# Flow Country Rivers Trust

# Marine Scotland National Electrofishing Programme for Scotland: Report to NDSFB on 2018 survey of salmon populations in the northern rivers.

Alan Youngson, March 2019.

# Contents

# 1. Introduction

## 1.1 Background to the National Electrofishing Programme for Scotland (NEPS)

Marine Scotland introduced the National Electrofishing Programme for Scotland (NEPS) in 2018. The aim of the NEPS is to collect high-quality information over coming years for all Scottish rivers to enable regional assessment of the status of juvenile salmon populations. The NEPS is described in an information leaflet posted on the Scottish Government website[1].

A substantial quantity of electric-fishing data has already been collected over many years for most rivers in Scotland, including those in the North. However, the methods used by operators have often differed making comparisons between sites, rivers or Districts problematic. The NEPS aims to deal with the problem at root by making a new start using standardised survey methods on randomly-chosen sites.

The NEPS is accorded high priority by Marine Scotland because of the role that electric-fishing data might play in formulating the Scottish Government's Conservation Regulations[2] and, in particular, the annual river grading exercise. The river gradings are presently based on rod catch data – the assumption being that, after appropriate adjustments, rod catches can serve as a useful measure of the spawning stock remaining in the river when the season closes.

The problem with this approach is that the rod catch is not always strongly linked with the number of adult fish that are present. This is particularly the case for small, spate rivers where catches vary greatly on a day-to-day basis as river flows and weather conditions change. This is an issue for the small northern rivers because catches are profoundly affected by fishing conditions and, for the northern spate rivers at least, the accuracy of river gradings based on catch data are therefore questionable.

The NEPS offers a potential solution to the problem. If electric-fishing data can be used to assess the status of juvenile populations then the data might also be used to devise a formal system of river grading. At the very least, juvenile assessments could be used to test and temper assessments based on rod catches of adult fish.

The first NEPS surveys were carried out in 2018. Marine Scotland requested the support of local Boards in acquiring survey data and each Board was asked to survey 30 sites in its area. The intention is that NEPS will continue in coming years if funding is available and that repeated annual surveys will be requested from the Boards. Therefore, the aims of this report are –

- To support planning of any future work that the Northern Board may carry out based on experience gained in 2018.
- To carry out a preliminary assessment of local survey data for 2018 for the Board's information.

[1] https://www2.gov.scot/Resource/0053/00538332.pdf
[2] https://www2.gov.scot/Resource/0054/00542422.pdf

## 1.2. NEPS methods

### 1.2.1. Choice of survey sites.

To avoid possible operator bias towards selecting "good" sites for survey, the NEPS survey sites are chosen randomly with the aim of generating an accurate, overall picture of juvenile populations. However, the choice of sites is restricted to streams of particular types. The NEPS excludes first-order streams because they are often too small to support salmon. Fifth-order streams (like the mainstem Naver) are also excluded because in many cases and most circumstances they are too wide, fast and deep for effective electric-fishing.

### 1.2.2. 1-Pass versus 3-pass

3-Pass electric-fishing methods are the gold standard for juvenile survey work because they generate the most accurate data and therefore allow the most telling comparisons to be made between sites or between years. In 3-pass fishing, the survey site (generally of an area greater than 100m$^2$) is delineated before fishing commences by setting stop-nets at the upper and lower limits of the site. The site is then electric-fished in exactly the same way on three consecutive passes. The second and third passes capture fish missed on the preceding pass and the number of fish captured on successive passes diminishes. The data for each pass are separately recorded.

So, as a simplified example, the first-pass of fishing on a site of 100m$^2$ might capture 60 fish, the second pass 24 fish and the third 10 fish – an overall total of 94 individuals. The rate of decline in the numbers caught on each pass can then be used calculate the efficiency of the team and also to estimate the real number of fish present in the site. In the example above, the efficiency of the team would be calculated to be 60% on each pass and the true number of fish present in the site would therefore be calculated to be 100 individuals rather than the 94 that were actually captured. The observed density of fish would be 0.94/m$^2$ but the true density of fish would be estimated as 1.0 fish/m$^2$.

The initial procedures for 1-pass electric-fishing are exactly the same as for 3-pass fishing but the survey ceases when the first pass has been completed. So, using the example above, 60 fish would be captured and the observed 1-pass density would be 0.60 fish/m$^2$. It is not possible to calculate operator efficiency using 1-pass fishing and, therefore, it is impossible to calculate the real density of fish. The only advantage of 1-pass over 3-pass electric-fishing is that takes less time to carry out the electric-fishing part of the survey exercise. The gains are not as large as might be expected because the time required to reach a site and to set up the equipment are the same for 1-pass and 3-pass surveys. Nevertheless, the NEPS protocol suggests that while two sites per day can be surveyed by 3-pass fishing, four are possible using 1-pass fishing. However, the latter figure over-estimates what can be achieved in the remoter parts of the northern landscape.

The NEPS protocol sets out to acquire data with wide coverage by requesting that a mixture of 10 x 3-pass and 20 x 1-pass sites are fished within each Board area and that the personnel involved at each site should be recorded. The aim then is to calculate the average efficiency of individual survey teams based on the 3-pass fishing data. This figure is then used to adjust the data for 1-pass sites fished by the same team in order to estimate the true number of fish present at sites where only 1-pass data has been obtained. To be valid, this approach requires that a survey team applies exactly same amount of effort to 1-pass fishing as to the first pass of 3-pass fishing. Even then, efficiency can be shown to vary substantially between sites for any of a number of valid reasons. So, for example, it is more difficult to extract fry from shallow riffle than it is to capture them in glides and it is more difficult to extricate fry where the streambed is clothed in filamentous algae.

### 1.2.3. Available data

The first Marine Scotland Science report on the NEPS is due shortly (May, 2019). For the purposes of the present report to the Board, the NEPS provides data on the number and size of fish captured in 17 x 1-pass and 11 x 3-pass sites in the Northern District rivers. In addition, the Flow Country Rivers Trust obtained 3-pass data for three non-NEPS sites on the River Borgie and these sites are included in this report.

Salmon fry and parr have been distinguished at each site based on the distribution of body length values. In addition, the length of each survey site is known and estimates of each site's average wet-width and average channel-width are available.

Combining the number of fish captured and the area of the survey site gives the densities of fry and parr. Densities observed on 1-pass fishing are available for all the total of 31 sites but the true densities can be estimated only for the 14 sites that were surveyed using 3-pass fishing.

## 1.3. Density variation among sites and among years

Densities of fry and parr vary between sites and between years for any of a large number of sometimes complex reasons and, even when rivers are saturated with young fish some sites are intrinsically capable of supporting more fish than others. Therefore, there is no single target value that can be used to judge the status of salmon at particular survey sites.

## 1.4. Evaluating survey data

In order to assess survey data it is necessary to compare the density values observed with some suitable benchmark value.

The Caithness surveys have shown the value of obtaining data repeatedly for the same sites and building up a picture of each site's average performance over several years. New survey data can then be compared with data for previous years to find out if there have been any notable changes or whether any trends are evident. In the case of the NEPS, however, data is presently available only for a single year so this approach is not possible.

Malcolm and colleagues in Marine Scotland Science have recently (2019) developed a set of site-specific expectations for fry and parr densities throughout Scotland using modelling techniques to examine electric-fishing data acquired between 1997 and 2015 by operators working across rivers in Scotland[3]. These are the benchmark values that Marine Scotland will use to evaluate juvenile salmon populations for 2018 based on the first round of NEPS data. The modelling exercise currently includes consideration of the broad scale environmental data (altitude, land-use and forestry) that partly determine the capacity of sites to support young fish but it does not yet include the site-specific measures of depth, substrate type and water quality that were obtained during the NEPS.

It remains to be seen how Marine Scotland will set about comparing the NEPS values with the benchmark values. At this point, however, it is likely to be some time before Marine Scotland can incorporate the NEPS site characteristics into models to provide the finer-grain scale that will be

[3] https://www.sciencedirect.com/science/article/pii/S1470160X18306812

necessary to unequivocally evaluate data for specific sites. In any case, the current benchmark data contained in Malcolm et al.'s report are not yet available in a form that can be used to support local analysis at District level, as in this report.

At present, the most useful benchmark values for fry or parr density are contained in a report to SNH by Godfrey in 2005[4]. The values refer to 1-pass data only. The values shown in Table 1 are taken from Godfrey and based on electric-fishing data obtained from 50 sites in the North Statistical Region; the values have previously proved useful for the interpretation of fish densities for survey sites in the Caithness rivers.

*Table 1. Critical values for salmon and fry densities on 1-pass of sites in northern rivers (Godfrey, 2005)*

| | Critical percentile values for density (n/m$^2$) | | | | | |
|---|---|---|---|---|---|---|
| | **20$^{th}$** | **40$^{th}$** | **60$^{th}$** | **80$^{th}$** | **100$^{th}$** | **> 100$^{th}$** |
| **Fry density** | 0.05 | 0.13 | 0.28 | 0.33 | 0.67 | > 0.67 |
| **Parr density** | 0.04 | 0.07 | 0.13 | 0.19 | 0.28 | > 0.28 |

Table 1 shows that for the case of fry densities obtained by 1-pass fishing the lowest 20% of sites are expected to contain fewer than 0.05 fry per m$^2$, the next 20% of sites are expected to contain between 0.05 and 0.13 fry per m$^2$ – and so on. The top 20% of sites are expected to contain between 0.33 and 0.67 fry per m$^2$ but, for the Caithness rivers, it was found necessary to insert an additional category (> 100$^{th}$) because some sites were found to contain more than 0.67 fry per m$^2$.

The benchmark system is identical for parr and the appropriate critical values are also shown in Table 1. Again, in practice it has been found necessary to insert an additional category to cover sites where parr density on 1-pass fishing is greater than 0.28 per m$^2$.

## 1.5. Approach to reporting on NEPS data

In the present report, the benchmark system outlined in Table 1 has been used below to classify 1-pass data for NEPS sites in the Northern District rivers. To aid visual comparison in maps and tables the various categories have been allocated colour-codes as shown in Table 2.

Table 2. *Categories for density on 1-pass of sites in northern rivers and associated colour-codes.*

| | Percentile values for density (n/m$^2$) | | | | | |
|---|---|---|---|---|---|---|
| | **< 20$^{th}$** | **20$^{th}$ - 40$^{th}$** | **40$^{th}$ - 60$^{th}$** | **60$^{th}$ - 80$^{th}$** | **80$^{th}$ to 100$^{th}$** | **> 100$^{th}$** |
| **Fry density** | < 0.05 | 0.06 - 0.13 | 0.14 - 0.28 | 0.29 -0.33 | 0.34 - 0.67 | > 0.67 |
| **Parr density** | < 0.04 | 0.05 - 0.07 | 0.08 - 0.13 | 0.14 -0.19 | 0.20 - 0.28 | > 0.28 |

[4] https://www2.gov.scot/Resource/Doc/295194/0096508.pdf

Fish density is obtained by dividing fish number by the area of the survey site; the area of each site is equal to its length times its average width. For this report site area has been calculated using the normal, full-channel width of the survey site, rather than its wetted width since full-channel area is the most conservative measure of the unit of fish production. Using full-channel width to calculate site area also avoids the risk of confounding variation in wetted width with differences in fish density when comparisons are made between sites or between years. The approach used for this report isolates the likely, but poorly understood, effects of drought years on fish numbers to be separately considered.

Salmon compete with other members of their own year-class and with other year-classes, too. The presence of competitors constrains density values for both fry and parr and it affects their growth (body size) as well. Body length can be converted to body weight using Shackley's formula[5] in order to calculate the weight of fish per square meter (biomass density). The Caithness surveys have shown that the biomass density of individual survey sites is rather constant between years even when fry and/or parr densities vary. Assuming the supply of fry is plentiful, biomass density appears to capture some aspect of habitat quality that determines variation in the capacity of individual sites to support fish. Biomass density is therefore considered in what follows.

Finally, NEPS and other data are available for survey sites in Caithness District[6]. Data for the Caithness rivers in 2018 is used to view the 2018 NEPS data for the Northern District rivers in a wider geographical context. Equally, the Caithness data are better viewed in the same, wider context.

# 2. NEPS Survey Results for 2018

## 2.1. Survey site data

Table 3 identifies the Northern survey sites using the NEPS codes, indicates their locations within catchments, and specifies the date on which they were fished and whether 1-pass or 3-pass electric-fishing was used. Table 3 also gives the average channel-width and the average wet-width for each site. Channel-width is always equal to or greater than wet width but, because of the drought in 2018, the disparity between the two measurements was often unusually large.

When stream levels are normal, survey site areas are chosen to be about 100-150$m^2$ in extent, partly because a site of this size is sufficient to generate data of sufficient quality and because of the constraints of time. However, drought conditions make the choice of survey site size more difficult because, as above, the wetted area of stream may be much less than the normal channel-width.

[5] Body mass = $2.8087 \times 10^{-6} \times \text{body length}^{3.3016}$

[6] See http://caithness.dsfb.org.uk/publications/

Table. 3. Survey site location, size and number of electric-fishing passes.

| Catchment | Date | Site Location | NEPS code | No. of e/f passes | Av. width wet (m) | Av. width channel (m) | Channel area ($m^2$) |
|---|---|---|---|---|---|---|---|
| Borgie | 13/09 | Dalness | 3440 | 3 | 9.28 | 14.16 | 191.2 |
| | 13/09 | Dalness Falls | 3424 | 3 | 10.36 | 12.20 | 169.6 |
| | 1/10 | Achnantot Burn | - | 3 | 3.50 | 3.50 | 80.2 |
| | 1/10 | Inchkinloch | 3422 | 3 | 9.56 | 9.56 | 120.5 |
| | 6/10 | Lettermore Burn | - | 3 | 3.00 | 3.00 | 64.5 |
| | 6/10 | Allt Borgie Beag | - | 3 | 2.45 | 2.45 | 100.5 |
| Halladale | 27/08 | Forsinard | 3554 | 3 | 3.12 | 4.58 | 146.5 |
| | 3/09 | Trantlemore | 3436 | 1 | 9.56 | 13.12 | 721.6 |
| | 3/09 | Forsinain | 3426 | 3 | 8.48 | 9.92 | 129.0 |
| | 4/09 | River Dyke | 3427 | 1 | 3.58 | 6.06 | 527.2 |
| | 13/09 | Trantlemore | 3568 | 3 | 10.72 | 11.88 | 118.8 |
| | 13/09 | Forsinain Burn | 3468 | 3 | 3.62 | 4.32 | 129.6 |
| Kinloch | 17/08 | A. na Luibe Moire | 3470 | 3 | 6.32 | 7.26 | 145.2 |
| Naver | 25/07 | Vagastie | 3593 | 1 | 3.82 | 6.66 | 133.2 |
| | 25/07 | Vagastie | 3573 | 1 | 8.38 | 8.56 | 102.7 |
| | 26/07 | Mudale | 3581 | 1 | 14.98 | 18.02 | 180.2 |
| | 26/07 | Mudale | 3585 | 1 | **7.62** | **22.12** | **331.8** |
| | 26/07 | Meadie Burn | 3429 | 1 | 15.62 | 21.06 | 147.4 |
| | 26/07 | Meadie Burn | 3561 | 1 | **6.12** | **13.10** | **262.0** |
| | 28/07 | Meadie Burn | 3565 | 3 | 8.16 | 9.16 | 119.1 |
| | 28/07 | Mudale | 3557 | 1 | 8.40 | 9.90 | 110.6 |
| | 7/08 | Mallart | 3582 | 3 | 10.96 | 12.62 | 101.0 |
| | 7/08 | Mallart | 3462 | 3 | 8.3 | 17.08 | 222.0 |
| | 9/08 | Mallart | 3466 | 1 | 11.5 | 12.50 | 100.0 |
| | 9/08 | Mallart | 3578 | 1 | **7.08** | **16.52** | **247.8** |
| | 9/08 | Mallart | 3558 | 1 | **7.34** | **16.54** | **248.1** |
| | 9/08 | A. Cnoc na Cloiche | 3430 | 1 | 1.42 | 1.56 | 78.0 |
| | 9/08 | Mallart | 3562 | 1 | 12.72 | 14.38 | 86.3 |
| | 10/08 | Skelpick Burn | 3571 | 1 | 3.84 | 6.16 | 123.2 |
| Strathy | 13/08 | Yellowbog Burn | 3559 | 1 | 1.98 | 2.70 | 405.0 |
| | 13/08 | Strathy (Upper) | 3583 | 1 | 2.64 | 3.56 | 356.0 |

Table 3 shows that four sites on the Naver catchment (3585, 3561, 3578 and 3558) were particularly shrunken by the drought. In the most extreme case (3585) the wetted width was only around 30% of the full channel width. In this and similar cases the channel area covered during the survey was much larger than would be the case under normal flow conditions because the wetted area available for fishing was so reduced.

Table 3 also shows that the channel area covered at another four sites (3436, 3427, 3559 and 3583) was surprisingly large given that they were not so profoundly affected by the low water levels.

The values shown on the last column of Table 3 are for full, channel area because this is the standard and most appropriate basis for comparing sites. Under normal flow conditions, when the wetted area of stream and the channel area are similar, the standard rate of electric fishing is around 2 or

3m² per minute. The rates of fishing reported under the drought conditions of 2018 can be considered in this context by examining the rate at which wetted area was reported to be fished.

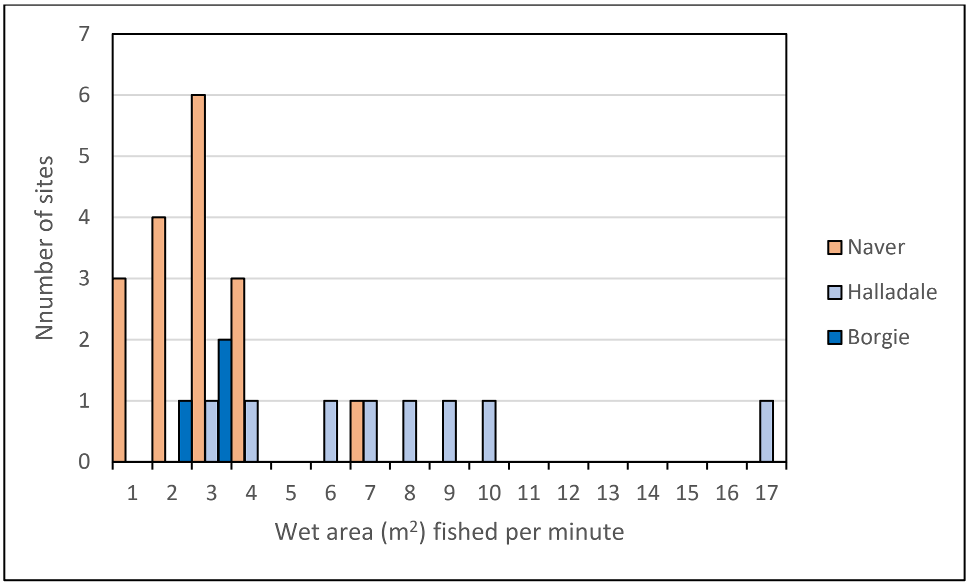



*Figure 1. Rate of fishing of wetted area of stream for 1-pass fishing or for the first pass of 3-pass fishing for all the NEPS sites. Those sites fished by each of the Naver, Halladale and Borgie teams are indicated.*

Figure 1 shows that most of the sites were fished at a rate of 1-4m$^2$ of wetted area per minute. It can be seen that the Halladale team worked more quickly than the others. In particular, the four anomalous sites identified in Table 3 (3436, 3427, 3559 and 3583) are again identified as anomalies in being the sites that were fished most rapidly of all. Site 3436, on the mainstem Halladale near Trantlemore, was most anomalous being fished at a rate of 17 m$^2$ per minute. It is possible that this anomaly will have affected the number of fish captured and the values for fish density. The values for the site on the River Dyke (3427) and for both of the Strathy sites (3559 and 3583) may be compromised in the same way. The values for all these sites should therefore be viewed with caution.

Table 4 shows the number of fry and parr captured on 1-pass fishing. Substantial numbers were captured at all the sites excepting the two sites in the Strathy catchment.

*Table 4. Number of fry and parr captured on 1-pass fishing or on the first pass of 3-pass fishing.*

| Catchment | Date | Location | NEPS code | 1-Pass fry n | 1-Pass parr n |
|---|---|---|---|---|---|
| Borgie | 13/09 | Dalness | 3440 | 20 | 18 |
| | 13/09 | Dalness Falls | 3424 | 49 | 22 |
| | 1/10 | Achnantot Burn | - | 9 | 9 |
| | 1/10 | Inchkinloch | 3422 | 29 | 9 |
| | 6/10 | Lettermore Burn | - | 39 | 20 |
| | 6/10 | Allt Borgie Beag | - | 33 | 5 |
| Halladale | 27/08 | Forsinard | 3554 | 44 | 12 |
| | 3/09 | Trantlemore | 3436 | 64 | 35 |
| | 3/09 | Forsinain | 3426 | 18 | 33 |
| | 4/09 | River Dyke | 3427 | 30 | 10 |
| | 13/09 | Trantlemore | 3568 | 5 | 20 |
| | 13/09 | Forsinain Burn | 3468 | 104 | 19 |
| Kinloch | 17/08 | A.na Luibe Moire | 3470 | 38 | 3 |
| Naver | 25/07 | Vagastie | 3593 | 28 | 23 |
| | 25/07 | Vagastie | 3573 | 12 | 16 |
| | 26/07 | Mudale | 3581 | 8 | 17 |
| | 26/07 | Mudale | 3585 | 26 | 21 |
| | 26/07 | Meadie Burn | 3429 | 10 | 7 |
| | 26/07 | Meadie Burn | 3561 | 21 | 7 |
| | 28/07 | Meadie Burn | 3565 | 19 | 22 |
| | 28/07 | Mudale | 3557 | 8 | 22 |
| | 7/08 | Mallart | 3582 | 153 | 4 |
| | 7/08 | Mallart | 3462 | 113 | 3 |
| | 9/08 | Mallart | 3466 | 34 | 14 |
| | 9/08 | Mallart | 3578 | 56 | 1 |
| | 9/08 | Mallart | 3558 | 105 | 15 |
| | 9/08 | A. Cnoc na Cloiche | 3430 | 15 | 21 |
| | 9/08 | Mallart | 3562 | 13 | 7 |
| | 10/08 | Skelpick Burn | 3571 | 64 | 49 |
| Strathy | 13/08 | Yellowbog Burn | 3559 | 0 | 1 |
| | 13/08 | Strathy (Upper) | 3583 | 3 | 2 |

## 2.2. 1-Pass densities of fry and parr

In Table 5 fry and parr densities are expressed in terms of the full-channel width of each site. Each site has been categorised and colour-coded as indicated in Table 2. The values and therefore the categorisations for Sites 3436 and 3427 are probably in question. The actual values for the two sites in the Strathy catchment, 3559 and 3583, are also in question but since very few fish were captured at either site their low categorisations are probably accurate.

*Table 5. Fry density (n/m²), parr density (n/m²) and total biomass density (g/m²) on 1-pass fishing or on the first pass of 3-pass fishing, all expressed in terms of the full channel area of the site. The fry and parr densities are colour-coded as per Table 2.*

| Catchment | Date | Location | NEPS code | Fry density | Parr density |
|---|---|---|---|---|---|
| Borgie | 13/09 | Dalness | 3440 | 0.10 | 0.09 |
| | 13/09 | Dalness Falls | 3424 | 0.29 | 0.13 |
| | 1/10 | Achnantot Burn | - | 0.11 | 0.11 |
| | 1/10 | Inchkinloch | 3422 | 0.24 | 0.07 |
| | 6/10 | Lettermore Burn | - | 0.60 | 0.31 |
| | 6/10 | Allt Borgie Beag | - | 0.33 | 0.05 |
| Halladale | 27/08 | Forsinard | 3554 | 0.30 | 0.08 |
| | 3/09 | Trantlemore | 3436 | ~~0.09~~ | ~~0.06~~ |
| | 3/09 | Forsinain | 3426 | 0.14 | 0.26 |
| | 4/09 | River Dyke | 3427 | ~~0.06~~ | ~~0.02~~ |
| | 13/09 | Trantlemore | 3568 | 0.04 | 0.17 |
| | 13/09 | Forsinain Burn | 3468 | 0.80 | 0.15 |
| Kinloch | 17/08 | A.na Luibe Moire | 3470 | 0.26 | 0.02 |
| Naver | 25/07 | Vagastie | 3593 | 0.21 | 0.17 |
| | 25/07 | Vagastie | 3573 | 0.12 | 0.16 |
| | 26/07 | Mudale | 3581 | 0.04 | 0.09 |
| | 26/07 | Mudale | 3585 | 0.08 | 0.06 |
| | 26/07 | Meadie Burn | 3429 | 0.07 | 0.05 |
| | 26/07 | Meadie Burn | 3561 | 0.08 | 0.03 |
| | 28/07 | Meadie Burn | 3565 | 0.16 | 0.18 |
| | 28/07 | Mudale | 3557 | 0.07 | 0.20 |
| | 7/08 | Mallart | 3582 | 1.52 | 0.04 |
| | 7/08 | Mallart | 3462 | 0.51 | 0.01 |
| | 9/08 | Mallart | 3466 | 0.34 | 0.14 |
| | 9/08 | Mallart | 3578 | 0.23 | 0.00 |
| | 9/08 | Mallart | 3558 | 0.42 | 0.06 |
| | 9/08 | A. Cnoc na Cloiche | 3430 | 0.19 | 0.27 |
| | 9/08 | Mallart | 3562 | 0.15 | 0.08 |
| | 10/08 | Skelpick Burn | 3571 | 0.52 | 0.40 |
| Strathy | 13/08 | Yellowbog Burn | 3559 | ~~0.00~~ | ~~0.00~~ |
| | 13/08 | Strathy (Upper) | 3583 | ~~0.01~~ | ~~0.01~~ |

Overall, the colour codes in Table 5 show that both fry and parr were present at densities covering the full range of the categories (ie. red = low through to dark blue = high) based on Godfrey's scheme.

The distribution of categories across sites can be considered in more detail. Figure 2 shows the number of sites that fall into each density category (colour-code) for fry; Figure 3 shows equivalent data for parr. The data for Sites 3436 and 3427 have been omitted from both figures for the reasons given above and the data are for the remaining 29 sites only. The light blue and dark blue categories have been combined to produce five categories that match Godfrey's 5-category range. Godfrey's benchmark values were set such that 20% of sites are expected to occur in each of the five categories. Since there are 29 sites in total. Therefore, if Godfrey's benchmark values and the NEPS data turn out to be in complete alignment almost exactly six sites (indicated by the broken lines imposed on the figures) would be expected to occur in each of the five categories.

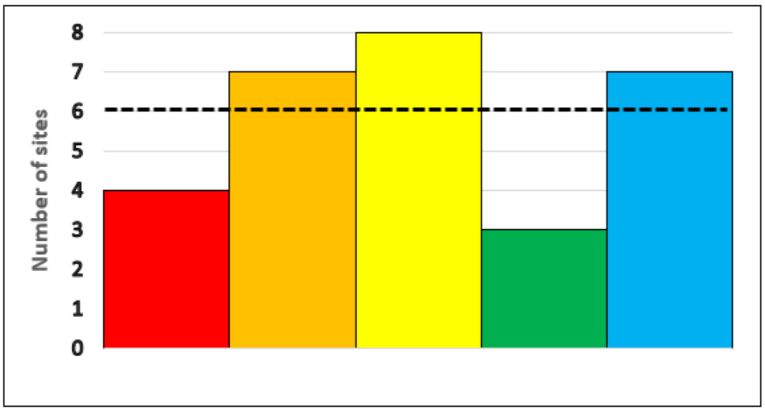



*Figure 2. Number of sites for which the density of fry on 1-pass fishing or the first pass of 3-pass fishing falls within each of Godfrey's five categories for abundance.*

Figure 2 shows that the distribution of fry density values for the NEPS sites closely matches the expected distribution.

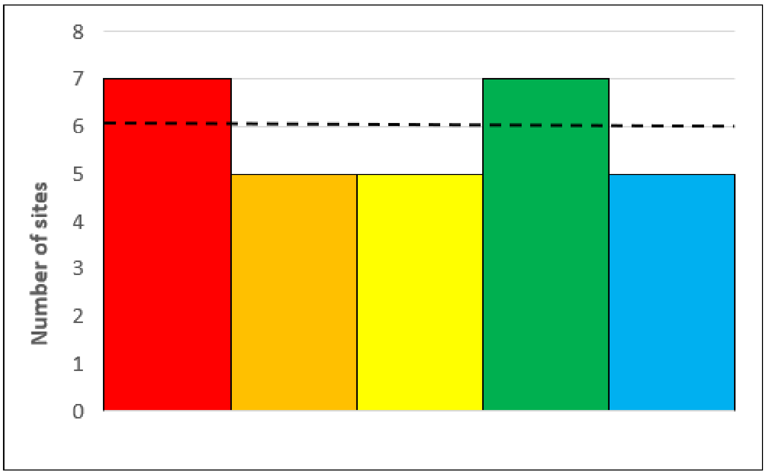



*Figure 3. Number of sites for which the density of parr on 1-pass fishing or the first pass of 3-pass fishing falls within each of Godfrey's five categories for abundance.*

Figure 3 shows that the distribution of parr density values also closely matches the predicted distribution.

Figures 4 and 5 show the colour-coded data for fry density and parr density, respectively, mapped onto the river network for the Northern District. Again, Sites 3436 and 3427 have been omitted.

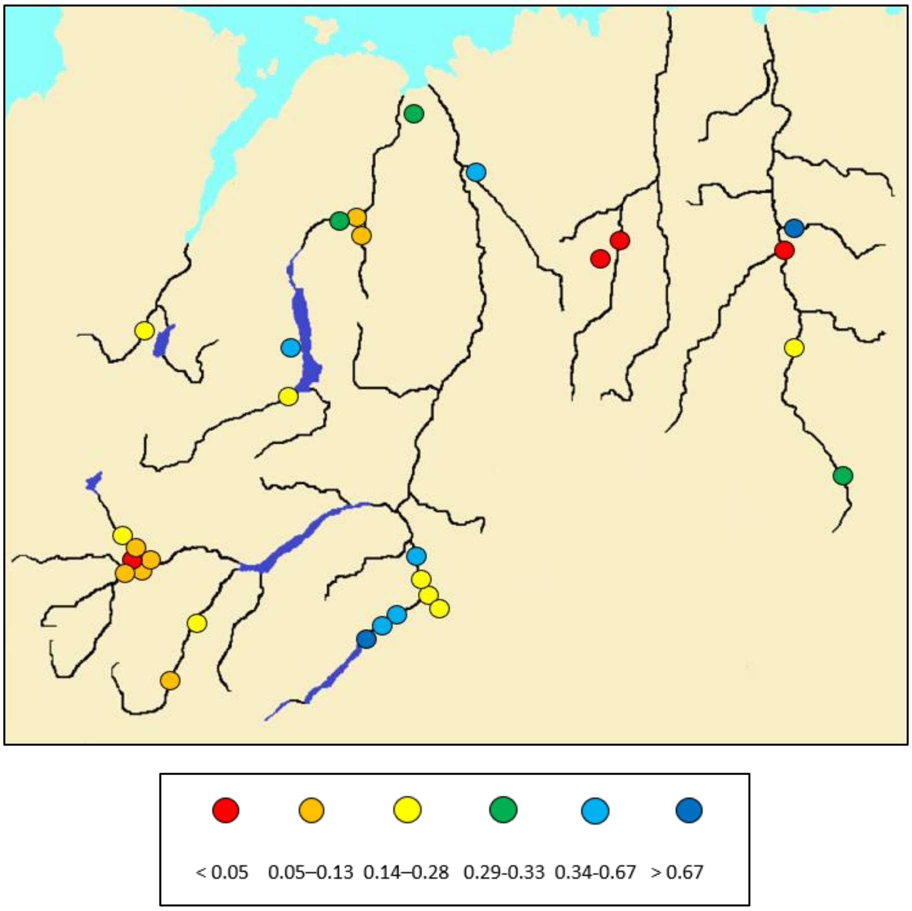



*Figure 4. Density of salmon fry (n/m$^2$) for 1-pass fishing or for the first pass of 3-pass fishing. The values are categorised as per Godfrey (2005) and colour-coded according to the key.*

Figure 4 shows that salmon fry were widely distributed in the Northern rivers with a group of four hot-spots (blue or dark blue) on the Mallart below Loch Coire. Further hot-spots were present at at Skelpick also in the Naver catchment, at Allt Tor an Tairbh near Lettermore in the Borgie catchment, and in the Forsinain Burn on the Halladale.

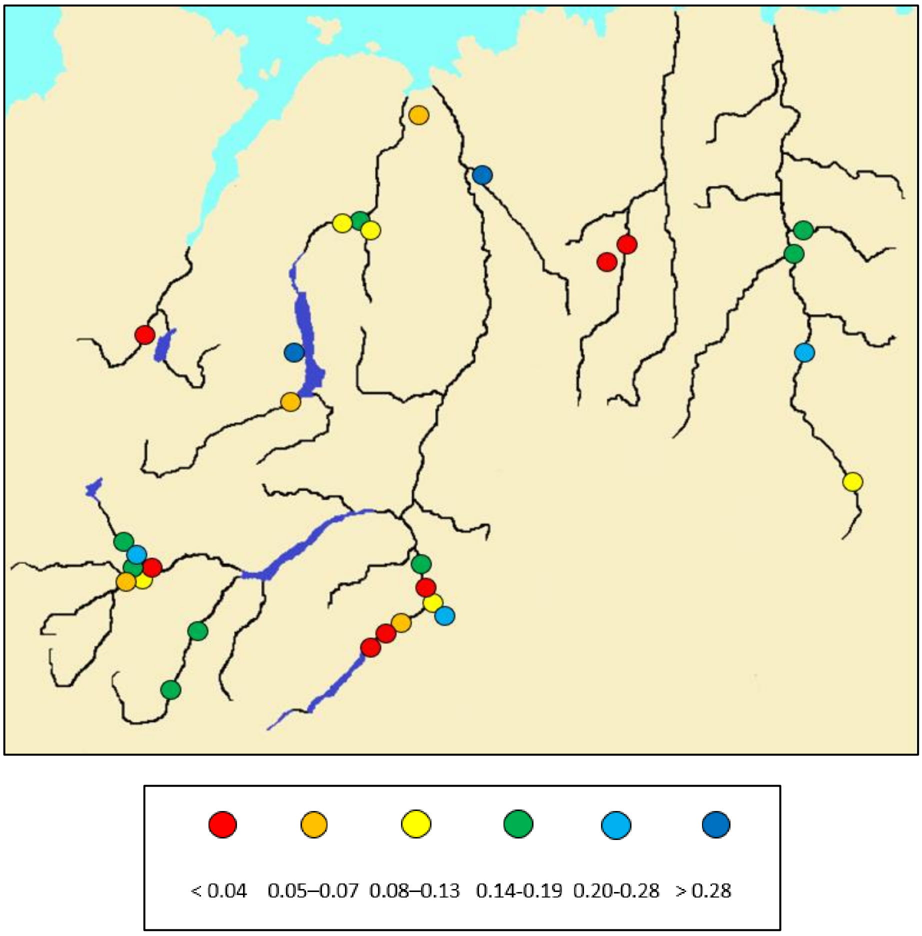



*Figure 5. Density of salmon parr (n/m²) for 1-pass fishing or for the first pass of 3-pass fishing. The values are categorised as per Godfrey (2005) and colour-coded according to the key.*

Figure 5 shows the equivalent values for parr. Single hot-spots for parr density were present at Skelpick, in the Meadie Burn and in Allt Cnoc an Cloiche (all in the Naver catchment), in Allt Tor an Tairbh near Lettermore in the Borgie catchment and at Forsinain on the mainstem Halladale.

## 2.3. 1-Pass biomass density

Table 6 shows the average length of the fry captured at each site and their estimated average weight. Parr have not been considered because their ages (from scale-reading) are not yet known and since they probably belong to several different age-classes.

It can be seen from the values shown in Table 6 that fry were consistently larger in the Halladale than in Borgie, Kinloch or Naver. The difference between Halladale and Naver may be due to the survey dates being earlier in Naver than in Halladale. However, Halladale fry were also consistently larger those in the Borgie catchment where the survey dates were later. So, fry in the Halladale appear to have shown substantially better growth rates than fry elsewhere in the Northern District - although too few fry were captured in the Strathy sites to allow comparison between Strathy and Halladale.

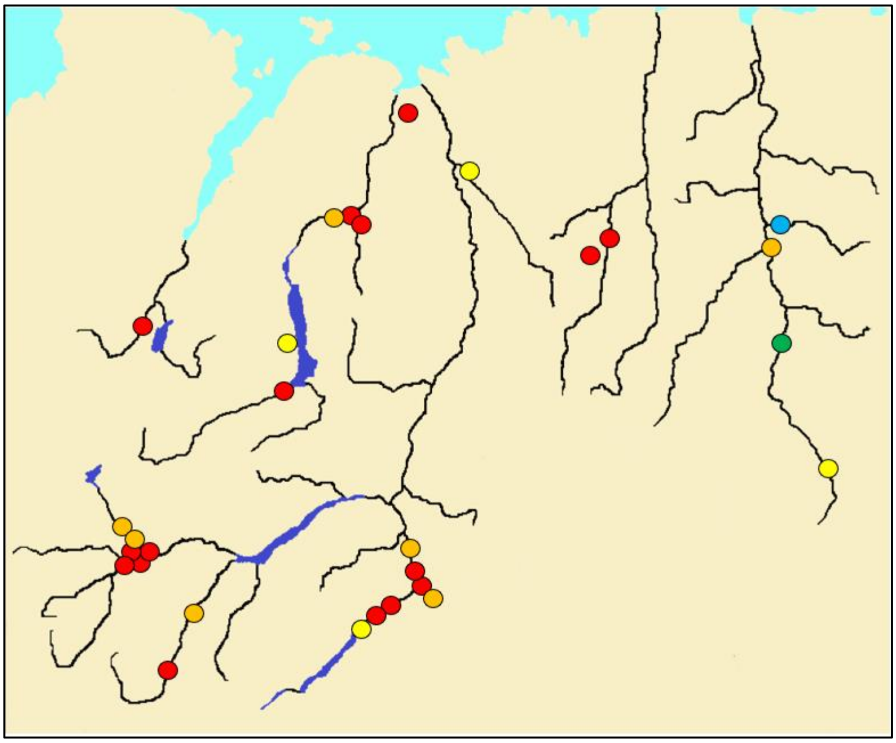
It can also be seen from Table 6 that differences in the body length of fry between sites convert to much larger differences in weight. The largest fry (at Dyke and in the Forsinain Burn) were eight times heavier than the smallest ones (at Allt Cnoc n  a Cloiche and at Site 3561 on the Meadie Burn).

*Table 6. Average fry length (mm), average fry weight (g) and biomass density (g/m$^2$) for 1-pass fishing or on first pass of 3-pass fishing.*

| Catchment | Date | Location | NEPS code | Av. fry length (mm) | Av. fry weight (g) | Total biomass density |
|---|---|---|---|---|---|---|
| Borgie | 13/09 | Dalness | 3440 | 50.4 | 1.2 | 0.81 |
| | 13/09 | Dalness Falls | 3424 | 45.0 | 0.9 | 1.06 |
| | 1/10 | Achnantot Burn | - | 52.8 | 1.4 | 0.85 |
| | 1/10 | Inchkinloch | 3422 | 53.3 | 1.4 | 0.80 |
| | 6/10 | Lettermore Burn | - | 46.7 | 0.9 | 2.59 |
| | 6/10 | Allt Borgie Beag | - | 52.8 | 1.4 | 0.88 |
| Halladale | 27/08 | Forsinard | 3554 | **63.0** | 2.5 | 2.05 |
| | 3/09 | Trantlemore | 3436 | **60.4** | 2.2 | omitted |
| | 3/09 | Forsinain | 3426 | **64.0** | 2.6 | 3.40 |
| | 4/09 | River Dyke | 3427 | **67.4** | 3.1 | omitted |
| | 13/09 | Trantlemore | 3568 | **66.7** | 3.0 | 1.98 |
| | 13/09 | Forsinain Burn | 3468 | **66.8** | 3.1 | 4.76 |
| Kinloch | 17/08 | A.na Luibe Moire | 3470 | 42.4 | 0.7 | 0.34 |
| Naver | 25/07 | Vagastie | 3593 | 41.1 | 0.6 | 1.01 |
| | 25/07 | Vagastie | 3573 | 37.8 | 0.5 | 0.53 |
| | 26/07 | Mudale | 3581 | 41.1 | 0.6 | 0.49 |
| | 26/07 | Mudale | 3585 | 44.3 | 0.8 | 0.44 |
| | 26/07 | Meadie Burn | 3429 | 38.0 | 0.5 | 0.17 |
| | 26/07 | Meadie Burn | 3561 | 35.0 | 0.4 | 0.14 |
| | 28/07 | Meadie Burn | 3565 | 46.6 | 0.9 | 1.24 |
| | 28/07 | Mudale | 3557 | 43.9 | 0.7 | 1.24 |
| | 7/08 | Mallart | 3582 | 51.2 | 1.3 | 2.66 |
| | 7/08 | Mallart | 3462 | 38.2 | 0.5 | 0.33 |
| | 9/08 | Mallart | 3466 | 46.1 | 0.9 | 1.18 |
| | 9/08 | Mallart | 3578 | 40.1 | 0.6 | 0.14 |
| | 9/08 | Mallart | 3558 | 39.4 | 0.5 | 0.61 |
| | 9/08 | A. Cnoc na Cloiche | 3430 | 35.9 | 0.4 | 1.08 |
| | 9/08 | Mallart | 3562 | 47.1 | 1.0 | 0.62 |
| | 10/08 | Skelpick Burn | 3571 | 46.5 | 0.9 | 2.62 |
| Strathy | 13/08 | Yellowbog Burn | 3559 | n/a | n/a | 0.07 |
| | 13/08 | Strathy (Upper) | 3583 | n/a | n/a | 0.17 |

Table 6 also shows, the total (ie combined fry and parr) biomass density for each site (3436 and 3427 have again been omitted) based on the estimated body weight of individuals calculated from their body length measurement.

Total biomass density is a potentially informative measure of the habitat quality of sites although its full value is revealed only when single sites have been examined in multiple years. Figure 6 shows the total biomass density value for each site mapped onto the Northern District river network. The highest values were for the Forsinain Burn and for the mainstem Halladale also near Forsinain.



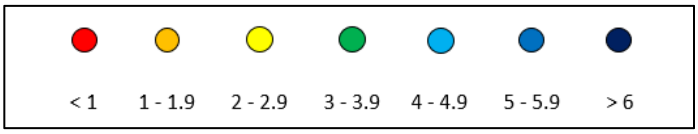



*Figure 6. Total biomass density (g/m²) of fry and parr for 1-pass fishing or for the first pass of 3-pass fishing. The values are categorised and colour-coded according to the key.*

## 2.4. Comparison of 1-pass data for the Northern and Caithness Districts

Figures 7, 8 and 9 re-map the values shown in Figure 4, 5 and 6, respectively, onto the river network for the combined Northern and Caithness Districts. As before, there are 29 sites for Northern District. In addition, data for 44 sites in Caithness District are shown. The Caithness sites comprise 30 NEPS sites and 14 sites that were fished expressly for the Caithness Board. All the data are for 2018.

## 2.4.1. Fry density

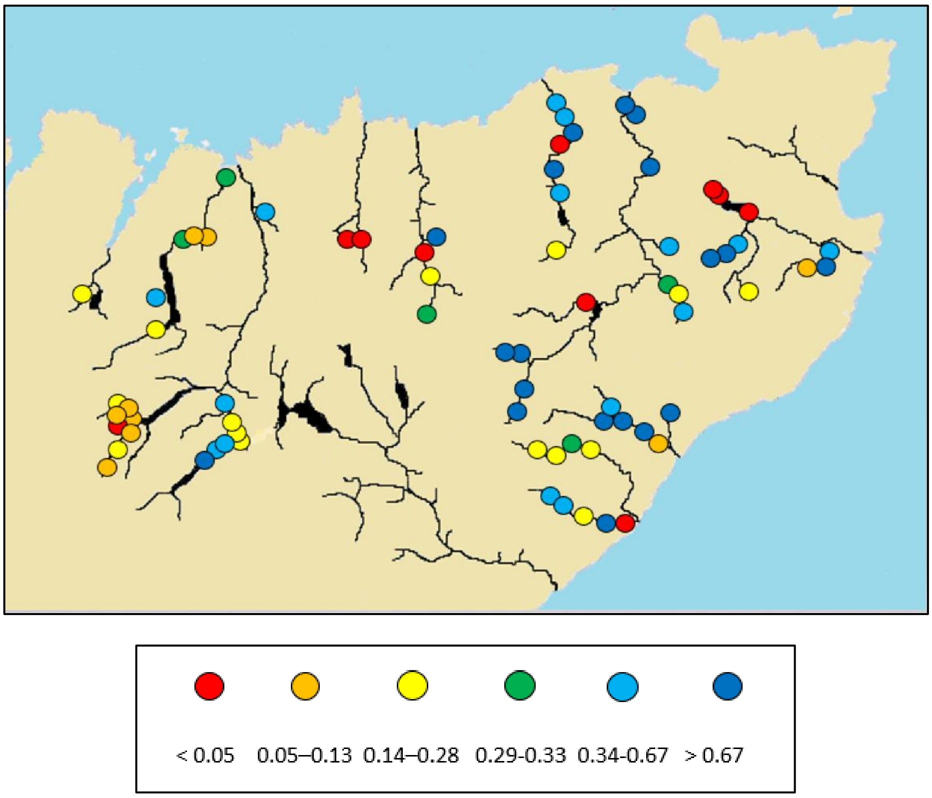



*Figure 7. Densities (n/m$^2$) of fry for 1-pass fishing or for the first pass of 3-pass fishing. The values are categorised and colour-coded according to the key.*

Figure 7 shows 1-pass fry density values, categorised according to Godfrey's benchmarks and colour-coded as previously. It can be seen that fry densities were generally higher in the Caithness rivers than in the Northern District with a greater proportion (61% v 24%) of sites colour-coded in the highest blue or dark blue categories. However, at the lower end of the scale the proportion of sites colour-coded red was the same (14%) for both districts.

Data are available for only one, exceptional (drought) year. There is a multiplicity of reasons why some sites should hold greater densities of fish than others. There are also differences in the survey dates and some of these are sufficient to explain some, but not all, of the variation.

However, taken at face value, the patterns of fry density indicate (1) a difference at the District scale (2) that spawning in 2017 and the resulting supply of fry in 2018 had been equivalently dispersed in both Districts because the same proportion of sites was graded in the lowest (red) category for both Districts and (3) that fry uptake had been greater in the Caithness set of sites.

## 2.4.2. Parr density

Figure 8 shows the equivalent data for parr densities. As for the fry, it can be seen that parr densities tended to be higher for the Caithness sites. The highest categories for abundance (blue or dark blue) were allocated to 45% of Caithness sites but only 17% of those in Northern District. The lowest category of abundance was allocated to 14% of the Caithness sites but to 24% of those in Northern District.

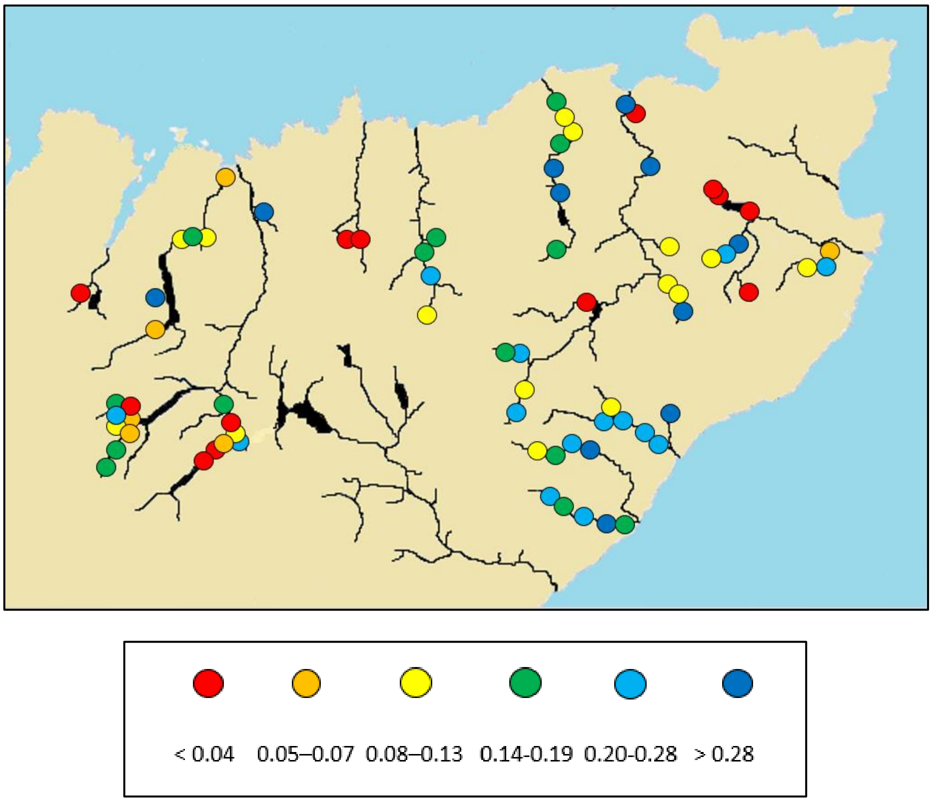



*Figure 8. Densities (n/m²) of parr for 1-pass fishing or for the first pass of 3-pass fishing. The values are categorised and colour-coded according to the key.*

### 2.4.3. Total biomass density

Figure 9 shows the total biomass density values for the combined Northern and Caithness District sites. The regional patterns are similar to those for fry and parr densities. However, the disparities are more pronounced because lower densities of fish tended to be associated with lower fish weights.

In Caithness, 30% of sites were allocated to the highest categories (blue, dark blue or black) rated at more than 4g/m$^2$; only a single Northern District site was allocated to this category. At the other extreme, 9% of Caithness sites were rated at less than 1g/m$^2$ and allocated to the lowest category (red) compared with 55% of Northern District sites.

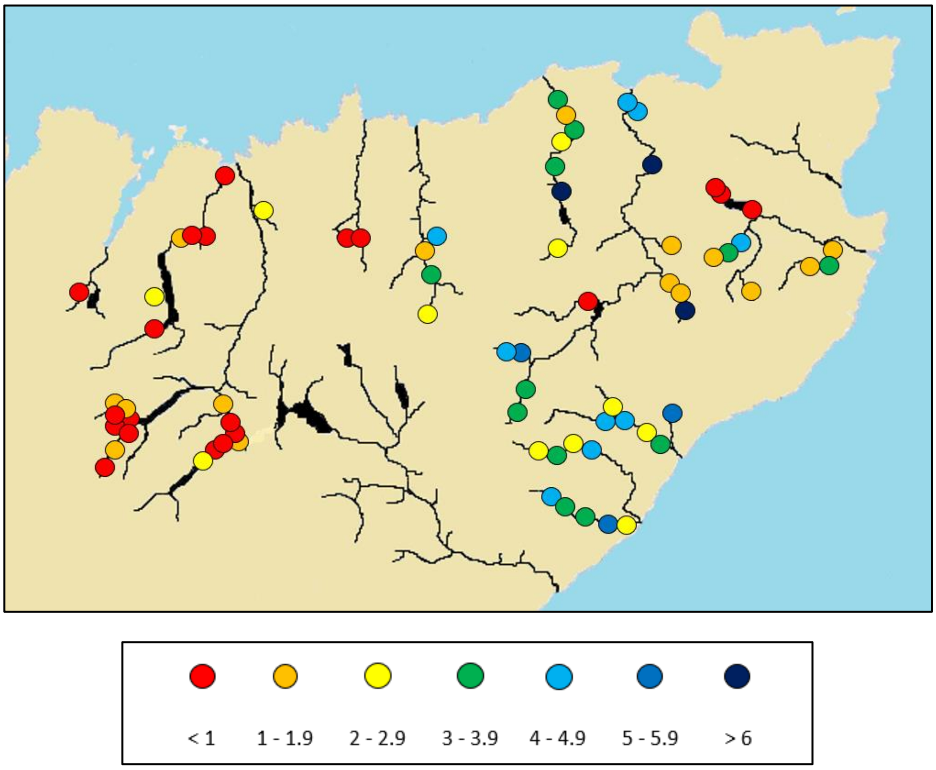



*Figure 9. Total biomass densities (g/m²) for 1-pass fishing or for the first pass of 3-pass fishing. The values are categorised and colour-coded according to the key.*

### 2.4.4. Conductivity

Figure 9 shows that spatial patterns of variation and discontinuities in the data tend to align with the separate Board areas. This may be partly due to differences in capture efficiency between Board teams due to variation in equipment and operating methods. However, the differences are too large to be explained away by this alone and another explanation must be sought.

The principal cause is probably associated with the obvious geographical distinctions between the western and eastern parts of the joint Northern/ Caithness District area. In particular, sedimentary bedrocks dominate to the east of an imaginary line from Berriedale in the south to Reay in the north. To the south and west of this division the geology is more complex and the bedrocks are mostly igneous or metamorphic. This discontinuity is associated with differences in hydrochemistry; environmental conditions are more benign in the streams that drain catchments lying over the sedimentary bedrocks. This matter is discussed in a FCRT report[7].

Figure 10 is taken from the FCRT report. It shows values for the electrical conductivity of stream water sampled at locations throughout the Trust's area. The values were obtained during the summer drought in 2018 when the proportion of recent rainwater in the streams was low. The survey was therefore of baseline values for stream water that had previously been in prolonged contact with minerals contained in local soils and rocks.

7 http://www.fcrt.org/Electrical%20Conductivity%20%20Measurements%20in%20the%20Northern%20Rivers%20v%20final.pdf

Bearing in mind that comparisons can only be made for the single year for which NEPS data is available, the spatial patterns of variation in conductivity appear to be a potential – but imperfect - match for the observed patterns of variation in fry and parr densities and, particularly, in total biomass density.

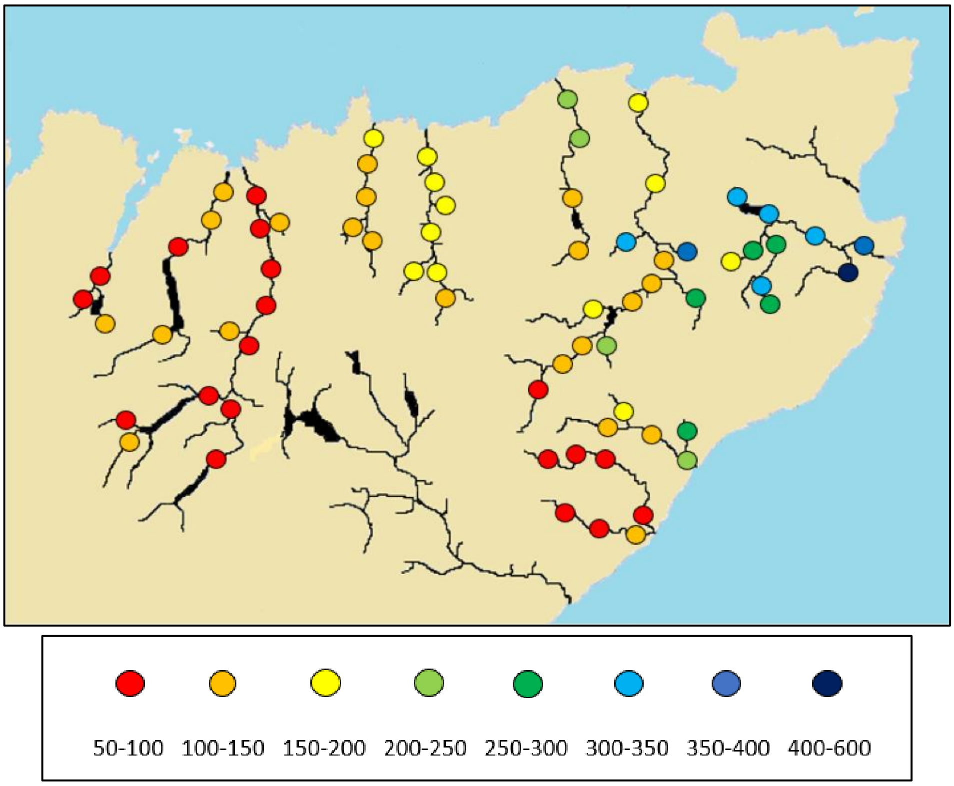



*Figure 10. Conductivity (µSi/ cm) in stream waters of the Northern District and Caithness District catchments. The data were obtained in 2018 during drought conditions.*

## 2.5. 3-Pass data

Table 7 shows data for the 14 of the 31 survey sites that were fished using 3-pass methods and with Zippin correction for variation in capture efficiency. For obvious reasons the values shown in Table 7 are greater than the equivalent values shown for 1-pass fishing in Table 5 but, as expected, the rankings of sites were generally similar for 1-pass and 3-pass fishing.

*Table 7. True fry density, true parr density and total biomass density from 3-pass electric-fishing.*

| Catchment | Date | Location | NEPS code | True fry density (n/m²) | True parr density (n/m²) | Total biomass density (g/m²) |
|---|---|---|---|---|---|---|
| Borgie | 13/09 | Dalness | 3440 | 0.14 | 0.15 | 1.15 |
| | 13/09 | Dalness Falls | 3424 | 0.44 | 0.16 | 1.37 |
| | 1/10 | Achnantot Burn | - | 0.42 | 0.15 | 2.36 |
| | 1/10 | Inchkinloch | 3422 | 0.30 | 0.11 | 1.04 |
| | 6/10 | Lettermore Burn | - | 0.79 | 0.33 | 2.82 |
| | 6/10 | Allt Borgie Beag | - | 0.46 | 0.12 | 1.59 |
| Halladale | 27/08 | Forsinard | 3554 | 0.46 | 0.12 | 2.98 |
| | 3/09 | Forsinain | 3426 | 0.33 | 0.52 | 7.39 |
| | 13/09 | Trantlemore | 3568 | 0.08 | 0.24 | 3.28 |
| | 13/09 | Forsinain Burn | 3468 | 1.30 | 0.22 | 7.78 |
| Kinloch | 17/08 | A.na Luibe Moire | 3470 | 0.45 | 0.07 | 0.73 |
| Naver | 28/07 | Meadie Burn | 3565 | 0.34 | 0.35 | 2.66 |
| | 7/08 | Mallart | 3582 | 2.63 | 0.10 | 4.96 |
| | 7/08 | Mallart | 3462 | 1.22 | 0.05 | 0.89 |

The 3-pass values confirm the high status of Sites 3426 (Forsinain) and 3468 (Forsinain Burn) in the Halladale catchment relative to the other Northern rivers. In particular, the sites' high biomass densities (7.4g and 7.8g/m$^2$, respectively) compare very favourably with equivalent 3-pass values for survey sites in Caithness District (Figure 11, see Appendix).

Figure 12 shows 1-pass versus 3-pass values for fry density. On average, 1-pass fishing captured about 60% of the real number of fry shown to be present by 3-pass fishing. However, there were differences among sites and capture efficiency on 1-pass fishing varied over a range between 42% and 76%.

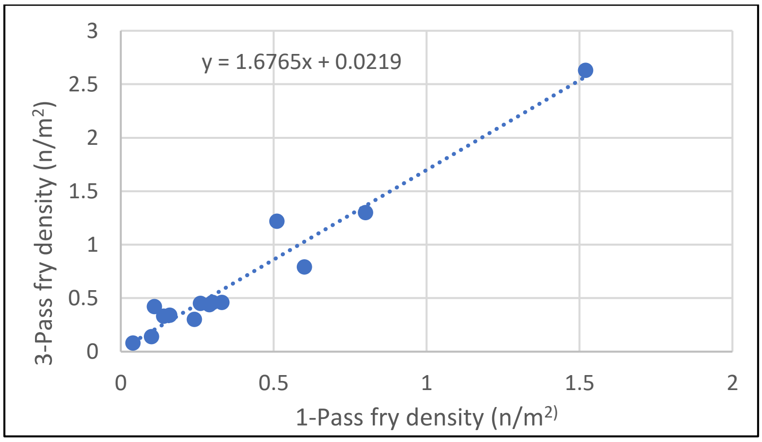



*Figure 12. 1-Pass versus 3-pass values for fry density.*

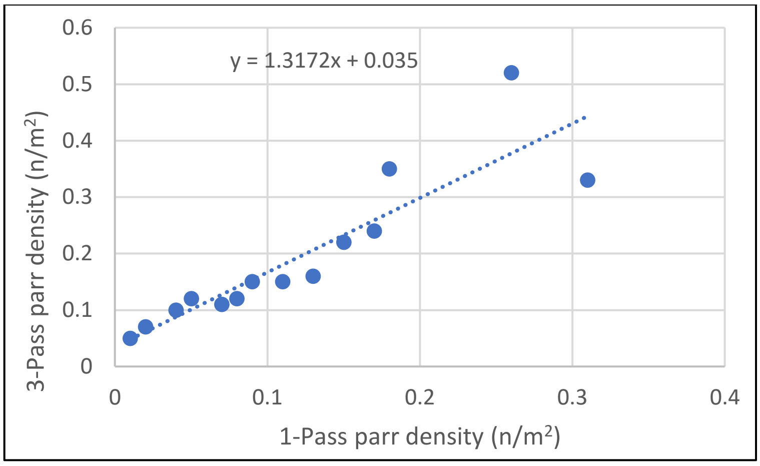



*Figure 13. 1-Pass versus 3-pass values for parr density.*

Figure 13 shows the equivalent comparison for parr density. On average, 76% of all the parr that were present were captured by 1-pass fishing. (Note that capture rates for parr tend to be greater than capture rates for fry because large fish are more susceptible to the effects of the electric-fishing equiment than small fish). Again, capture efficiency on 1-pass fishing varied over a substantial range (50% - 90%).

Overall, however, Figures 12 and 13 show that the field teams (Naver, Halladale and Borgie) worked consistently and with rather uniform effectiveness despite the wide range of water conditions encountered in 2018.

## 3. Conclusions.

Interpretation of electric-fishing data is challenging because of the multiplicity of effects that determine the distribution, density and size of young salmon. Targeted survey designs like the NEPS are most likely to be successful but sound working methods and accurate survey data are also required because both reduce the level of background noise. The drought of 2018 posed unusual difficulties for the survey teams and these were solved on the ground in different ways.

The NEPS is a national programme directed towards evaluating juvenile salmon populations on a regional scale. However, the data are also potentially informative at the finer scales (rivers or sites) of particular interest to the Board. The 2018 NEPS proved informative despite so far being for a single and exceptionally dry year. Additional survey work in future years under the NEPS, or any separate Board or river arrangement, would disproportionately increase the level of information available to the Board.

Judged by Godfrey's criteria the condition of the salmon populations in the Northern District in 2018 was similar to their condition pre-2005, when the data examined by Godfrey was obtained. This point is illustrated in Figures 2 and 3.

Figures 4 and 5 show that both fry and parr densities covered all of the expected range of values. Spatial coverage was too patchy to judge how evenly fish were present across individual catchments or sub-catchments.

In the wider context, comparison with the 2018 NEPS data for the Caithness rivers showed that fry and parr densities (Figures 7 and 8) were generally higher to the east. However, the disparity between the eastern and western rivers was greatest for total biomass density (Figure 9) showing that fish were larger in the eastern than in the western catchments. These difference in density and body size are probably attributable to systematic variation in habitat quality rather than the relative status of local populations of fish. Figure 10 suggests that hydrochemical variation linked to catchment geology is the underlying cause.

Figure 10 also suggests that the hydrochemistry of the Halladale catchment is more benign than it is in rivers further west. Coverage of the Halladale was relatively sparse but the densities of fry and parr and the total biomass densities were greater in the Halladale than in rivers to the west. Table 6 shows that the Halladale fry were also much larger than those in more western locations. Among the other Northern District rivers, therefore, salmon in the Halladale catchment may benefit from a hydrochemical environment that is intermediate in quality between the groups of rivers lying further to the east or to the west.

NEPS coverage of the Kinloch River (only 1 survey site on a minor tributary) and the River Strathy (only two sites on high headwater streams) was particularly sparse. NEPS survey sites on the Naver were heavily biased towards the uppermost part of the catchment. If the NEPS continues then some increase in spatial coverage is scheduled in the programme design. However, the NEPS sites are randomly chosen to facilitate a regional rather than a river-by-river or site-by-site analysis and, as it stands, the NEPS is not ideally-suited to addressing river- or stream-specific issues. In the meantime, therefore, local electric-fishing programmes in Northern District should be retained.

# Appendix

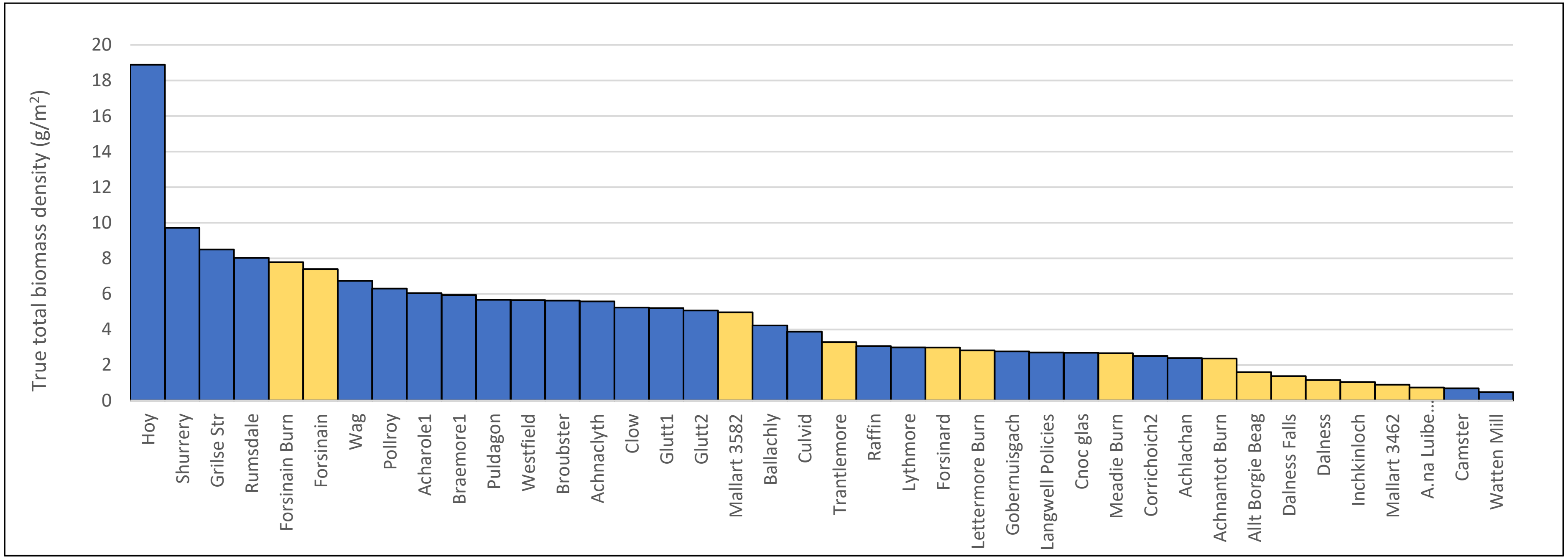



*Figure 11. 3-Pass biomass density values (g/m$^2$) for 2018 ranked by site for the combined Northern Board and Caithness Board areas. Sites in the Northern District are colour-coded orange and those in Caithness District are colour-coded blue.*