12% higher in 2019 than 2018 depending on how this was assessed. Salmon fry density declined by 44% between 2018 and 2019, largely in response to a substantial reduction in spawner numbers. Salmon parr density also declined, although the reduction was smaller at

ca. 17%. In both cases some of the differences in density will reflect differences in wetted widths as higher wetted widths result in lower observed densities for the same overall juvenile production. The overall status of salmon at the national scale (based on fry and parr) declined from Grade 1 in 2018, to Grade 3 in 2019 (Grade 2 averaged across years). The number of NEPS regions classified as Grade 3 for salmon fry increased from 9 to 14 (of 27), although the regional performance of parr improved slightly (decreasing from 14 to 12) reflecting a stronger 2018 cohort year for fry. Future developments of the NEPS programme will include the introduction of a benchmark for trout and revisions to survey design to better reflect the spatial configuration of local management organisations, reporting needs, management of over-samples and improvements to the sample frame to reflect changes in the mapping of barriers, lochs and canals. Scientific challenges associated with spatial configuration of data providers and availability of suitable multi-pass data to parameterise capture probability models were identified. It is suggested that data providers obtaining funding for NEPS sampling in future years should be required to meet minimum specified criterion in terms of experience and multi-pass data provision.

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 levels (The European Commission Habitats Directive, 92/43 EEC). 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 largely 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. Between 2015 and 2018 total reported rod catch for Atlantic salmon (caught and released) declined from 56,006 to 37,586, with 2018 being the lowest recorded rod catch in Scotland since records began in 1952.

Brown trout exhibit a wide range of life history strategies that includes freshwater resident and diadromous forms (sea trout). Sea trout rod catches have declined almost since records began in 1952. The rod catch for sea trout in 2018 was the lowest on record (Marine Scotland, 2020b). Because it is not easily possible to differentiate resident and anadromous forms of brown trout at the juvenile lifestage, surveys and assessments often focus on the species as a whole.

The last economic assessment of wild fisheries in Scotland (PACEC, 2017) indicated that the activity (which is dominated by salmon and trout angling) contributed around £79.9m Gross Value Added (GVA) to the Scottish economy each year, supporting 4,300 full-time equivalent jobs. Evidenced based fisheries management of these valuable natural resources thus requires defensible, quantitative assessments of population status to ensure sustainable management.

Electrofishing data are one of the most commonly collected sources of information on the status of salmon and other freshwater and diadromous species (those spending time in marine and freshwater environments). Electrofishing data can also provide assessments at nested spatial scales ranging from individual sites (10s m), to sub-catchments, catchments, regions or whole countries. This spatial flexibility and potential for upscaling makes juvenile assessment particularly attractive for management decision making.

In 2018 Marine Scotland Science established the National Electrofishing Programme for Scotland (NEPS), a collaborative programme of data collection supported by local fisheries managers and funded by Marine Scotland (MS), the Scottish Environment Protection Agency (SEPA) and Scottish Natural Heritage (SNH). In 2019, the programme was run for a second year with funding support from MS and Crown Estate Scotland (CES).

Malcolm et al. (2019b) provided a report using the first year of data from NEPS that outlined 1) survey design and protocols 2) a capture probability model for estimating salmon abundance from electrofishing data 3) a "benchmark" for salmon against which observed densities could be compared to assess status 4) approaches for scaling site-wise estimates of abundance and the benchmark to larger spatial scales 5) assessments of the status of salmon in 2018 at site, catchment, regional and national scales using a 3-level grading system that reflected estimates of abundance and associated uncertainty relative to the benchmark.

This report is an extension of this previous work, adding a second year of data and addressing the following objectives:

- Compare hydrological conditions between 2018 and 2019 and assess the potential consequences for estimates of wetted width and thus survey area and abundance
- Develop a capture probability model for salmon and trout
- Present site-wise and regional information on the abundance of salmon and trout for 2019
- Compare regional abundances of salmon and trout between years (2018, 2019)
- Combine surveys from 2018 and 2019 to provide an average estimate of abundance, and in the case of salmon, status, across years

- Outline an approach for combining NEPS survey data with additional local surveys to obtain enhanced assessments of abundance and status at finer spatial scales than NEPS regions using a case study for the River Clyde.

Materials and Methods

Survey design

Full details of the NEPS survey design are provided by Malcolm et al. (2019b). However, in brief, NEPS is a Generalised Random Tessellation Stratified (GRTS) sample for survey over time. The sample frame consists of all rivers below impassable barriers, with a Strahler river order of 2-4, where there are also registered salmon fisheries within the catchment. The NEPS survey was designed to operate over a period of up to 9 years, but will be re-designed for 2021. The design consists 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) designed to balance spatial coverage and trend detection. Sample site selection is weighted towards areas of the network where higher juvenile salmon densities are expected (based on the Benchmark model predictions).

Electrofishing data

Electrofishing was undertaken by local fisheries managers following standard operating procedures developed by Marine Scotland Science in consultation with NEPS collaborators where full details can be found (see Appendix 1). All electrofishing data were area delimited. During 2018, ten of the 30 sites in each region 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. In 2019, the same procedure was followed. However, three passes were only carried out where at least one salmon was caught on the first pass. If no salmon were caught on the first pass, then the requirement for 3-pass fishing would pass to the next 1-pass site that was visited. This adjustment aimed to improve the data available to estimate capture probability for salmon. The effort expended on the first pass of the multi-pass electrofishing and the single pass electrofishing should be the same. It was expected that sampling should be completed between 01 June and 30 September, with data entry and QC completed by the end of October. Basic habitat information was recorded at each site and water quality samples collected for analysis at MSS-FFL. Genetic samples were obtained from all 3-pass sites. During 2019 all data were stored in the Marine Scotland Science Fish Observation (FishObs) database, making use of the FishObs Data Processing Utility (DPU) for data entry (Appendix 2). This greatly improved project management, work flows, quality control and reporting procedures.

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. Covariates were generated for every node on the GRTS Digital River Network (DRN) and for all electrofishing sites using an in-house R package (FFL GIS) and scripts following the methods described by Jackson et al. (2017) and Malcolm et al. (2019a) where further details can be found.

The influence of inter-annual variability in flow conditions on estimates of wetted width

The effects of between-year flow variability on wetted width (and thus area) were investigated through two approaches. Firstly, the log transformed width data collected from common sites in 2018 and 2019 (i.e. the annual samples) were plotted against each other alongside a 1:1 line to visually assess potential differences between years. Subsequently a linear mixed model (LMM) was fitted to these data to test for between year differences in width measurement. This can be written symbolically as:

$$logWidth_{measured} \sim Year + RE(Region{:}Year) + RE(Site)$$

where RE indicates random effects, : denotes an interaction and a significant Year effect would indicate differences in wetted width between the survey years.

Secondly, the wetted widths in 2018 and 2019 were plotted against a static measure of river width obtained from the Ordnance Survey MasterMap spatial dataset. All width data were log transformed prior to analysis. River width from the Ordnance Survey dataset was calculated by dividing river polygon areas by river length.

Unfortunately, only larger rivers are represented as polygons in the MasterMap dataset, with smaller rivers represented as line features. The scale at which rivers are captured as polygons also varies spatially and depends on landuse categories e.g. urban (1m) and moorland / mountain (2m). To address this issue any GIS derived widths of zero (line features) were excluded from the comparison. Differences in the relationships between field derived wetted widths in the two years and GIS derived widths were then assessed using a second LMM where Region was a factor for GRTS strata, Site was a factor representing unique sites.

$$Width_{measured} \sim Year + Width_{GIS} + Year{:}Width_{GIS} + RE(Width_{GIS}{:}Region) + RE(Site)$$

A significant $Year$ effect would indicate differences in level and thus wetted widths between years (when conditioned on GIS width). A significant $Year{:}Width_{GIS}$ effect would indicate the slope of the relationship between GIS and measured widths also varied between years.

Both models were fitted using the package lme4 1.1 – 23 (Bates et al., 2015). Model selection and significance tests were performed using the package lmerTest 3.1-2 (Kuznetsova et al., 2017). Model selection was based on AIC. The significance of model terms was determined by t-tests using Satterthwaite's method.

Estimating capture probability

Capture probability was estimated following the methods described by Millar et al. (2016) and Malcolm et al. (2019a) where full details can be found. The capture probability model was fitted to a dataset that included previously published multi-pass electrofishing data collected across Scotland between 1997- 2015 (Malcolm et al. 2019a), ad-hoc data collected between 2016 and 2017 and new data collected under NEPS in 2018 and 2019. In contrast to previous analyses, the capture probability model was fitted to both salmon and trout. Capture probability was modelled as a logistic function of covariates representative of people and equipment (Organisation-Team), fish size and behaviour (life-stage and electrofishing pass / run), time (Year and Day of the Year, DoY), habitat (e.g. Altitude, Upstream

Catchment Area, UCA; River Distance to Sea, RDS; and Gradient), land use (Conifer, Deciduous and Mixed trees, Urban area) and geographical region (Hydrometric Area, HA). The term Organisation (as an indicator of staff) was divided into broad time periods (Organisation Team) to reflect major organisational changes identified from an assessment of staff names / abbreviations identified in the SFCC database and available web based materials. Model selection followed a step-up-down procedure starting from a large model. The model scope (maximum possible model complexity) allowed for 3-way interactions between Species, Lifestage, HA, Year, Organisation-Team and Pass, and 4-way interactions between all combinations of Species, Lifestage, Pass; and DoY, landscape and habitat covariates (RDS, Altitude, UCA, Gradient, Conifer + Mixed + Deciduous + Urban). In some cases it was not possible to estimate capture probability for individual Organisation - Teams due to small samples sizes (see discussion). In these circumstances it was necessary to group teams within a region or adjacent time period (e.g. Nairn 2019 was given the same factor level as Nairn, Findhorn and Lossie fisheries trust 2018).

Estimating site-wise (observed) salmon and trout densities

Fish densities were estimated for each species, lifestage and electrofishing site following the methods described by Glover et al. (2018) and Malcolm et al. (2019a) 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 count for each species / lifestage combination 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 (salmon only)

Site-wise benchmark densities were calculated for salmon, 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. (2019a). Benchmark densities were calculated separately for fry and parr life-stages and represent the densities that would be expected for a particular site (on average) assuming adequate spawner numbers in the absence of major environmental impacts.

Scaling benchmark densities to region (salmon only)

The regional scaled benchmark for salmon 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), see Malcolm et al. (2019b) for further details.

Scaling site-wise observed densities to region

The R package “spsurvey” (Kincaid et al., 2020) 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 the 2018 and 2019 surveys. 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 of sample frame) in each strata or combination of strata (e.g. national scale) together with associated 95% confidence bounds. Post stratification can also allow for estimates at smaller spatial scales e.g. sub-catchments within strata.

Combining surveys across years

Within a single year, a juvenile salmon survey characterises at least two and potentially more spawning years depending on age at emigration to sea. However, adult based assessments average river performance over a longer period of 5 years to avoid short term (year-to-year) perturbations in river grades. It is possible to combine two annual surveys for a given species and lifestage as follows. Let $\hat{A}_1$ and $\hat{A}_2$ be the estimates of mean density in years 1 and 2 respectively from the individual surveys. Then

$$\hat{T} = \frac{1}{2}(\hat{A}_1 + \hat{A}_2)$$

is an estimate of the mean density across the two years. $\hat{T}$ has variance:

$$Var\,\hat{T} = \frac{1}{4}\left(Var\,\hat{A}_1 + Var\,\hat{A}_2 + 2Cov\left(\hat{A}_1, \hat{A}_2\right)\right)$$

where the covariance term is required because some sites are sampled in both years. An approximate upper bound for the covariance is:

$$Cov = \frac{m}{\sqrt{(m + n_1)(m + n_2)}}\ \sqrt{Var\,\hat{A}_1 \times Var\,\hat{A}_2}$$

where m denotes the number of common sites across both surveys and n_1 and n_2 denote the number of unique sites in surveys 1 and 2 respectively. The first term in the covariance formula can vary between zero (no common sites and the surveys are independent) and one (where all sites are shared between years).

Combining surveys within years: supplementing NEPS survey data

The NEPS survey design is constrained in terms of budget and the capacity of collaborating organisations to deliver field programmes. However, in some circumstances it will be desirable to assess the status of stocks at finer scales than NEPS regions. Where there are many NEPS samples collected within a single river catchment, it may be possible to achieve this through post-stratification of the NEPS survey (Malcolm et al., 2019b). In other circumstances, local fisheries managers may wish to supplement the NEPS survey for one or more catchments within a region. In these circumstances, the NEPS data can be post-stratified and combined with a second independent survey. In these circumstances, both surveys represent independent samples of the same resource in the same year and as such the surveys can be weighted by the sample size as follows:

$$\hat{T} = \frac{n_1 \hat{A}_1 + n_2 \hat{A}_2}{n_1 + n_2}$$

Where $\hat{T}$ is the mean of the two surveys, $\hat{A}$ are the estimates of mean density in the two surveys and n is the number of sites in the surveys.

The uncertainty of the combined surveys can be estimated as follows, again using the sample sizes of the individual surveys:

$$Var\,\hat{T} = \frac{n_1^2\ Var\,\hat{A}_1 + n_2^2\ Var\,\hat{A}_2}{(n_1 + n_2)^2}$$

where Var is the is the variance of the individual surveys.

Regional assessments of status for salmon (grades)

Since 2016, Scottish rivers have received one of three conservation grades associated with an adult assessment method (Marine Scotland, 2020c). 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, 2020c). 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 fry and parr 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. Grades were established for 2018, 2019 and 2018/19 combined for each life-stage using the following rules, which are also illustrated in Figure 2:

- Category 1: The mean observed density exceeds the benchmark
- Category 2: The benchmark is within the 95% confidence limits of the mean observed density
- Category 3: The upper 95% confidence limit of the mean observed density is below the benchmark

In circumstances where the observed densities are highly skewed, the assumptions and approximations used in the calculation of confidence limits break down, resulting in lower confidence limits of <0. Where this was associated with estimates of mean abundance that exceeded the benchmark, an additional rule was invoked to make these regions Grade 2, rather than Grade 1, to reflect the high levels of uncertainty (Figure 2).

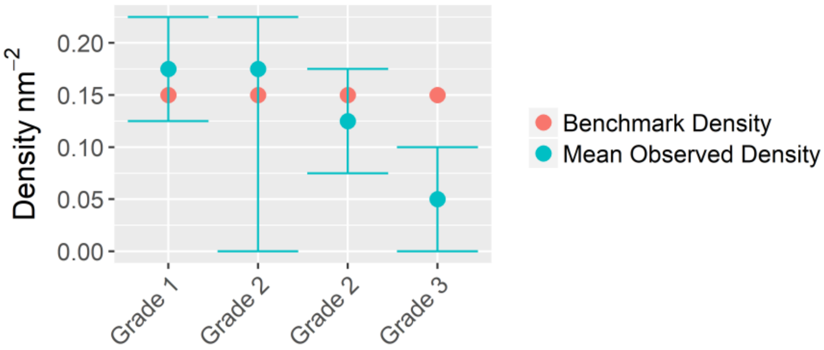

Figure 2 Theoretical scenarios under which a region would be classified as Grade 1, 2 or 3.

Next, the grades for the two life-stages are combined to provide a single juvenile assessment grade for 2018, 2019 or 2018/19 (combined years). The combined status favoured the better of the two lifestage 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, 2018a), particularly the north and north/east of the country where rainfall was <50% of the 1981-2010 average (Fig. 4, Met Office, 2020). This resulted in unusually low river flows across Scotland with exceptionally low flows in northern rivers (CEH, 2018, Fig. 5). During September rainfall was higher than average in the north and west, resulting in high river flows and challenging sampling conditions in the final month of the specified monitoring period.

In contrast, the summer of 2019 was the second wettest Scottish summer on recorded, with rainfall ca. 147% of the long-term average (Fig. 4). Above average rainfall was seen across most of Scotland in July and August, with many areas experiencing >200% of the long-term mean (1981-2010). September was characterised by above average rainfall in the south of the country, and below average rainfall in the north and west. High rainfall gave rise to higher than average flow conditions, particularly during July and August (Fig. 5).

The summers of 2018 and 2019 therefore provided strongly contrasting hydrological conditions that represent the extremes of summer rainfall and flow conditions observed under current climate in Scotland.

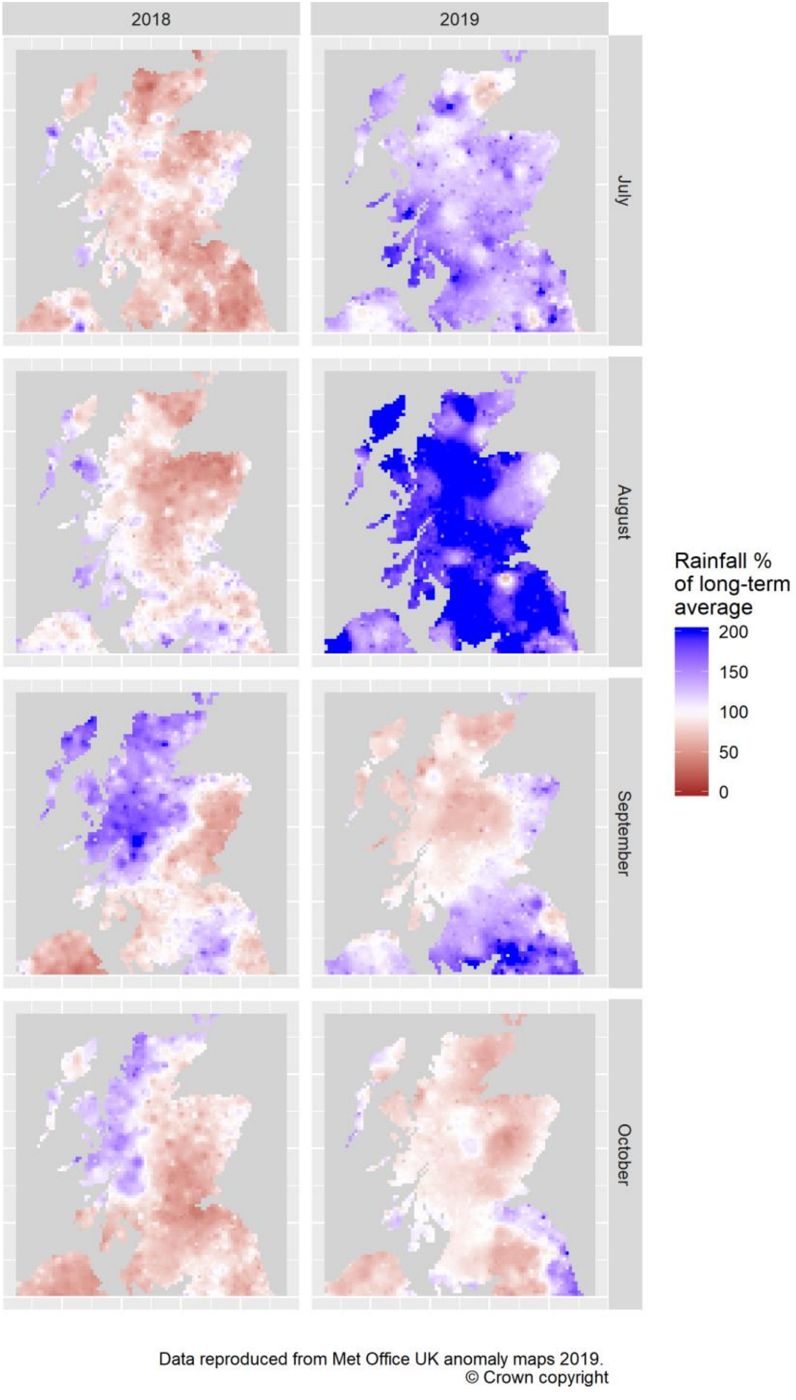

Figure 4 Percentage of long-term average rainfall for July-October when electrofishing was undertaken. Reproduced from MET Office (2020) UK actual and anomaly maps.

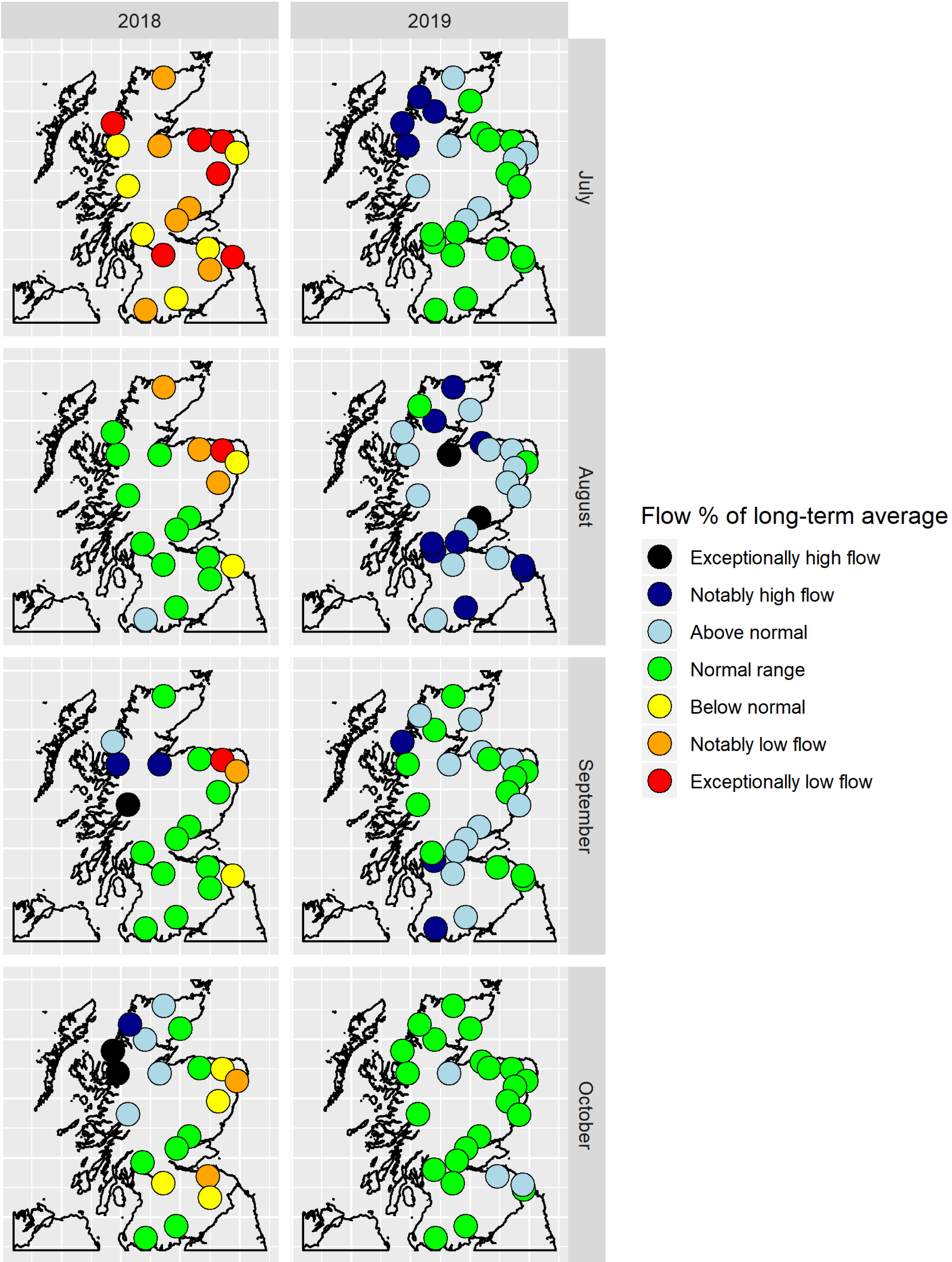

Figure 5 River flows across Scotland during the electrofishing season compared to a 20 year baseline (1981-2010). Colours indicate the 2018 and 2019 flow ranking relative to baseline years.

Inter-annual variability in hydrological conditions and wetted width

The wetted width of sites visited in both years was on average 11% higher in 2019 compared to 2018 (P <0.05, Fig. 6). The Brora-Helmsdale region appeared to be an outlier in this overall pattern, potentially reflecting different implementation of standard SOPs for the measurement of wetted width (and improved guidance) across survey years. If Brora-Helmsdale sites were removed from the analysis then wetted widths were on average only 7% higher in 2019 (P <0.001)

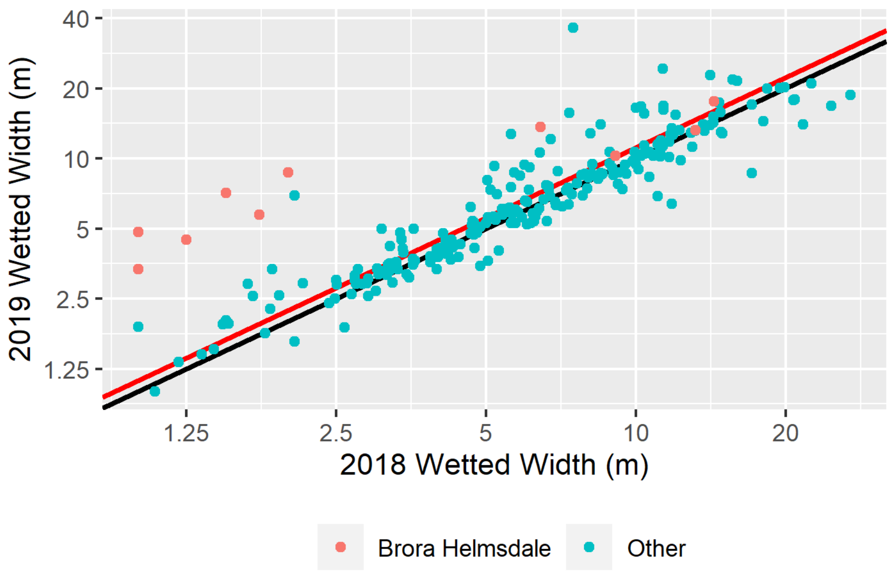

Figure 6 Relationship between wetted width measurements in 2018 and 2019 for sites that were visited in both years. The black line represents unity. Points above the black line were wider in 2019 than 2018 and vice versa. Red line shows the effect of 2019 for the model including Brora-Helmsdale.

When all survey sites were considered, wetted widths were typically larger than GIS derived widths in smaller channels, but smaller than GIS widths in larger channels. In common with the analysis of repeat sites, modelling suggests that wetted widths in 2019 were on average ca. 12% greater than those in 2018 when conditioned on GIS width (P <0.001). There was no interaction between Year and GIS width in the final model suggesting that the slope of the relationship between GIS and wetted widths was broadly consistent between years.

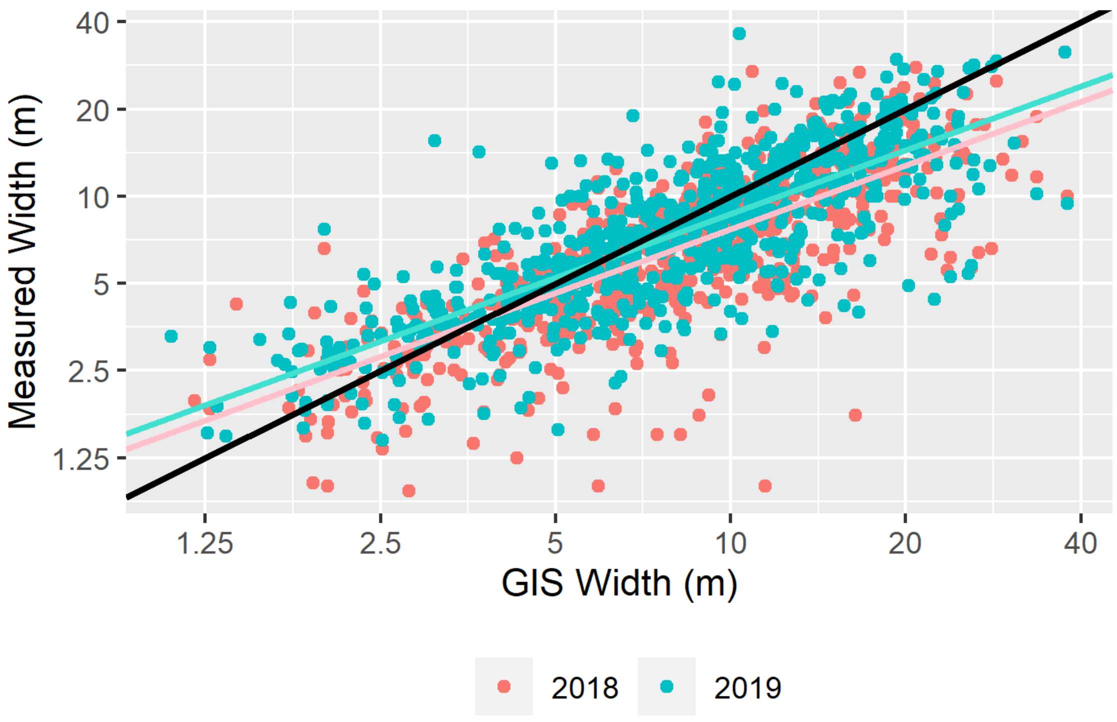

Figure 7 Relationship between measured wetted widths and GIS derived channel widths for all electrofishing sites sampled during 2018 and 2019. Black line indicates unity. Coloured points represent electrofishing sites. Points above the black line indicate wider measured widths than GIS widths and vice versa. Coloured lines indicate fitted relationships between GIS and measured widths.

Timing of electrofishing data collection

NEPS data providers were asked to electrofish between July and September and to complete data entry by the end of October. In some cases the timing of electrofishing in 2019 was affected by unsuitable flow conditions (Fig. 6). Nevertheless, all but two regions completed the surveys in full and this was generally within requested time scales. It was not possible to complete all surveys in Lochaber and Northern regions where 29 and 28 (of 30) sites were completed respectively. Unfortunately five of the sites in the Clyde subsequently proved to be located above impassable barriers and were thus excluded from further analysis.

Figure 8 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 (*P*)

The final capture probability model for salmon and trout was:

logit P ~ species + lifestage + pass + species:lifestage + lifestage:pass + Organisation - Team + Year + Altitude + species:Altitude + s(UCA:lifestage) + s(Gradient) + s(DoY:lifestage) + s(HA)

where s() denotes smoothed responses and : indicates an interaction term (Fig. 9).

Capture probability was higher for trout than salmon (Fig. 9A), for parr than fry and the first pass versus subsequent passes. There were also small differences in the effect of lifestage between species (greater increase in *P* for salmon parr than trout parr) and the effect of pass between lifestages (greater increase in *P* for fry than parr on second or subsequent passes).

Capture probability varied temporally with Year (Fig. 9B) and DoY (Fig. 9D). Year was a positive linear effect. DoY was a modal response varying by lifestage where modality was greater for fry than parr, the latter exhibiting a more linear positive response.

Capture probability varied spatially with Altitude, Gradient, UCA and HA. The response was negative with Altitude (Fig. 9E), Gradient (Fig. 9F) and UCA (Fig. 9G). The response to Altitude also varied between species, with stronger negative effects for trout than salmon. The negative response to UCA varied with lifestage and was steeper for parr than fry. There were complex spatially correlated regional patterns in *P* associated with HA (Fig. 9H).

Capture probability varied substantially between Organisation - Teams (Fig. 9C), although major differences were typically between Organisation, rather than between Teams within Organisation. 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 regional (HA) and Organisation effects (Organisation - Team). To address this issue Figure 10 combines the effects of Organisation and HA for those Organisation - Teams undertaking sampling for NEPS in 2019.

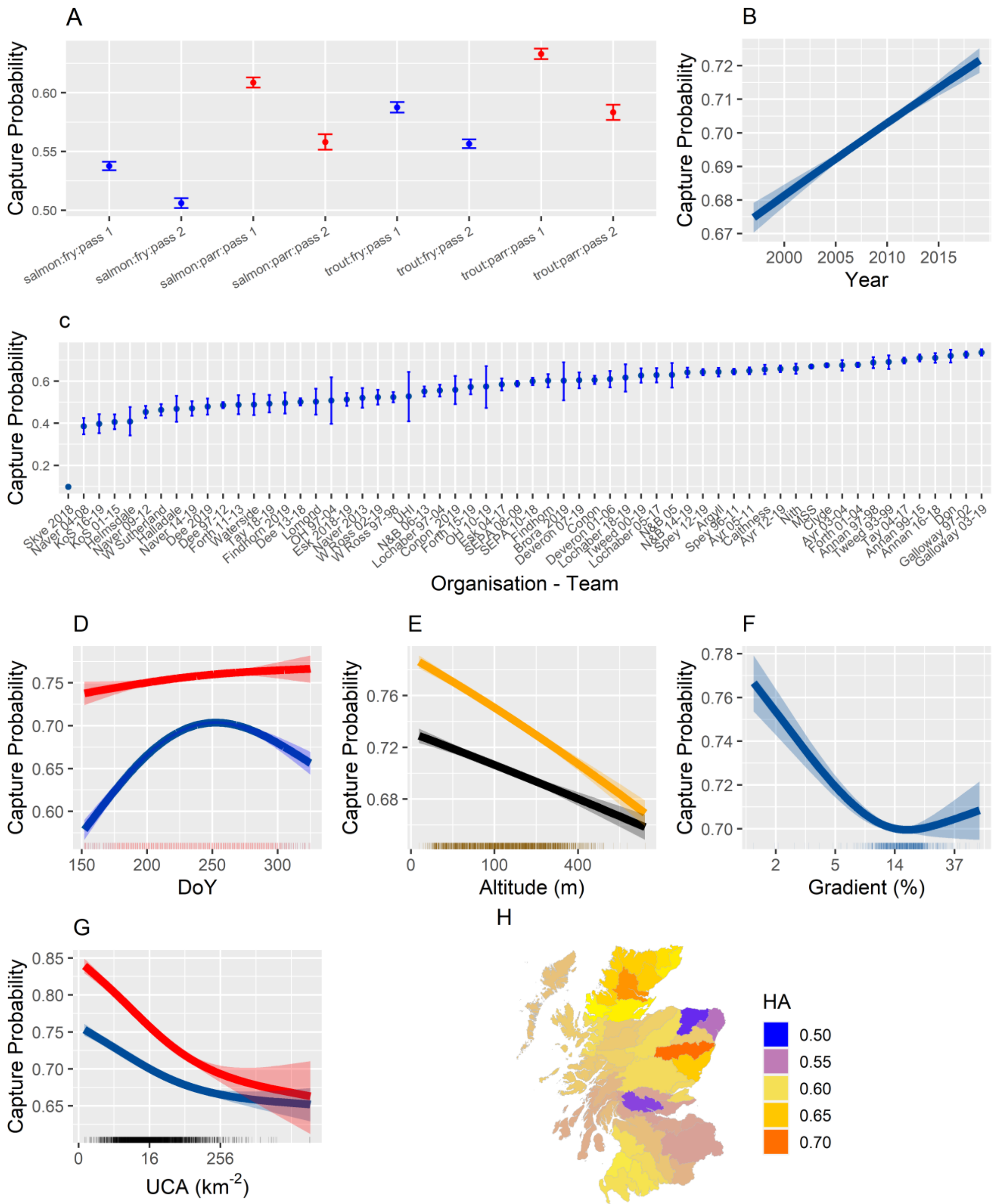

Figure 9 The effects of species, lifestage and pass (A), Year (B), Organisation - Team (C) Day of the Year : lifestage (D), Altitude : species (E) Gradient (F) Upstream Catchment Area : lifestage (G), and Hydrometric Area (H) on capture probability. Where effects differed between Species or Life-stage they are plotted separately for salmon (black), trout (orange) fry (blue), parr (red). 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. A rug indicates the distribution of the data on the x-axis.

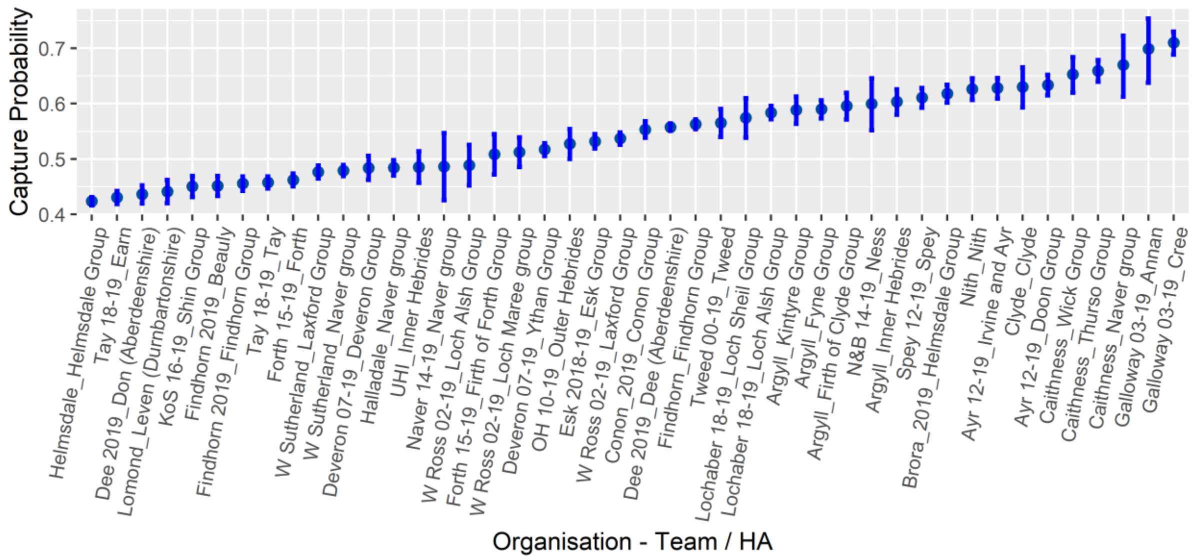

Figure 10 Combined partial effect of Organisation - Team and HA on capture probability. All effects are scaled to the mean fitted first pass capture probability. Approximate 95% pointwise confidence intervals are shown as vertical lines.

Site-wise estimates of abundance (salmon and trout) and status (salmon)

Estimates of the density of trout and salmon from the 2019 NEPS survey are shown in Figures 11 and 12 respectively. High trout densities were observed at sites in the Tweed (particularly in the case of fry) and the north-east of the country. Densities were generally low in the north and west.

A large number of the 2019 NEPS sites contained no salmon fry (black points, Fig. 9A), although the situation was somewhat better for parr (Fig. 9B). Salmon fry abundances were generally greater in the east and north of the country, with lower abundances in the north-east and west, particularly the south-west. Salmon parr densities were higher in the northern half of the country, although the north-east was again associated with low abundances or sites without salmon.

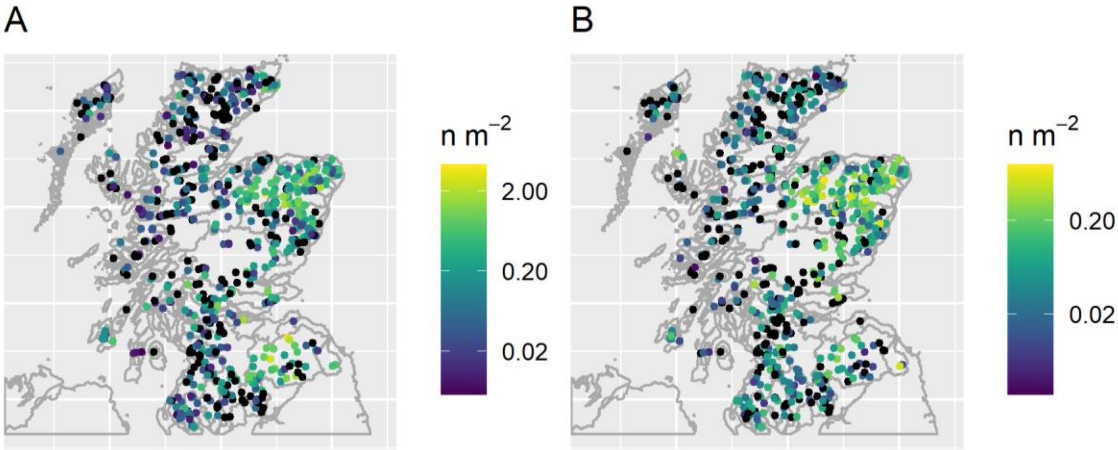

Figure 11. Maps showing spatial variability in trout densities for fry (A) and parr (B). Black points indicate sites where no fish (of the relevant life-stage) were caught.

Not all sites are expected to produce the same densities of fish. This is due to spatial variability in habitat quality. In the case of salmon, this is captured by spatial variability in the benchmark (Malcolm et al., 2018). Unfortunately a benchmark is not currently available for trout. The performance of salmon at individual sites can therefore be assessed through comparison with the benchmark (Fig. 12 C, D). The 2019 data showed a wide range of performance against the benchmark, but sites where observed densities were below the benchmark dominated the picture, particularly for fry. Parr densities indicate a slightly better picture, especially in the north of the country and to a lesser extent the south-west.

While 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 and is illustrated in Figure 12 (E, F). It can be seen that production is often substantially below expectation across much of the country, although the North of Scotland appears to perform better.

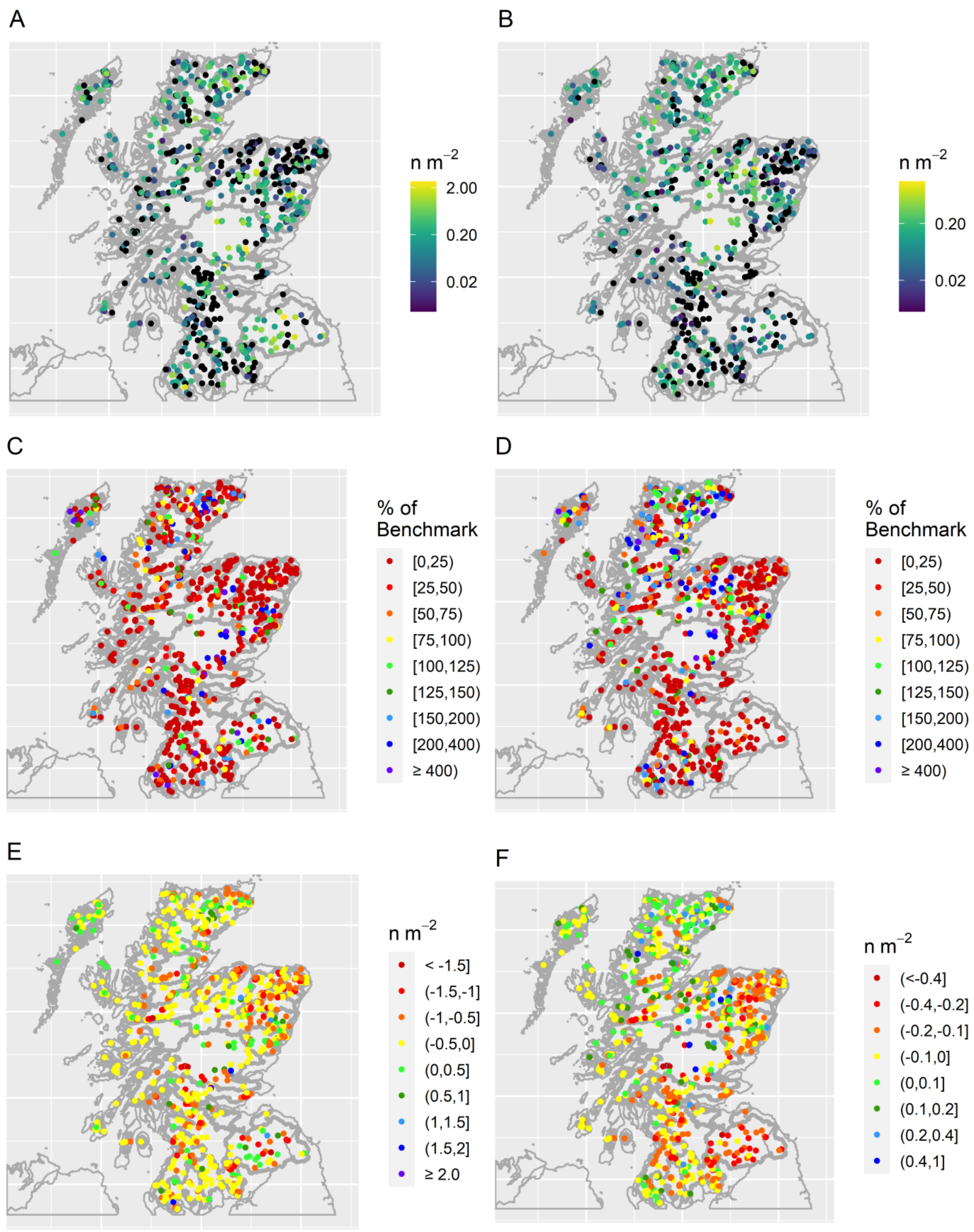

Figure 12. Maps showing spatial variability in observed salmon densities (A, B) together with their percentage (C, D), and absolute (E, F) performance against benchmark. Panels A, C and E show the results for fry. Panels B, D and F show results for parr. Black points indicate sites where no fish (of the relevant life-stage) were caught.

Regional abundance of salmon and trout

Salmon fry densities were lower in 2019 than 2018 across much of the country. Abundances were particularly low in north-east and west. Salmon parr abundances were more stable but declined particularly in the north and west.

Spatial patterns of abundance for trout were more consistent across years, although densities were generally lower in 2019 than 2018. In 2018 trout fry were particularly abundant in the Tweed, Tay, Spey, and to a lesser extent Clyde, Deveron and Ugie regions. In 2019, high abundances of trout were also evident in the Don. Patterns of trout parr abundance were generally similar, but lower in the Tweed, potentially reflecting early migration of sea trout parr. Trout fry and parr abundance were generally lower in 2019 than 2018.

Spatial and temporal variability in abundance is further illustrated in Figure 14, where the performance against the benchmark is also illustrated for salmon. Overall, regional rankings in abundance were generally maintained among years indicating broadly consistent spatial patterns of abundance. The decrease in salmon, and to a lesser extent trout fry numbers between 2018 and 2019 is again apparent.

By applying the assessment rules set out in Figure 2, it is possible to generate a salmon grading for each region, year and lifestage, but also for the combined 2018 and 2019 surveys. From the individual lifestage grades it is then possible to generate overall grades. These various combinations are illustrated in Figure 15. Of the 27 regions, the number classified as Grade 3 for fry increased from nine to fourteen between 2018 and 2019. However, the number of regions recorded as Grade 3 for parr decreased from 14 to 12. Regions where the overall assessment (fry and parr) was Grade 3 increased from 7 to 8 balancing the differences observed in the performance of fry and parr. If both the annual surveys are combined, and lifestages are also combined to provide an overall assessment, then nine regions attained Grade-1, eight Grade-2 and ten Grade-3. Grade 3 rivers were generally in the south-west and north-east of the country.

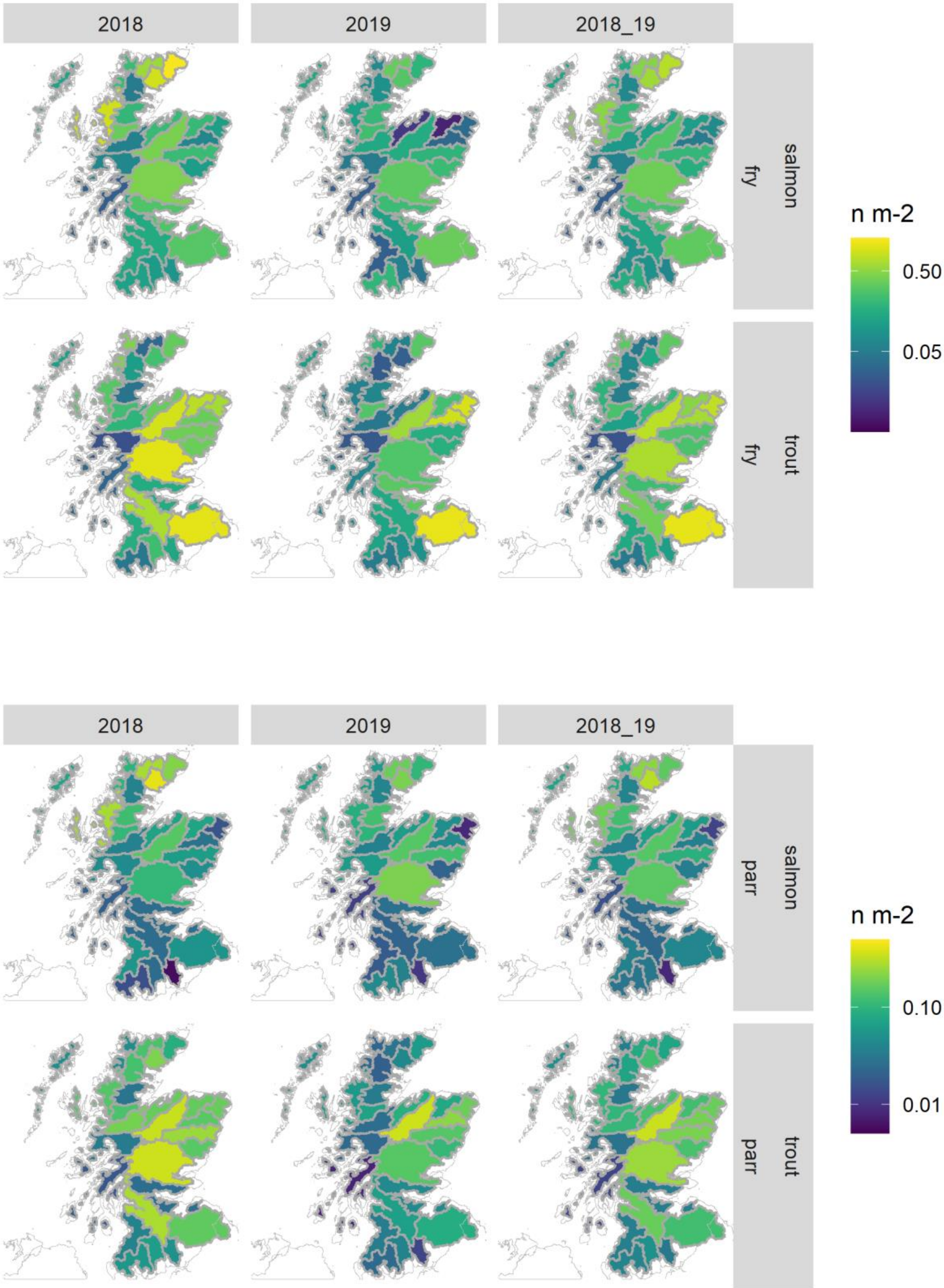

Figure 13 Regional estimates of abundance for salmon and trout, fry and parr obtained from the NEPS GRTS survey data in 2018, 2019 and averaged across both survey years.

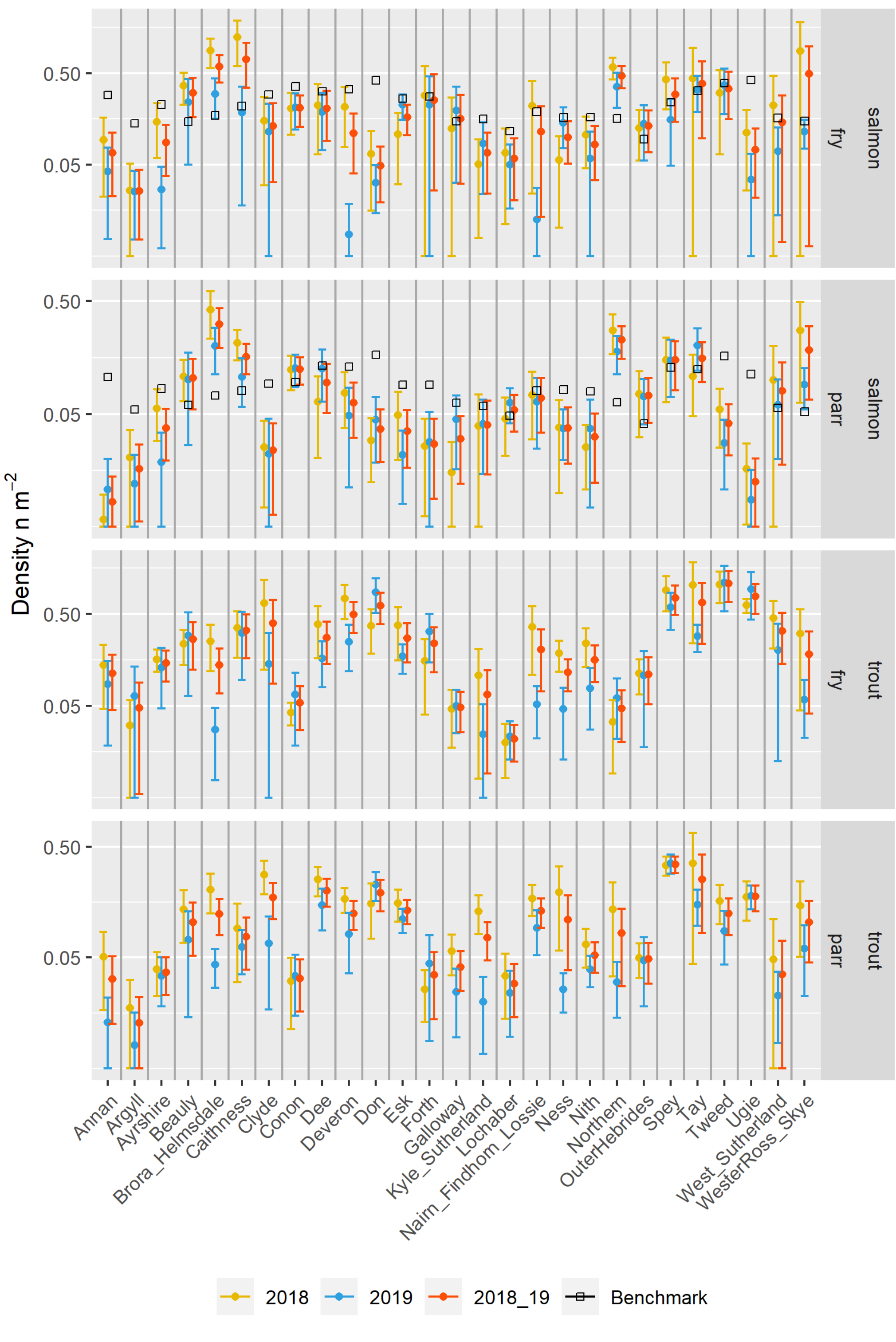

Figure 14 Estimates of mean observed densities of salmon and trout, fry and parr estimated from GRTS samples. In the case of salmon, these can be compared with regional benchmark densities (scaled up from the national benchmark using the DRN). Vertical bars indicate 95% confidence bounds about the mean 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.

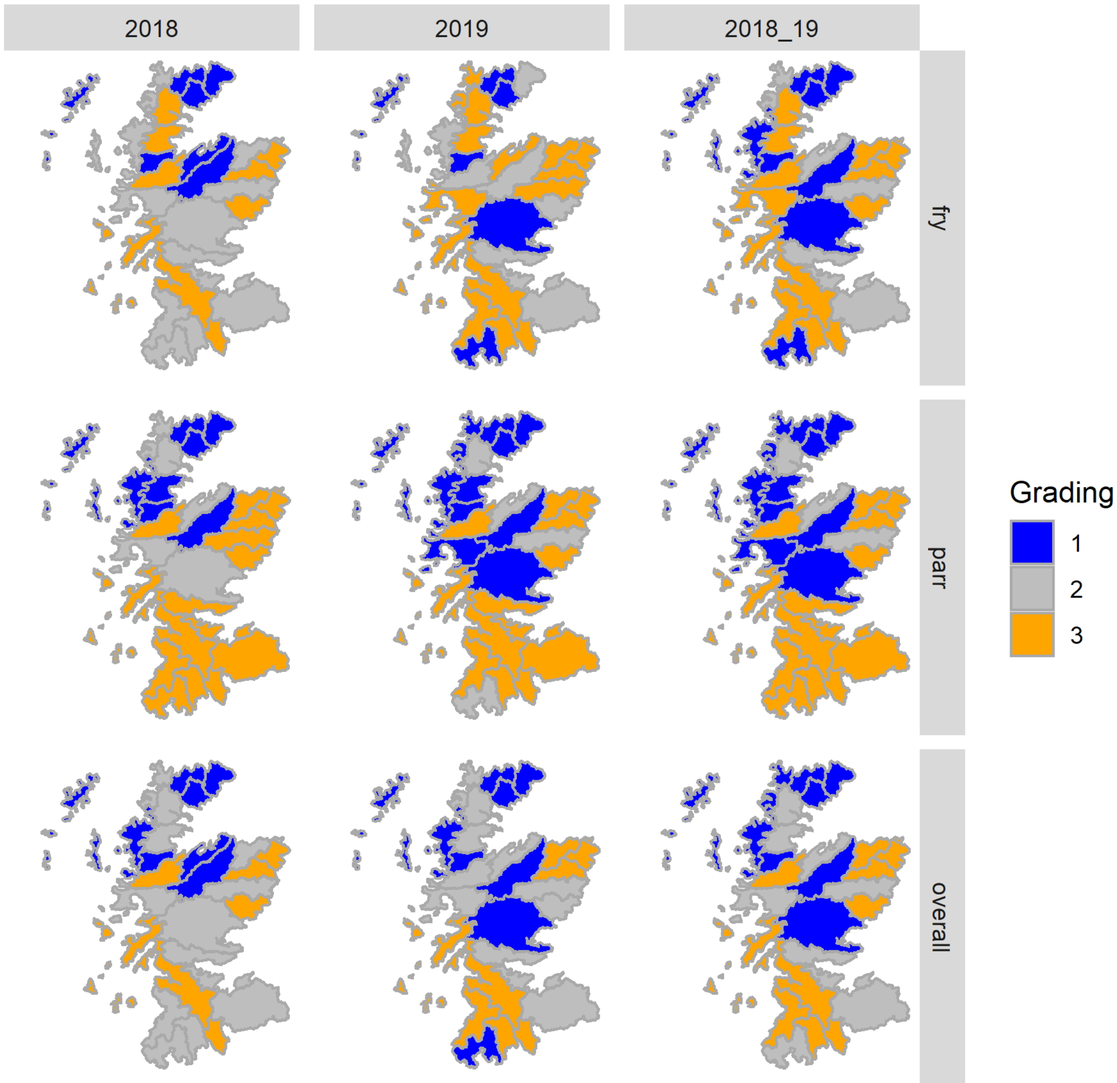

Figure 15 Maps showing regional assessment Grades for salmon fry, parr and both life-stages (overall) for 2018, 2019 and both (2018_19) survey years combined.

Combining NEPS surveys with local GRTS surveys

Where there is a desire to improve understanding of the status of individual catchments or regions within a wider NEPS survey region it is possible to undertake an additional independent survey for the area of interest. An estimate of abundance (with associated uncertainty) can then be obtained from post-stratification of the NEPS survey (Malcolm et al., 2019b) and from the independent survey and combined (see methods). In 2019 an additional survey was undertaken by the Clyde Foundation to supplement sampling within the NEPS Clyde region that also includes

Loch Lomond. There were 15 useable sites in the NEPS survey of the Clyde and 12 sites in the additional independent sample (Fig. 16). The NEPS estimate of mean abundance was slightly higher than that from the independent survey. Unfortunately both surveys were associated with high inter-site variability and thus wide confidence intervals. Nevertheless all survey results suggest that mean abundance of salmon fry and parr is considerably below the benchmark. Given that the upper 95% confidence interval does not include the Benchmark, the Clyde would be classified as Grade 3 for both fry and parr and thus receives an overall Grade 3 classification.

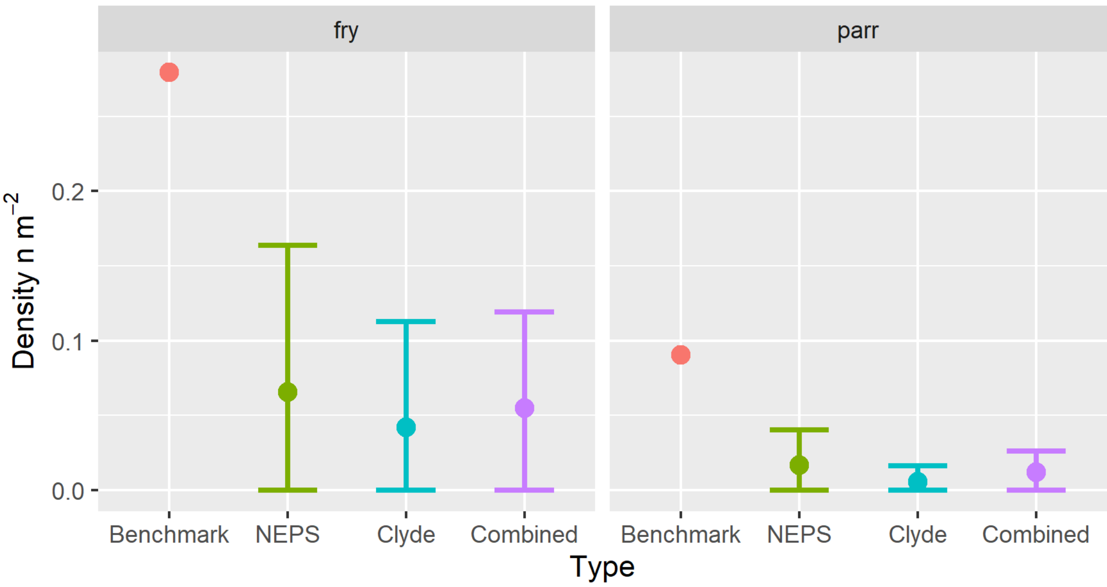

Figure 16 Estimates of the mean abundance of salmon fry and parr from a post-stratified analysis of the NEPS data for the Clyde (NEPS), an independent survey of the Clyde (Clyde) and the combined surveys (Combined). Estimates of mean abundance are plotted alongside the relevant Clyde Benchmark for salmon.

National abundance of salmon and trout

The inter-annual variability in salmon abundance observed at site and regional scales is even more apparent at the National scale. There were sharp declines in the abundance of salmon fry and trout parr between 2018 and 2019, although some reduction in the abundance of all four species / lifestage combinations was observed (Fig. 17). In 2018 Scotland's national salmon abundance was assessed at Grade 1 for fry, Grade 2 for parr and Grade 1 overall. In contrast, an assessment for 2019 would classify both fry and parr as Grade 3, leading to an overall assessment of

Grade 3. Averaging across years would give Grade 2 for fry, Grade 3 for parr and Grade 2 overall.

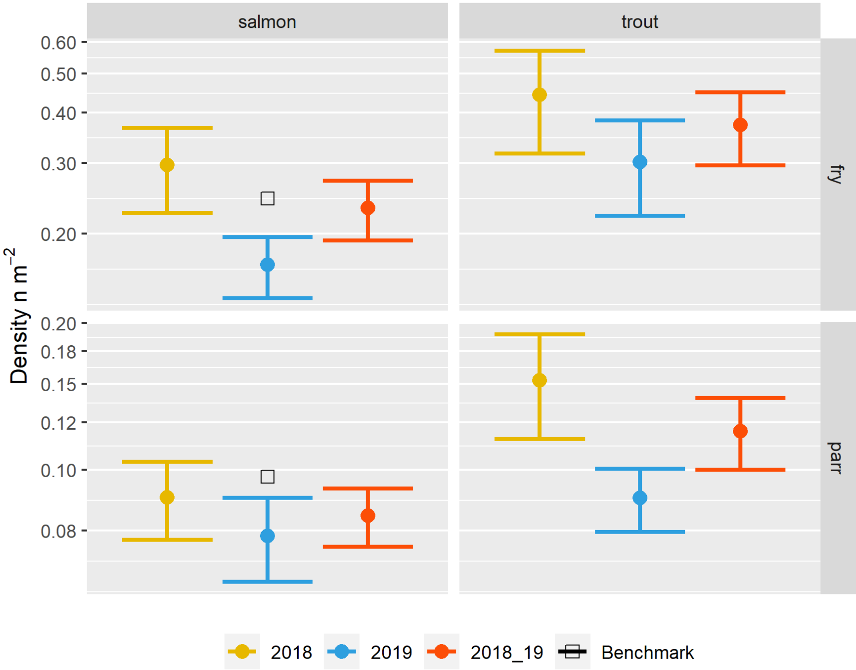

Figure 17. Estimates of the mean abundance of salmon and trout across Scotland in 2018, 2019 and averaged across years (2018_19). The national Benchmark (which is common across all years) is also shown for salmon.

Discussion

This report provides information on the abundance of salmon and trout, and the status of salmon from the second year of the National Electrofishing Programme for Scotland (NEPS). The report builds on previous work reported in 2018 by 1. Adding a second year of data from the NEPS programme 2. Assessing the influence of inter-annual variability in hydrological conditions on estimates of wetted width (and thus wetted area and abundance) 3. Fitting a new capture probability model for salmon and trout 4. Reporting on the abundance of salmon and trout for 2018 and 2019 4. Illustrating how surveys can be combined across years to provide estimates of average abundance and status, and within years to improve assessments of smaller areas within NEPS regions. These issues are discussed further below.

Capture Probability

The capture probability model presented in this report builds on previous models for salmon to also include trout. This allowed the abundance of trout to be estimated from the NEPS 1-pass and 3-pass data. In general trout were more catchable than salmon, potentially reflecting inter-species differences in size between lifestages, or varying habitat use.

There was a positive linear effect of year in the final *P* model. This indicates that capture probability increased over time at the national scale. Similar trends have been reported at smaller spatial scales over longer time periods (Glover et al., 2019). However this is the first time that these trends have been reported at the national scale. This has major consequences for the use of single pass and timed electrofishing for assessing population trends. Specifically, the use of uncalibrated single pass or timed data could result in biased trend assessments, potentially leading to inappropriate management decisions (Glover et al., 2019).

There were a number of challenges in fitting the capture probability model that reflected the composition (multiple Teams within Organisation) and spatial configuration of data providers. When NEPS was designed, it was assumed that data collection would make use of Scotland's well-developed Fishery Board and Trust network, that most organisations contributing to NEPS would have extensive pre-existing multi-pass electrofishing data and that NEPS regions would typically be served by a single data collection organisation thereby ensuring a continuous supply of new 3-pass data form all Organisations from which to assess year effects. In reality some Organisations contained smaller independent teams representing sub-regions (e.g. three data providers in Northern Region, or two data providers in Skye and Wester Ross) or multiple teams where some teams contained new staff members. Additionally some organisations contributing data in 2019 had no substantial documented history of multi-pass electrofishing (e.g. University of the Highlands and Islands (UHI) or Nairn District Salmon Fishery Board). In these circumstances, where substantial high quality multi-pass data were not available to inform the *P* model, pragmatic decisions had to be taken, grouping Organisation-Teams in some circumstances. In future years it would be desirable to specify a minimum number of pre-existing multi-pass data (e.g. 30 sites) and annual multi-pass data (e.g. 10 sites) from those organisations funded to provide data to NEPS. Not all multi-pass data would need to come from the NEPS programme, it could come from other sampling programmes, provided that organisations followed similar protocols.

Wetted area

The Benchmark salmon density model for Scotland was fitted to electrofishing data collected over the period 1997-2015. Density predictions therefore reflect estimated densities for average flows (under which electrofishing was undertaken) over this period. For consistency, Malcolm et al. (2019b) used wetted area to estimate the abundance of salmon from the NEPS survey data. However, they also discussed challenges relating to the measurement of wetted area and the potential for it to vary between years depending on hydrological conditions. If fish production remained relatively static with summer flow conditions (Glover et al., 2020), but wetter years produce higher estimates of wetted widths, then this would result in lower observed densities in wetter years and higher densities in dry years, independent of real changes in production (total number of fish produced by the river / region). However, Malcolm et al. (2019b) also discussed the tendency for managers to fish under low flow conditions (to ensure reasonable capture efficiency and safety) and the limited accuracy of field recorded wetted widths, which typically measure the maximum spatial extent of wetted area using a tape measure. Because these measurements do not address issues around emergent roughness elements and because fishing is generally under lower flows, inter-annual variability in measured wetted widths is likely to be smaller than expected. These hypotheses were supported by data from long-term monitoring sites on the Girnock Burn, Deeside, where wetted widths varied between 0 and 16% across a four-fold range of summer discharges.

The strongly contrasting summers of 2018 (record breaking dry summer) and 2019 (second wettest summer on record) provided an opportunity to quantify the likely scale of these effects. This was achieved through two approaches 1. Compare wetted areas among sites visited in both 2018 and 2019 (NEPS annual panel) 2. Assess differences between wetted widths in 2018 and 2019 using (static) GIS derived widths to control for varying site locations. Both approaches produced similar estimates of effect size, suggesting that wetted widths were on average ca. 7-12%

higher in 2019 than 2018 depending on how this was assessed. Given these approaches and a developing calibration dataset it may be possible to control for inter-annual variability in wetted areas when comparing observed abundances between years or with the benchmark. Nevertheless, it is re-assuring to know that even without calibration, inter-annual variability in wetted area is generally small even between the most extreme of years.

Abundance of trout

Unfortunately a benchmark model is not currently available for brown trout. However, work is under way to develop this model using the same approaches developed for Atlantic salmon previously (Malcolm et al., 2019a). This will allow future iterations of NEPS to assess the status of both salmon and trout. Trout densities declined between 2018 and 2019, potentially reflecting the influence of returning sea trout numbers (and marine environmental conditions) on observed trout densities, particularly in those rivers supporting large sea trout runs. The presentation of abundance data for trout is the first stage in the development of reporting for this economically important salmonid species.

Abundance and status of salmon

Fry densities in 2018 and 2019 reflect spawner abundance in 2017 and 2018 respectively. Parr numbers reflect spawner numbers from one or more prior years, depending on age at emigration. The total reported rod catch (retained and released) of all salmon (grilse and salmon) between 2015 and 2018 was 56006, 55707, 50988 and 37586. The 2018 spawning year was the lowest ever recorded rod catch in Scotland since records began in 1952. Although there are problems in using exploitation data to assess absolute numbers of adults, the data still provide a useful proxy for adult abundance (Thorley et al., 2005) and thus context for interpreting the NEPS surveys.

Across Scotland as a whole salmon numbers remained generally healthy, in 2018, classifying as Grade-1 for fry, Grade-2 for parr and Grade-1 overall. In 2019 a substantial reduction in fry numbers and smaller reduction in parr numbers resulted in an overall status of Grade-3. Averaged across years (and combined across lifestages), Scotland as a whole was classified as Grade-2.

Changes in status at the national level were underpinned by spatially varying changes in regional status, particularly for fry where the number of Grade 3 regions increased from 9 to 14 between 2018 and 2019. The number of grade 3 regions for parr actually declined, reflecting the relatively strong fry cohort in 2018.

The substantial reduction in abundance between 2018 and 2019 is generally consistent with other (appropriately lagged) indicators of abundance including rod catches, counters and traps. The reduction in status is of concern and suggests that Scottish rivers are no longer supporting sufficient juvenile salmon to maximise smolt output with consequences for subsequent adult returns. Even averaged across survey years (which reflect ca. 4 cohort years of juvenile production), there remain substantial concerns for juvenile production, especially in the south-west and north east of Scotland.

Future work

Water quality as a predictor of abundance

Water quality influences capture probability and is a critical control on juvenile salmon survival and abundance through effects on fish physiology (Malcolm et al., 2014), in-stream productivity and food availability (Williams et al., 2009). Water quality is not included in the current benchmark model (Malcolm et al., 2019a), nor will it be included in the forthcoming trout benchmark model. However it is a potentially important predictor that could further explain within and between catchment differences in salmonid 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 be developed (e.g. Smart et al., 2001; Monteith et al., 2015). This requirement was highlighted in the NEPS 2018 report (Malcolm et al. 2019b). Since then progress has been made in preparing spatial data ready for these analyses and this remains a high priority in the coming year.

A NEPS survey design 2021 and beyond

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 should be made prior to 2021.

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. In the current NEPS design, the sample frame consists of Strahler river orders 2-4. During the winter of 2019 and spring of 2020 we investigated the potential to use alternative criteria including upstream catchment area, Shreve river order and gradient supported by information on fishable and non-fishable rivers supplied by biologists from the Forth, Spey, Tay, West Sutherland and Ayrshire. This work suggested that alternative predictors of “fishable” rivers did not provide an improved sample frame and that any benefits would be outweighed by the loss of comparability with previous surveys.

NEPS sampling in 2018 and 2019 highlighted many previously unrecorded barriers (particularly natural barriers). This information was fed to SEPA to update the Obstacles to Fish Migration dataset. Similarly, a number of barriers have been removed from catchments following successful fish passage projects. These changes have been incorporated into the spatial data layers that will be used to underpin the next NEPS survey design.

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. Nevertheless challenges remained where regions contained more than one management organisation / data provider because over samples could fall anywhere in the region. Looking forwards it is important that NEPS analyses are still performed at regional scales to provide comparability with previous years. However, for practical reasons it may be better that design strata at the scale of “Management Organisation” within “NEPS region” or “Management Unit” within “NEPS Region” where management unit could be a single medium to large river or a collection of small rivers. These approaches would allow sample numbers to be increased in particular areas dependent on the need for management information. However, it would avoid the need for additional surveys (as trialled for Clyde 2019), resolve issues around over-samples being allocated, varying management organisations and streamline data analysis. A similar approach could be taken for west coast SAC rivers where sample sizes are often too small to provide useful assessments. However, there would be a need to decide on minimum sensible strata / sample sizes (given 3 panel survey design) and to ensure that there was a commitment to fund any denser sampling strata at smaller spatial scales (e.g. west coast SAC rivers) since a failure to adequately sample whole strata would affect national assessments of status.

Status Assessment

This report has highlighted the ability of juvenile assessments to provide a catch independent measure of population health for salmon (and in future trout and potentially eel) populations. There remains a need to agree an approach for combining adult and juvenile assessments for Conservation Regulations. Despite a desire to harmonise adult and juvenile assessments, complete agreement should not be expected given the major differences in underlying principles, data, assumptions and implementation (see Malcolm et al. 2019b for discussion). Instead future efforts should focus on addressing issues around differing spatial scales of assessment and consider options for combining adult and juvenile assessments in a rule based strength of evidence framework accepting differences between the methods. In some circumstances this could involve reporting catchment (as well as regional) status from the juvenile assessment where individual catchments contain some minimum number of samples. This would address catchment scale assessment requirements for larger rivers, but leave smaller rivers to be assessed only at regional scales or through use of adult data alone.

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Appendix 1:

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 please contact neps@marlab.ac.uk or the MSS-FFL main office (FL_Admin@gov.scot, 0131 244 2900).

Protocol: Timing

Electrofishing should be undertaken between 1st July and 30th September.

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.
    - In the case of annual sites this should be as close to the previous year's start point as possible
- If the sampling location falls in the middle of a pool then move the shortest possible distance upstream to the nearest location where it is possible to wade. However, do not move more than 50m up or downstream from the specified GPS coordinates.
- If the sampling location falls on a braided section of river fish all channels
- 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, bed and bankfull widths (in metres). Note the distance along the length that each width measurement is taken. See Appendix 1 for further details and illustrations of width measurement protocols.
- When fishing sites on a braid, record the site length for each channel, if on a bend record site length on all banks. Record 5 equally distributed wetted, bed and bankfull widths (in metres) for each channel. Next sum these to ensure only 5 overall equally distributed widths which reflect the widths of all channels. Note the distance along the length that each width measurement is taken. See Appendix 2 for further details and illustrations of measurement protocols for braided channels.
- 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.

- If zero salmon (of any lifestage) are caught at a site on the first pass then do not undertake passes 2 and 3. Instead carry out 3–pass fishing at the next 1-pass site that is fished where salmon are present. This maintains the balance of 3:1 pass fishings. If the number of 3-pass sites remaining to be fished equals the number of sites remaining, then fish all as 3-pass regardless of numbers of fish caught. I.e. every region should have a minimum of 10 3-pass sites.
    - Note that in regions where there are multiple data collection organisations it should be ensured that the number of 3-pass sites fished equals the number of 3-pass sites provided.
- 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 **the first 50** salmon parr and **the first 50** trout parr in each run. 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 day processing number** (from DPU OR the row number in the field data sheet which will correspond to the day processing number when entered into DPU) on **all** scale packets, thereby allowing scale ages to be related back to individual fish records. Use an elastic band to group together the labelled scale packets for each electrofishing event (site visit).
    - You may wish to consider the use of stamps with waterproof ink for rapidly filling out scale packets. Appendix 3 shows some examples of scale packet completion.
- For eels process as per salmonids (individuals with length), recording sizes of up to 50 fish per run. You may wish to use eel bag measuring, see page 23 of the following report: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/297344/geho0411btqf-e-e.pdf
- 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
- Once all NEPS sites have been fished **all** scale packets (grouped with elastic bands by electrofishing site visit) should be returned to MSS-FFL, in the scale boxes provided, even if they do not contain samples.

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 £20 per site will be provided for collecting these samples.

- Tissue samples should only be taken from up to 30 salmon 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.
- Work sequentially through the sample tube box so that the genetics sample tube numbers follow on from each other, starting with the lowest number
    - Note that if you are using the DPU NEPS template, the genetic sample tube number will increment automatically once ‘Tissue Sample Link’ has been clicked. If samples are not collected in order this **must** be corrected in the Tissue Sample tab.
- 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 salmon parr until either 30 samples have been obtained or all salmon parr available have been sampled.
- Once all NEPS sites have been fished **all** genetics sample tubes should be returned to MSS-FFL, even if they do not contain samples.

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 return these samples 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 returned, if possible.
- On accumulating 2 samples please return these as soon as possible.

Sample Return

- Sample return will be by Royal Mail.
- Labelled jiffy bags for samples are provided which will hold up to 2 samples.
- Ensure the bottle is dry and use the tape provided to seal round the lid. See Appendix 4 Figure 4.1a.
- Place each of the samples in a polythene bag as provided and tie a knot. See Appendix 4 Figure 4.1b.
- Place the bottles upright in the jiffy bag provided and add message to keep upright. See Appendix 4 Figure 4.1c.
- Include the correct, completed sample record sheet with the samples in the jiffy bag.
- Seal down the jiffy bag and attach stamps (provided) to the value of **£3 only.**
- Take samples to post office ASAP.

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
- Stamps for entering information onto scale packets (if used)

Essential equipment provided by MSS

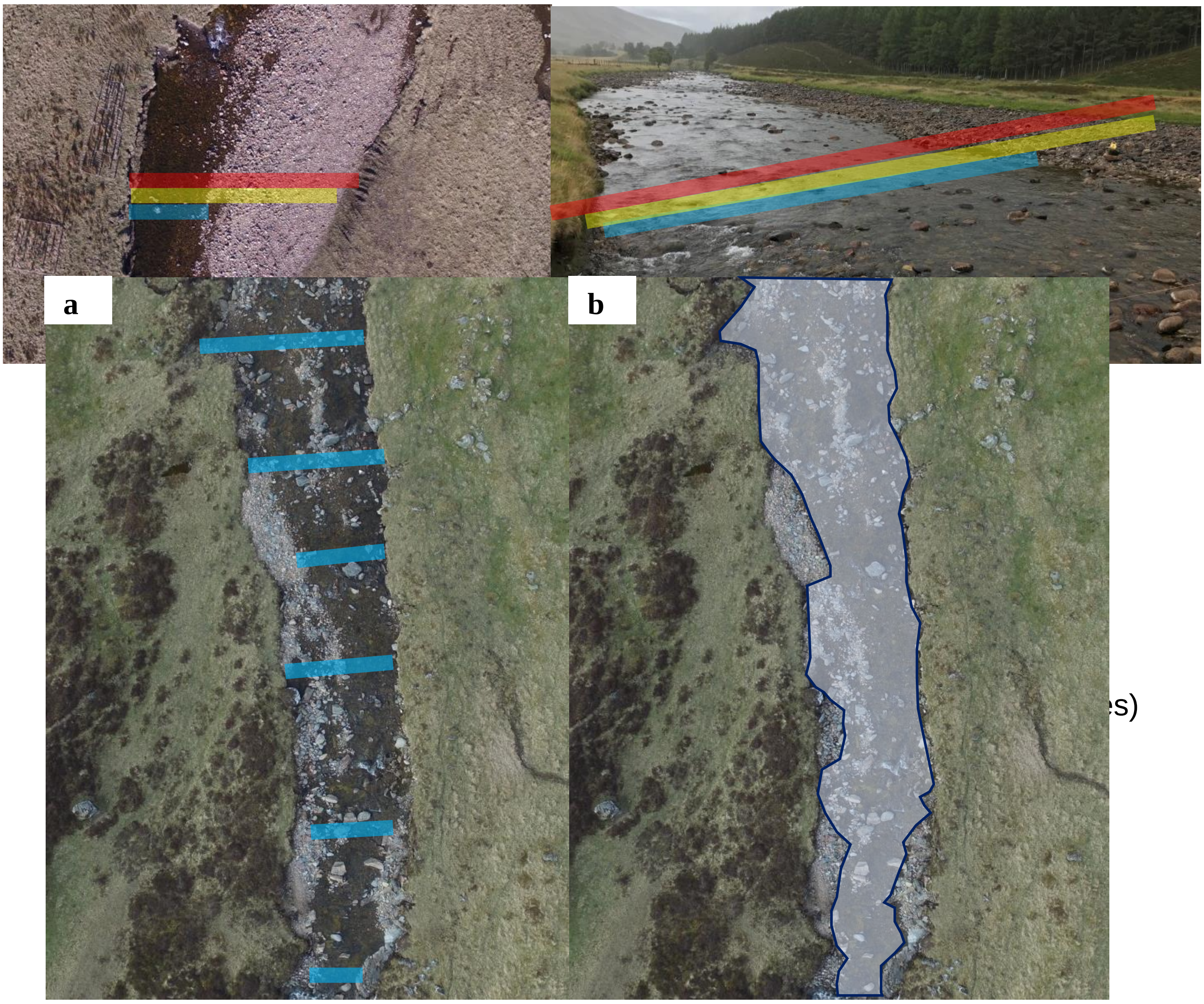
- Scissors for taking fin clips (multi-pass sites)
- Tweezers
- J-cloth (for wiping scissors between samples)
- Labelled tubes of ethanol for genetic sampling (multi-pass sites)
- Scale packets (salmon and trout) and storage box
- Labelled water sample bottles
- Water sample datasheet
- Habitat substrate definitions
- Tape for water bottle lid and plastic bag
- Jiffy bags and stamps for postage
- Copies of standard operating procedures

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

Appendix 1 – Measuring electrofishing site widths

Record 5 equally distributed wetted widths (in metres). This is the wetted part of the river channel, including wetted areas beneath visibly overhanging banks and excluding exposed river beds or bars. Note the distance along the length that each width measurement is taken.



Appendix 2 Measuring electrofishing sites on braided channels

When a sampling location falls on a braid all channels should be fished. Site length, wetted, bed and bankfull width measurements should also be taken for each channel fished (Figure A2.1). Widths, for each width metric, should be summed to provide a single width at each measurement interval, which reflects the width of all widths (see example below). Ensure that you measure and fish the same length of river in all channels.

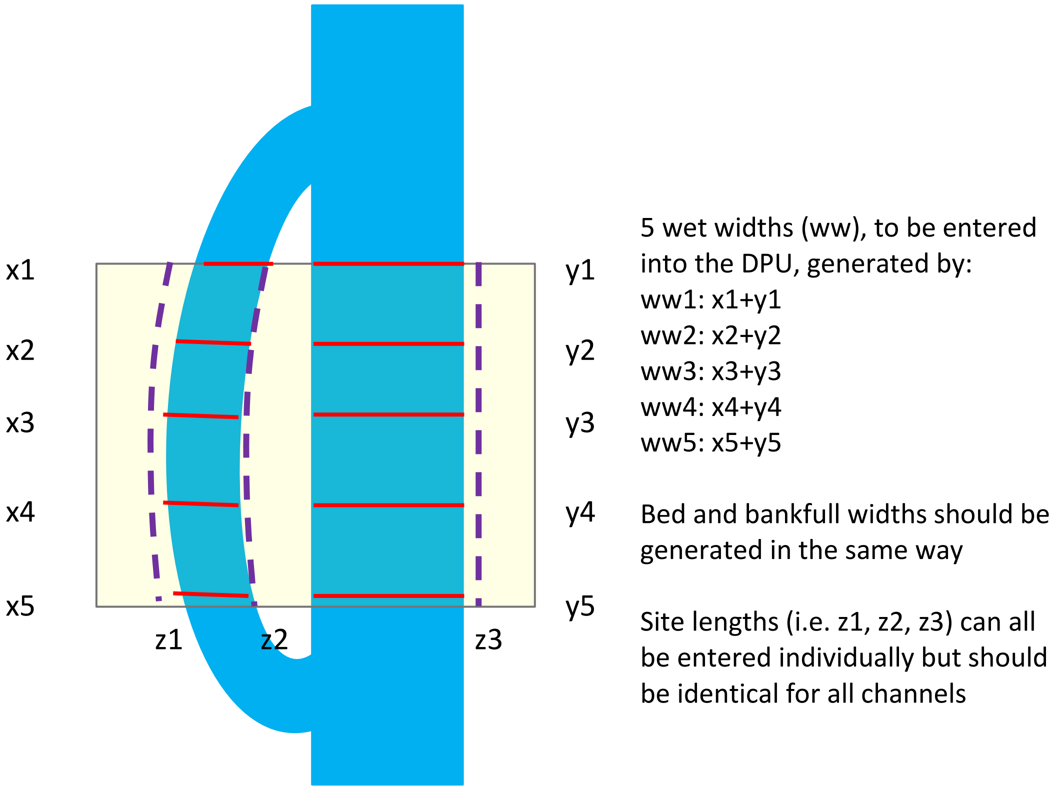


Figure A2.1 Example of width and length measurements for braided electrofishing sites, where x1:5 denote the 5 width locations on one channel, y1:5 denote the 5 width locations on the second channel. These should be summed at each interval to generate an overall channel width representative of both channels. Note that bed and bankfull widths would also be taken. Z1:3 denote the site lengths, which can all be added individually to the DPU. Ensure that you measure and fish the same length of river in all channels.

Appendix 3 – Scale packet completion

Data providers need to ensure that relevant information is included on all scale packets including Site, Date, Day Processing Number and fish length to allow ages to be assigned to fish in the database at a later date

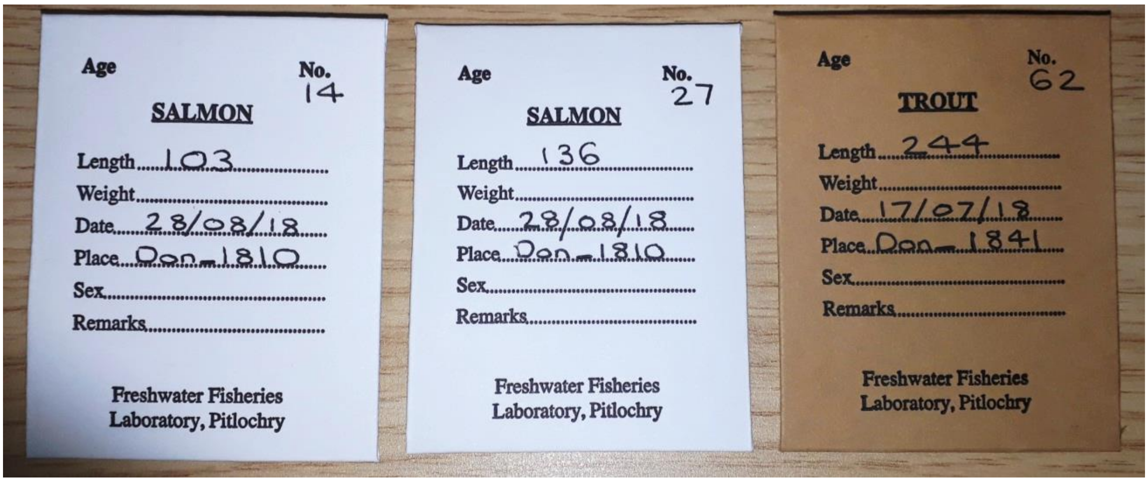


Figure A3.1 Example of minimum scale packet requirements, where 'No.' is the day processing number ('DayProcNo' from DPU OR the row number in the field data sheet which will correspond to the day processing number when entered into DPU), 'Length' is the fish length (mm), 'Date' date the electrofishing was undertaken, 'Place' is the site name provided by MSS.

Appendix 4 - Water sample return

Data providers need to ensure that water samples and associated sample record sheets are returned as soon as possible (once 2 samples are available) to MSS-FFL using Royal Mail.

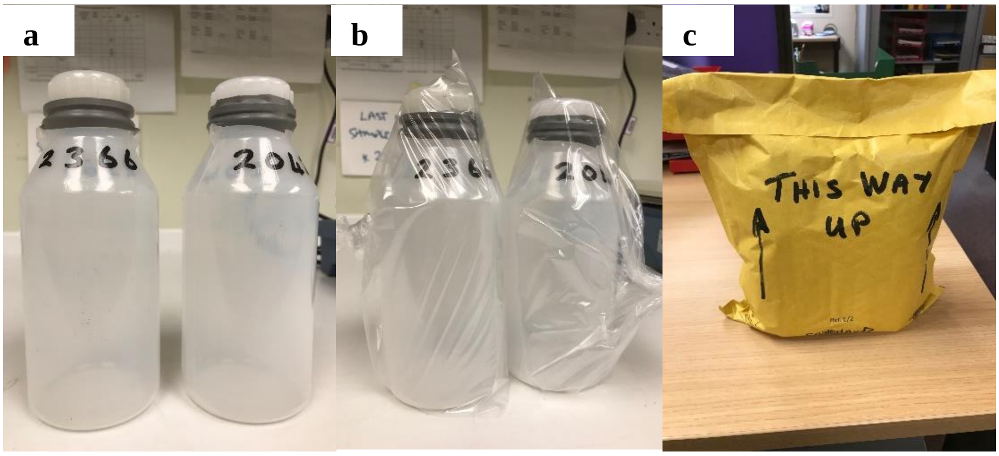


Figure A4.1 a) taped samples b) bagged samples c) jiffy bag labelling ready for postage

Appendix 2:

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 v32 User Guide' giving detailed worked examples of data entry via the DPU. There is also a video user guide available for download. 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.

The FishObs DPU is a new tool for many NEPS collaborators. As such, please first upload one completed single pass and one completed multi-pass electrofishing file using the 'file request link' for the region. MSS-FFL will then provide feedback to prevent any data entry issues being replicated across all data files and potentially time consuming corrections. Note that when data is uploaded using the 'file request link' MSS-FFL will receive an email notification. For queries on this protocol please contact neps@marlab.ac.uk or the MSS-FFL main office (FL_Admin@gov.scot, 0131 244 2900) and request to speak to someone about data entry for the National Electrofishing Programme.

Installing the DPU on your computer

- An up to date version of the DPU can be downloaded from the DPU folder link provided by MSS.
- Save the contents of the download into a folder named 'FishObsDPU' on the computers C drive
    - Contained in this folder you should see the following 4 objects: 'FishObsDesktop' 'FishObsDesktop.exe' 'Settings.FOB' and a folder 'NEPS_Data'
    - The folder 'NEPS_Data' contains a template .xml file. This template prevents the need to set-up the DPU each time data is entered as column attributes (e.g. visible columns, column order, width, sticky) and unchanging default values (e.g. 'Campaign' and 'Project') have already been set in the .xml file.
    - A fifth folder named 'Files' will be created after the DPU application has been opened for the first time. This is where the DPU saves automatic backup files and is where template files and site visit files can be saved. If the DPU crashes, back-up files can be loaded into the DPU from this folder (select the relevant user folder and then the most recent back-up file)
    - Note that if you have any earlier versions of the DPU on your machine these should be deleted or moved to a folder with a different name (e.g. FishObsDPU_version_number)
- For ease, create a shortcut to your Desktop – Right click on FishObsDesktop and click 'Send to' / 'Desktop (create shortcut)'
- Open the DPU by clicking on the icon on your Desktop

Options – Load a DPU template file

- Click ‘Load File’ and navigate to the ‘NEPS_Data’ folder within the ‘FishObs_DPU’ folder where the ‘NEPS_Template.xml’ file is saved
- Click on the file which loads it into the DPU
    - This ensures that all of the required fields are already selected and formatted (e.g. made sticky where they will be unchanging within a visit)
    - Unchanging fields such as ‘Campaign’ and ‘Project’ have already been entered.

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
    - Note that if you are using the NEPS template this will have already been done

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
    - Note that if you are using the NEPS template this will have already been done

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
    - Note that if you are using the NEPS template this will have already been done
- 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)

    - Note that if you are using the NEPS template this will have already been done
- 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.
    - Note that red cells may require your attention (e.g. a date entered incorrectly)
- If you have taken a tissue sample (for genetics) click ‘TissueSampleLink’ 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
    - Note that if you are using the NEPS template this will have already been done
- Enter the information in each column for each fish where a tissue sample was taken (rows with a Tissue sample tube number)
    - ‘DayProcNo’ is automatically generated and provides the link between individual fish entered on the fish tab, tissue samples and scale packets.
    - If using the NEPS template the ‘TissueType’ and ‘TissueBoxNumber’ columns are ‘sticky’ so will be automatically copied to all rows after the first row has been entered
    - If using the NEPS template the ‘TissueSampleNumber’ will increment automatically once ‘TissueSampleLink’ has been clicked, after the first ‘TissueSampleNumber’ has been added. If you have worked sequentially through the sample tube box (so that the genetics sample tube numbers follow on from each other, starting with the lowest number) once you click ‘TissueSampleLink’ you will not need to update any of the columns in the Tissue Sample tab, after the first row has been completed.
    - If samples are not collected in order ‘TissueSampleNumber’ **must** be corrected in the Tissue Sample tab.
- Click ‘FishObLink’ to return to the ‘Fish’ tab and continue entering fish data

Site Measures (Site & Team Datasheet)

- Click on ‘*Change Fields’* and place a tick in the following boxes: MeasurementId, Measurement, MeasurementType, Units, MeasurmentNumber, DistanceAlong, MeasuredAlong

- Note that if you are using the NEPS template this will have already been done
- 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" where the site name is the site name provided by MSS-FFL and selected in the DPU
- Close DPU, re-open DPU, re-open template file and enter your next site
- Note that the DPU will ask you to save your file when you go to close it, if you have already clicked on '*Save File*' and saved the .xml you do not need to save again here
- Upload all .xml files using the 'file request link', for the region, provided by MSS-FFL.
    - As the FishObs DPU is a new tool for many NEPS collaborators, please first upload one completed single pass and one completed multi-pass electrofishing file using the 'file request link' for the region. MSS-FFL will then provide feedback to prevent any data entry issues being replicated across all data files and potentially time consuming corrections.
    - Note that you can upload files as you go (you do not need to wait until all sites have been fished and data entered into the DPU)
    - When data is uploaded using the 'file request link' MSS-FFL will receive an email notification. You will also receive a notification of what was uploaded to the email provided
- If you have any problems please contact neps@marlab.ac.uk

Returning Photographs

- Site photographs can be stored in the FishObs database, however they cannot be loaded into the DPU
- Please name all site photographs with the filename being "sitename_fishingdate_direction" where the site name is the site name provided by MSS-FFL and selected in the DPU and the direction describes what the photographs shows (e.g. Caithness_0901_020719_facing_downstream)
- Upload all photographs using the 'file request link', for the region, provided by MSS-FFL
    - When data is uploaded using the 'file request link' MSS-FFL will receive an email notification. You will also receive a notification of what was uploaded to the email provided