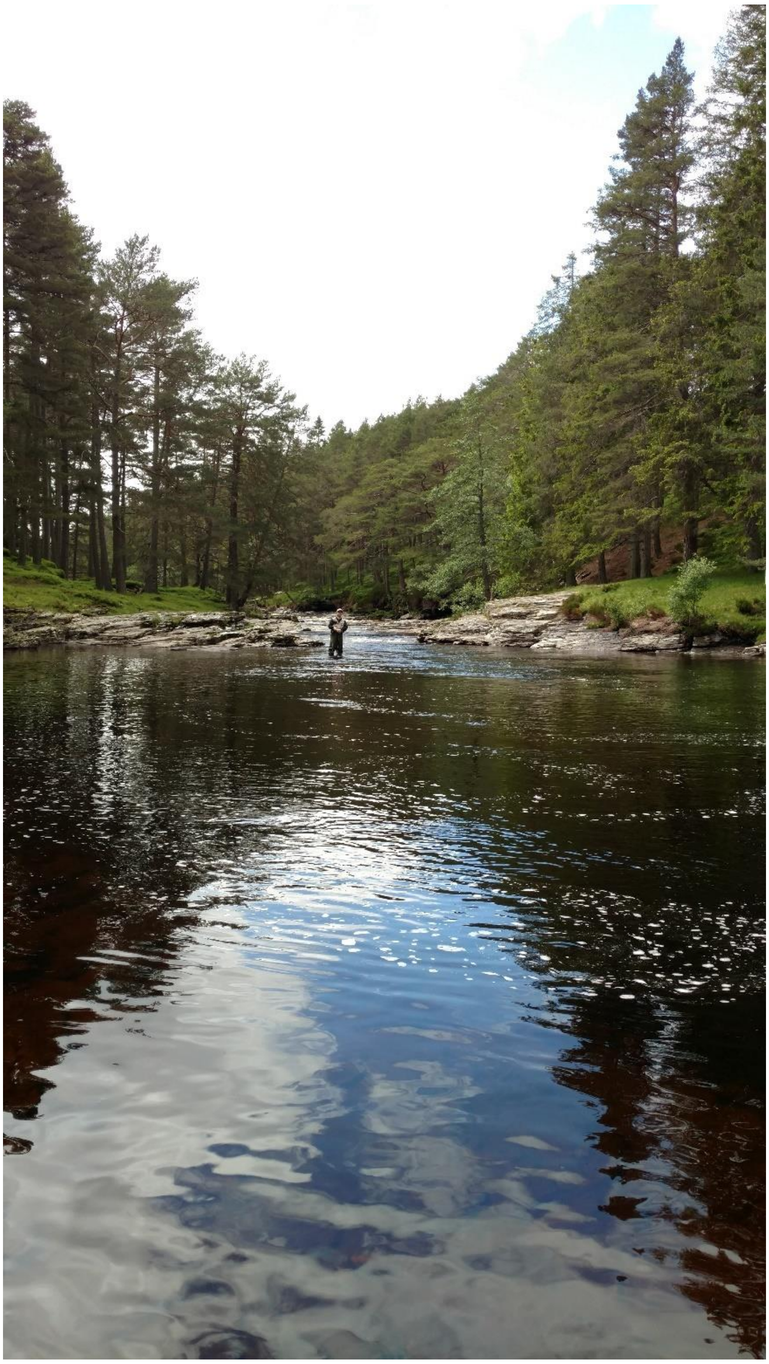
The River Dee

2016 Stock assessment

January 2017



The River Dee

Executive summary

This report assesses the juvenile salmon stock in the Dee catchment in 2016 to determine whether it is currently in a healthy state. The first juvenile stock assessment was made in 2015 and a similar method is used here to analyse juvenile data collected by electrofishing in 2016.

Salmon fry abundances at each site in 2016 were calculated by Marine Scotland Science based on the numbers of fish caught during electrofishing, using the capture probability model developed by Millar et al (2015). This model incorporates habitat factors to account for differences in capture efficiency between sites to give a more accurate reflection of real fish densities.

The 2016 fry densities at each electrofishing site were then compared to a reference density, or benchmark, based on expected fry densities at a site with similar habitat characteristics. The benchmark is what could be considered as indicative of a healthy catchment. In simple terms the benchmarks derived from this model can be thought of as the mean expected fry density for the River Dee in a good year, for the specific habitat characteristics at the electrofishing site.

Fry densities throughout the Dee catchment were found to be considerably below the benchmark in 2016, with many sites containing less than 10% of the fry numbers that would indicate a healthy fry population. In contrast, fry densities in 2012 – which were expected to be high due to high spawner abundance in 2011 – were close to the benchmark and showed the catchment had been close to maintaining maximum fry production in 2012. Fry densities in 2016 were also substantially below those in 2015, in terms of the number of sites attaining a national benchmark. However, other analyses showed that parr densities in 2016 had not declined from 2015 and had even shown an overall increase in the surveyed tributaries.

The reduction in fry densities since 2015 could be due to several reasons. Firstly, the flood caused by Storm Frank (30 December 2015) was the biggest flood since at least 1829, and had a huge impact on substrate at a time of year when salmon eggs were buried within the substrate. Therefore, this single event is likely to have had an impact on 2016 fry production.

However, low fry numbers seemed to be a more widespread issue in 2016, with unpublished reports from other large Scottish rivers suggesting low or patchy fry densities and rivers in Wales, reporting a severe decline in fry numbers. These rivers did not suffer the magnitude of flooding that the Dee experienced following Storm Frank, suggesting that there is another factor influencing fry abundance at a wider scale.

A third factor is that rod catches indicate that 2015 had the poorest spawner abundance on the Dee on record. Therefore, reduced spawner abundance may have contributed to low fry abundance. Indeed, Marine Scotland Science data for the Girnock burn shows fry production is generally consistent with the low adult returns in recent years.

The likelihood is that a combination of factors has led to low fry abundance in 2016. It is hoped that 2017 will see an improvement in fry densities, as spawner numbers appear improved from 2015 and the low numbers of fry seen in 2016 may benefit the 2017 fry cohort through reduced competition.

Background

Rod catches can be a useful indicator of stock health. The catch records for the Dee show that a decline occurred between the 1960s and 1990s, which was driven specifically be a decline in spring salmon catches. Improved catches since the 1990s were due to increased catches in the later (summer and autumn) stocks of fish, which peaked in 2010. Since then, there has been a general decline in all spring, summer and autumn stocks (Figure 1).

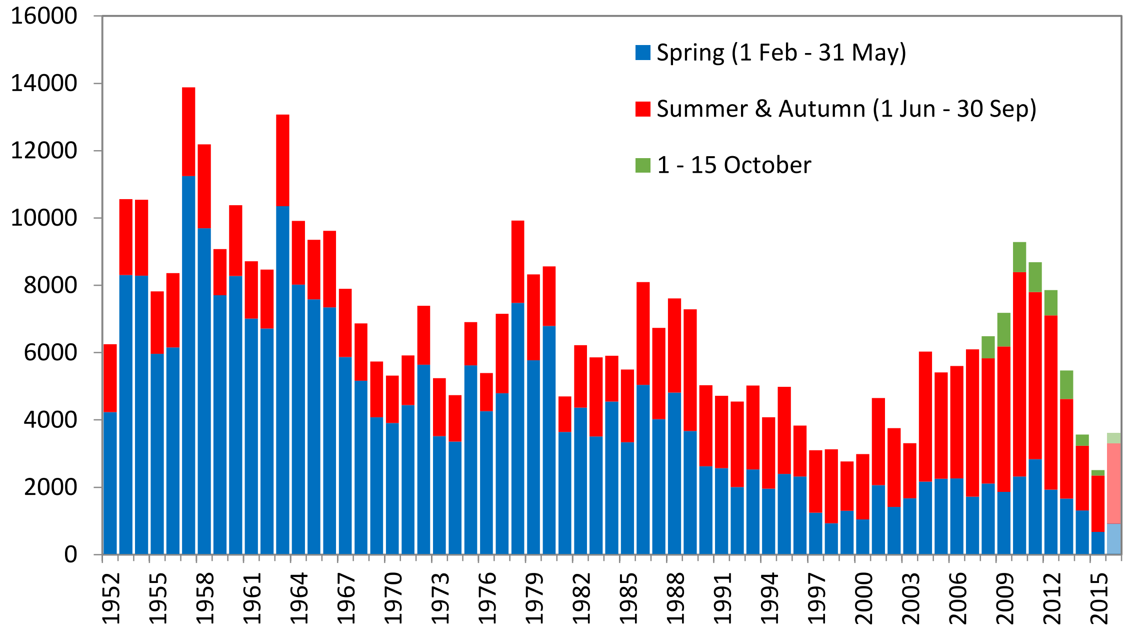


Figure 1. Salmon rod catches for the River Dee, 1952 – 2015 (Marine Scotland Science data). 2016 data based on FishDee reports.

The decline between the 1960s and 1990s is common to nearly all rivers nationally and internationally, and is due to a decline in the survival of salmon at sea. Monitoring on the neighbouring River North Esk by Marine Scotland Science (MSS) suggests that marine survival in this region has decreased from approximately 40% in the 1960s to around 6% in the last decade, although unfortunately recent years have not been monitored. Returns of female spawners to the Girnock and Baddoch fish traps have also shown a decline: The total number of emigrants from these two burns (i.e. spring smolts and autumn parr migrants) that return to spawn is now less than 20% of what it was in the 1970s (latest data is from 2012 emigrants; http://www.gov.scot/Topics/marine/Salmon-Trout-Coarse/Freshwater/Monitoring/Traps/AdultReturnRates), although these survival rates are a combined result of mortality in the marine and freshwater environments, and as a result of fisheries.

The improved catches seen generally throughout Scotland from 2000 – 2010 may have been due to reduced pressure from coastal netting, allowing more salmon to enter the rivers. However, over this period, international monitoring has shown that marine mortality has continued to increase.

The decline that has occurred on the Dee since 2010 is not widespread at a national level, leading to concern that additional, local or regional factors may be impacting on the Dee's stocks. In support of this, recent work by MSS (in review) found evidence of a local (North East) trend, whereby rod catches on the Dee, Don, Ythan, Deveron and Lossie have all recently declined, which is distinct from other Scottish rivers.

The Conservation of Salmon (Scotland) Regulations 2016 has led to the production of stock assessments for all Scottish salmon rivers, based on catch data. The assessments estimate whether the number of adults returning to the river in each of the previous five years will produce sufficient numbers of eggs to keep the population size above a critical threshold.

For the Dee, the assessments have shown a declining trend since 2011 (Figure 2). Given this, it may seem surprising that the Dee has therefore been categorised as a grade 1 river, meaning that the stocks have most likely (at least an 80% probability on average) been above this critical threshold - the Conservation Limit - over the last five years. The management implication of this assessment is that the current level of exploitation is sustainable and no additional management is required (Marine Scotland Science 2016a).

The conclusion from this assessment reflects that despite the decline seen in Dee stocks, the absolute number of salmon returning to the Dee is still sufficient to maintain a stable (rather than declining) population size. It does not suggest that the salmon stock is thriving from a biological perspective or that it could withstand further exploitation.

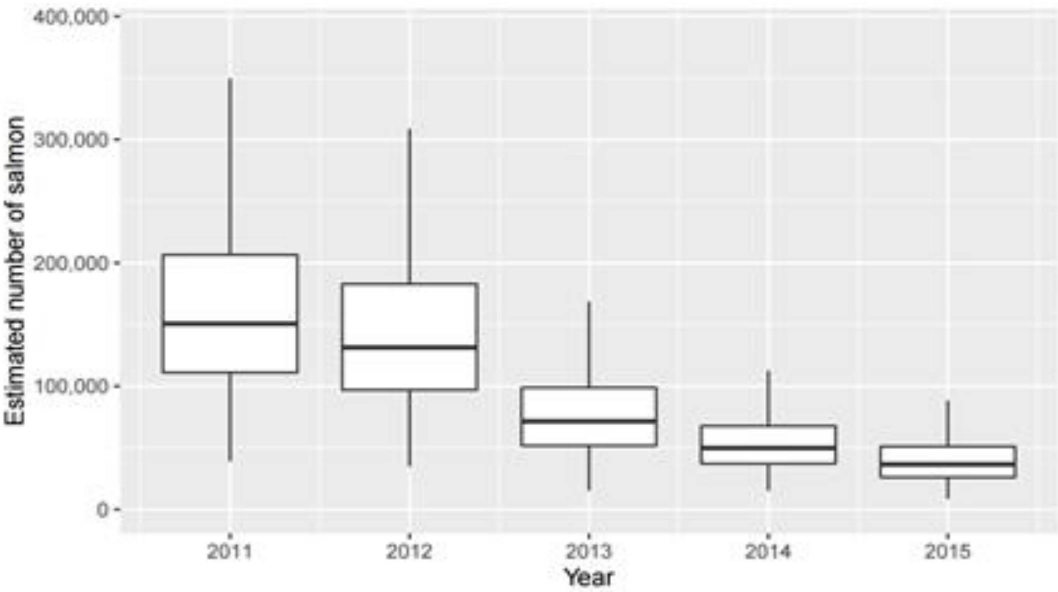


Figure 2. Salmon numbers for the River Dee estimated as part of the 2016 Conservation Regulations. The horizontal line within each box represents the likely population size, with the box and vertical lines representing possible error in the population size estimates (from *Salmon Conservation Regulations for 2017*, Marine Scotland Science 2016b. © Crown copyright 2016).

Aims

This report assesses the juvenile salmon stock on the Dee in 2016. The first juvenile stock assessment was made in 2015 (2015 Dee Stock Assessment) and this report uses a similar method to analyse 2016 juvenile data collected by electrofishing. The technical details of the models and their application to the Dee are described by Malcolm et al. (2016). The original assessment model (Millar et al 2015), is being refined iteratively and these improvements will be incorporated into our annual stock assessments.

The aims of this report are:

1. To determine whether the juvenile salmon stock in the Dee catchment is in a healthy state in 2016;
2. To determine whether or not juvenile stocks have increased since 2015;
3. To consider why juvenile stocks may have changed over the last year.

Methods

Electrofishing data

Juvenile salmon (fry and parr) densities were obtained from electrofishing surveys carried out in the summer of 2016. These included 44 semi-quantitative (1-sweep) and 18 fully-quantitative (3-sweep) surveys which are spread throughout the catchment (these excluded survey sites above obstacles or recently-installed fish passes). An additional 11 sites surveyed by Marine Scotland Science on the Girnock and Baddoch burns were also included in the analysis, to give a total of 73 sites.

Salmon fry densities at each site in 2016 were estimated by MSS based on the numbers of fish caught during electrofishing, using the national capture probability model developed by Millar et al (2015). This model incorporates habitat factors to explain the variation in capture probability between sites, including distance to sea, upstream catchment area, altitude (the main three factors influencing fry densities), plus channel width, gradient and land use.

Benchmarking

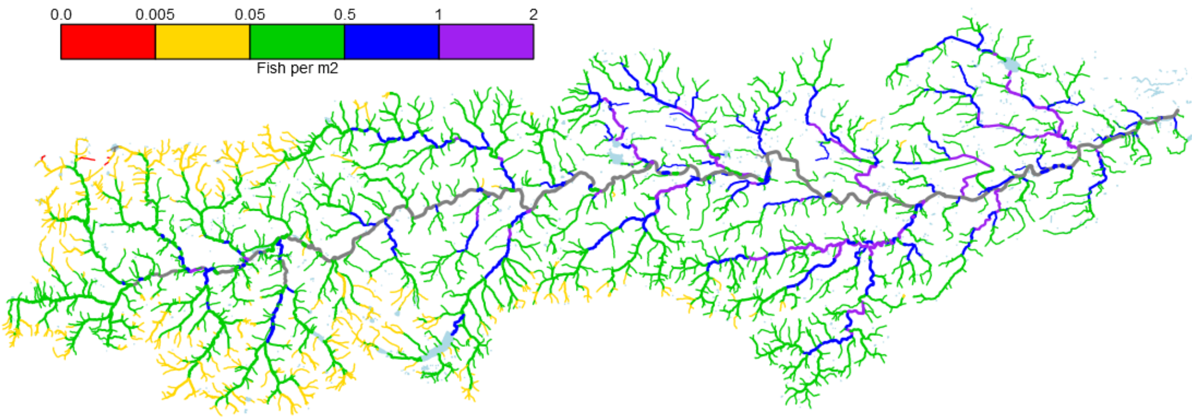
The 2016 observed fry densities at each electrofishing site on the Dee were then compared to a reference density, or benchmark, based on expected fry densities at a site with similar habitat characteristics. In the 2015 stock assessment, the benchmark was a national average for a given habitat ("National Reference"). This national data set was collected by MSS, SEPA, Fisheries Trusts and Boards for a variety of purposes. In total, it consisted of 3743 electrofishing observations from 1875 sites, surveyed between 1997 and 2013. The benchmark fry densities for each of the Dee sites were calculated for the year with the highest mean national fry density, incorporating the habitat effects.

For the assessment of 2016 fry densities, an alternative benchmark developed by MSS was used. This benchmark ("Dee Reference") was a higher level than the benchmark used in 2015, to reflect the higher-than-average fish densities on the Dee in a good spawning year, compared to the national average. For the 2016 benchmark, the capture probability model was still fitted with the national dataset, but predictions of fry densities on the Dee were made using some catchment habitat data that were specific to the Dee. In simple terms the benchmark can be thought of as the mean expected fry density for the River Dee in a good year, for the specific habitat characteristics at the electrofishing site. For full details of the calculations, see Malcolm et al (2016).

The suitability of the two possible benchmarks for the Dee has been assessed by Malcolm et al (2016) by comparing the results to an independent benchmark of fry density, developed from a stock-recruitment relationship for the Girnock burn. This comparison indicated that the "Dee Reference" was more consistent in terms of fry production predicted from the stock-recruitment relationship. In contrast, it was found that the National Reference was considerably too low as a benchmark of fry production in the Girnock Burn. The prediction from the Dee and National References are shown in Figure 3, and demonstrate how the Dee Reference sets a higher benchmark (higher fish densities expected) than the National Reference.

To help put the 2016 fry assessment into perspective, the fry densities in 2012 were also assessed against the benchmarks. 2012 was chosen for the comparison as it is expected that fry densities were high in that year, because of high adult spawner abundance in 2011 (based on rod catches (Fig. 1) and redd counts (River Dee Trust, 2015, unpublished)).

(a) Dee Reference predictions



(b) National Reference predictions

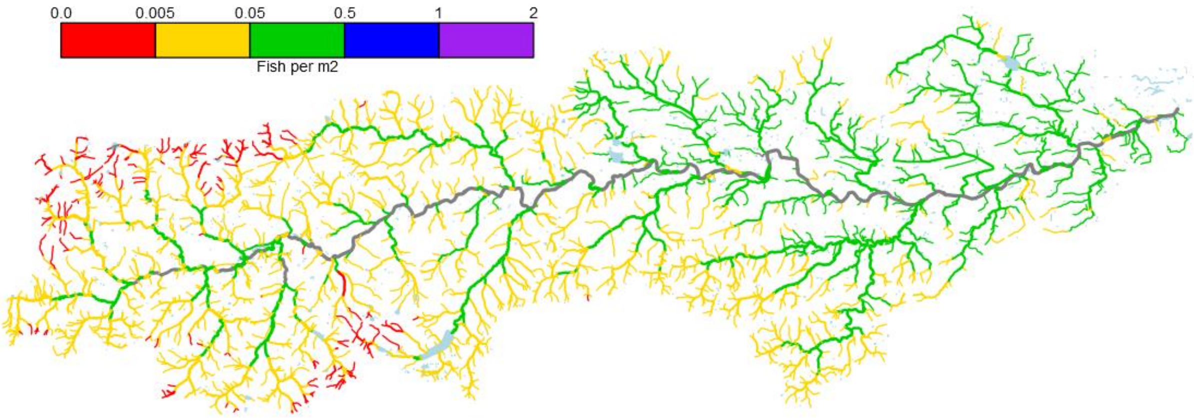


Figure 3. Maps showing predicted reference densities (benchmarks) (a) using the Dee Reference and (b) the National Reference. It was not possible to predict expected densities for watercourses shown in grey (most of the main stem) as their site characteristics were outside of the environmental range of the national electrofishing dataset. Figure reproduced from Malcolm et al., (2016). Contains Ordnance Survey data. © Crown copyright and database right 2016. Based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH). Moore RV, Morris DG and Flavin RW, 1994. Sub-set of UK digital 1:50,000 scale river centre-line network. NERC, Institute of Hydrology, Wallingford.

2015 and 2016 comparison

To determine if juvenile stocks have changed since 2015, two comparisons were made. Firstly, the assessment of 2015 fry densities against the National Reference (River Dee Trust 2016) was compared to the assessment of 2016 fry densities against the National Reference, based on a comparison of 66 sites that were electrofished in both 2015 and 2016, plus an additional seven sites that were electrofished for the first time in 2016. Secondly, the electrofishing data collected at the catchment health monitoring sites were compared. This included 28 (semi)quantitative surveys conducted at the same tributary sites in both 2015 and 2016 (Fig. 4), for which minimum population density estimates were calculated based on the numbers of fish caught in the first run of the electrofishing survey.

Changes in population size between 2015 and 2016 were tested for statistical significance using paired t-tests. For these statistical tests, the density data was first transformed (square root transformation) to make the data normally distributed. However, untransformed data is used in the figures for ease of interpretation.

In addition, nine sites on the main stem were surveyed in 2006, 2011, 2013 and 2016. These were timed electrofishing surveys which allow a catch per unit effort (CPUE) to be calculated. Although timed electrofishing does not provide an estimate of fish density, it is the only feasible electrofishing survey technique suited to wide, shallow rivers such as the main stem. Change in CPUE over the years was tested for statistical significance using repeated measures analysis of variance (ANOVA) tests. In both ANOVA and t-tests, statistical significance is indicated if the P-value is less than 0.05, and therefore these values are reported in the Results section of this report.

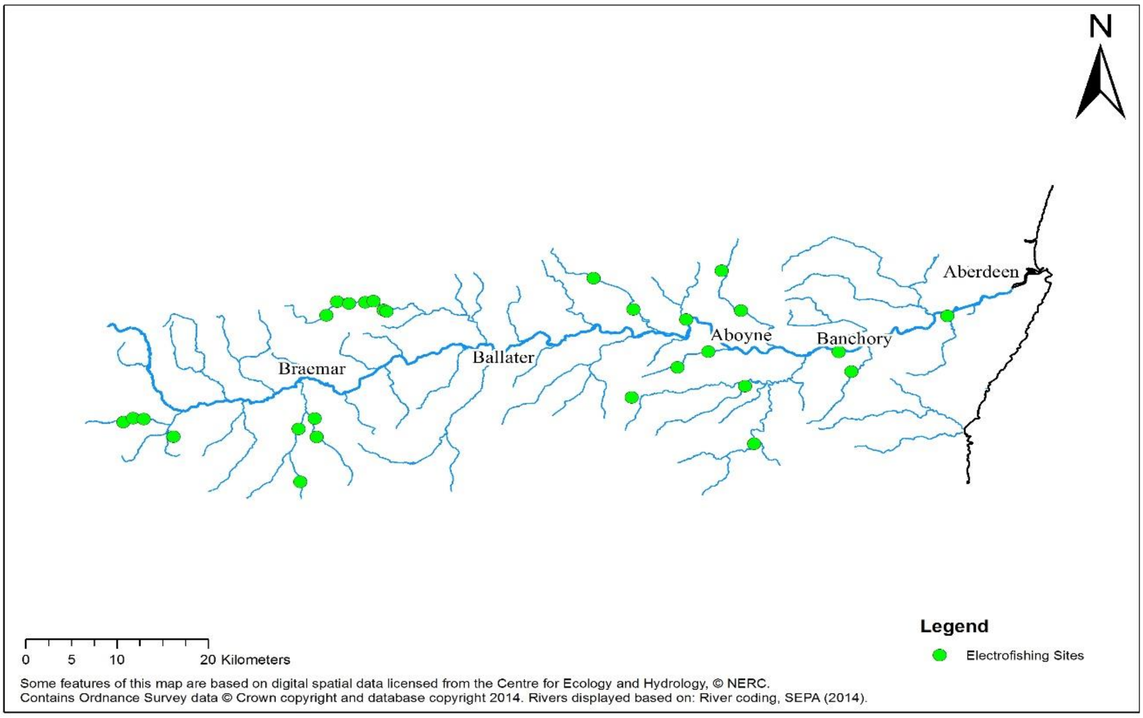


Figure 4. Location of 28 electrofishing sites surveyed in 2015 and 2016.

Results

2016 fry densities

The median salmon fry density in 2016 was very substantially lower than the Dee Reference benchmark (-0.303 fry per metre squared (m^{-2}); Fig. 5a), with many sites containing less than 10% of the expected fry numbers.

The fry densities at sites in different parts of the catchment can also be seen in Figure 5. Any sites affected by impassable or only recently removed barriers have been removed from the above analysis and maps to avoid negative bias in the assessment. The low fry numbers are throughout the catchment and only three of the 73 sites exceeded their benchmark.

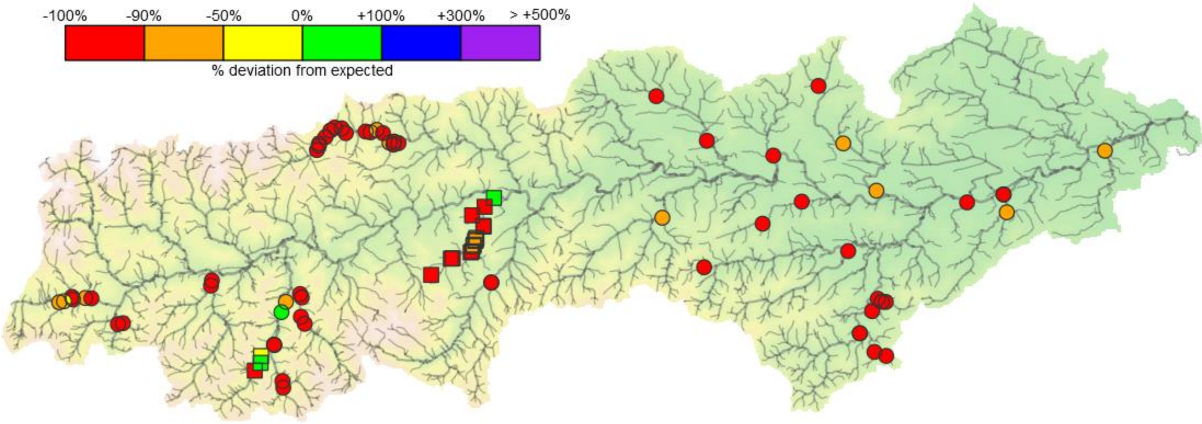
Note also that in the fry assessment of the Girnock burn (Malcolm et al 2016), Girnock fry stocks in 2016 failed to meet the Dee Reference benchmark, the National Reference benchmark and the maximum emigrant production benchmark based on the stock-recruitment relationship derived from the numbers of female spawners.

2012 fry densities

2012 is expected to have had high fry production, relative to recent years. The median salmon fry density in 2012 was substantially greater than 2016 fry densities, having on average, approximately 21 more fry per 100 m^2 in 2012 than in 2016. The median 2012 fry densities were very slightly lower than the Dee Reference benchmark in 2012 (-0.095 fry m^{-2}; Fig. 5b). This is interpreted as that the catchment was close to maximising fry production in 2012, under conditions of high spawner returns in 2011.

Sites in the upper catchment were approximately equally distributed either side of the Dee Reference (Fig. 5b), as would be expected if the target were being met. Unfortunately, there were limited electrofishing data available from the lower catchment in 2012, and thus the assessment is mostly driven by sites in the upper catchment. The fry abundances at the few sites in the lower catchment was generally less than expected relative to the Dee Reference benchmark. There were no obvious patterns indicating that certain tributaries were doing substantially better or worse than might be expected.

(a) 2016 fry densities



(b) 2012 fry densities

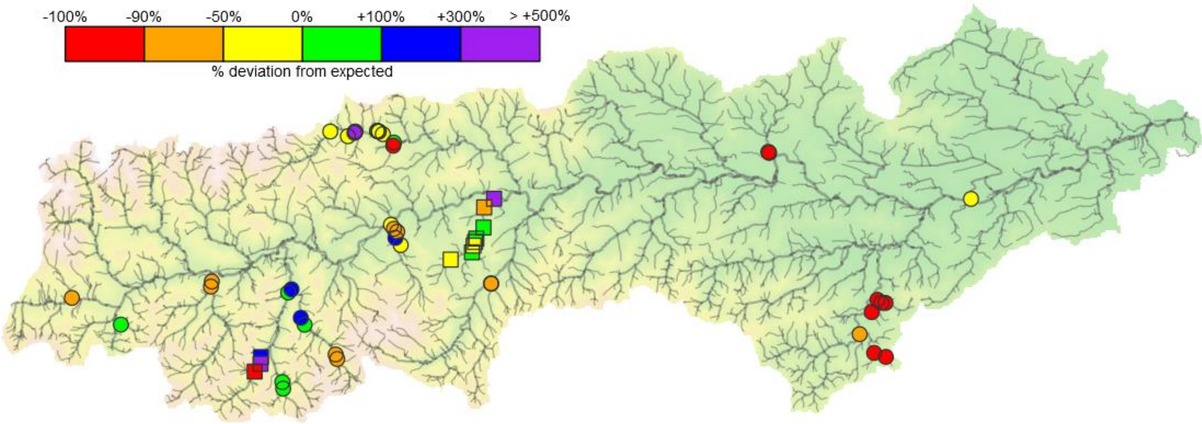


Figure 5. Percentage differences between fry densities in (a) 2016 and (b) 2012, compared to benchmark densities from the Dee Reference. Figure reproduced from Malcolm et al., (2016). Contains Ordnance Survey data. © Crown copyright and database right 2016. Based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH). Moore RV, Morris DG and Flavin RW, 1994. Sub-set of UK digital 1:50,000 scale river centre-line network. NERC, Institute of Hydrology, Wallingford.

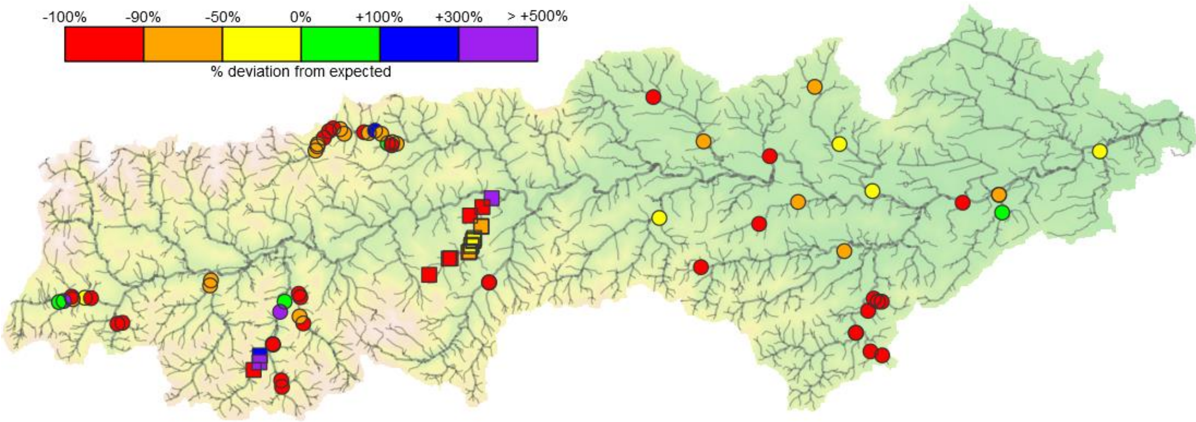
2015 and 2016 comparison

The comparison between fry densities in 2015 and 2016 is based on individual sites' performances against the National Reference benchmark. As discussed in the Methods section, this is a lower benchmark than the Dee Reference used above, but was all that was available a year ago when the 2015 assessment was undertaken (River Dee Trust 2016).

The median salmon fry density in 2016 was slightly lower than the National Reference level (-0.043 fry per metre squared; m^{-2}). Against the National Reference, 10 of the 73 sites (14%) exceeded the benchmark (Fig. 6a). The median fry densities in 2015 approximately met the National Reference level, with 32 out of 66 sites (48%) exceeding this benchmark (Fig. 6b).

To account for unequal distribution of electrofishing sites between tributaries, the number of tributaries that exceeded the benchmark was also assessed. In 2015, 58% (seven out of 12) of tributaries exceeded the National Reference. In 2016, none of the 15 tributaries surveys exceeded the National Reference (one tributary met the reference level and 14 tributaries fell below it).

(a) 2016 percentage differences in fry densities



(b) 2015 percentage differences in fry densities

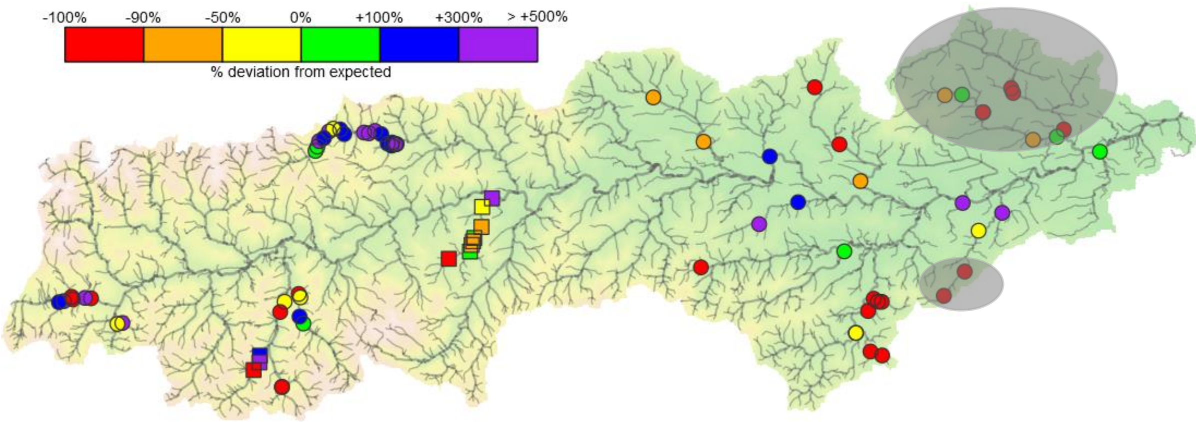


Figure 6. Percentage differences between fry densities in (a) 2016 and (b) 2015, against benchmark densities from the National Reference. Sites covered by grey circles have no or only recent accessibility to salmon (Culter burn and Sheeoch burn) and are excluded from analysis. Figure reproduced from Malcolm et al., (2016). Contains Ordnance Survey data. © Crown copyright and database right 2016. Based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH). Moore RV, Morris DG and Flavin RW, 1994. Sub-set of UK digital 1:50,000 scale river centre-line network. NERC, Institute of Hydrology, Wallingford.

Based on the 28 tributary sites that were electrofished in both 2015 and 2016, salmon fry densities have shown a significant reduction between 2015 and 2016, from an average of 10.3 fry 100 m^{-2} to 3.0 fry 100 m^{-2} (minimum fry density estimate; t-test, P < 000.1; Fig. 7). In contrast, parr densities have shown a significant increase in 2016, from 4.9 to 9.4 parr 100 m^{-2} (minimum parr density estimate; t-test, P = 0.021, Fig. 8).

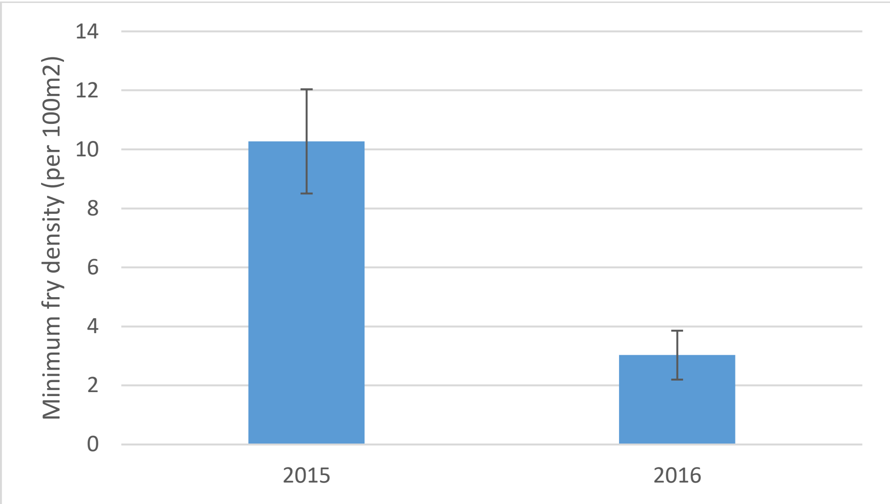


Figure 7. Mean salmon fry densities (with vertical bars representing variation between sites - standard error) across 31 catchment health monitoring sites. Minimum densities are reported based on one-sweep quantitative surveys.

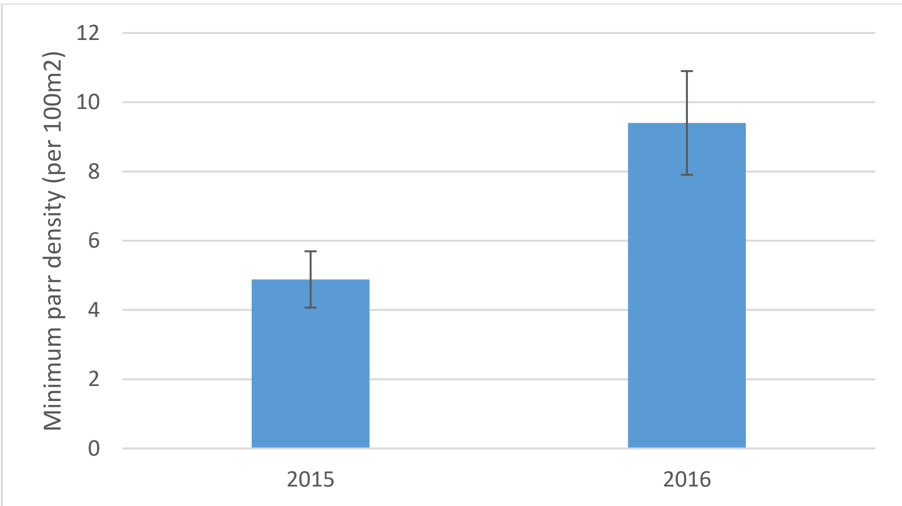


Figure 8. Mean salmon parr densities (with vertical bars representing variation between sites - standard error) across 31 catchment health monitoring sites. Minimum densities are reported based on one-sweep quantitative surveys.

Nine sites on the main stem have been surveyed in 2006, 2011, 2013 and 2016. These have been timed surveys which allow a catch per unit effort (CPUE) to be calculated. This indicates a similar pattern to that seen in the tributaries: Fry numbers are much lower in 2016 than in previous years (ANOVA; $P < 0.0001$; Fig. 9) whereas parr numbers have not significantly declined (Repeated measures ANOVA; $P = 0.841$; Fig. 10).

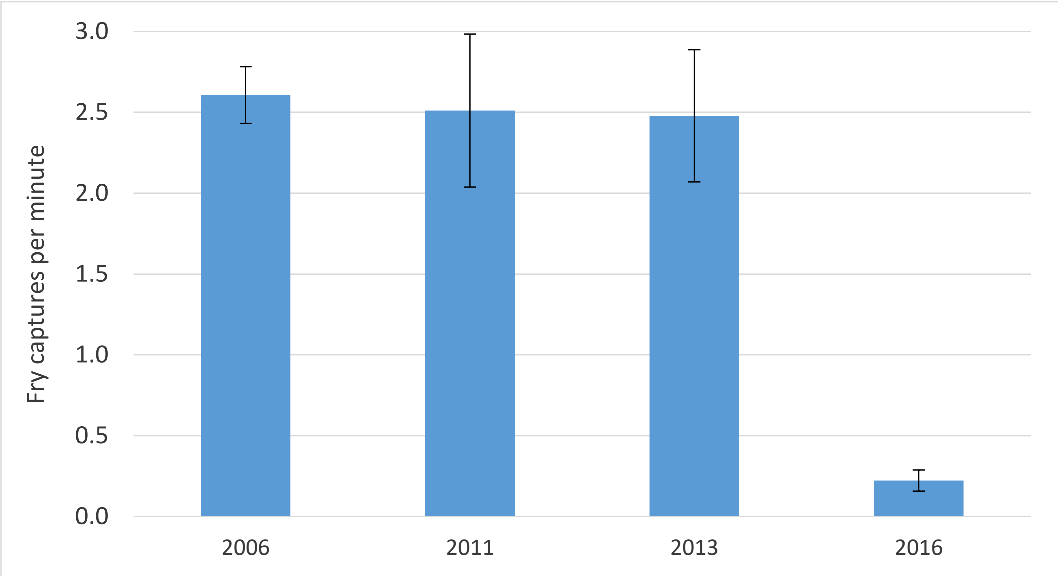


Figure 9. Number of fry caught per minute (with vertical bars representing variation between sites - standard error) at nine main stem monitoring sites.

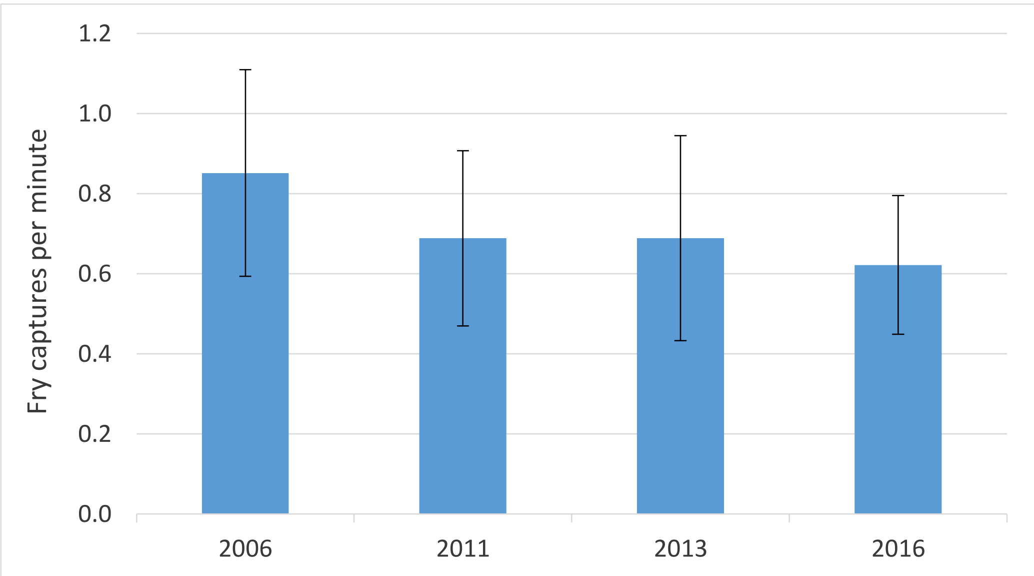


Figure 10. Number of parr caught per minute (with vertical bars representing variation between sites - standard error) at nine main stem monitoring sites.

Conclusion

Average fry densities in 2016 were only around 5% of the Dee Reference benchmark. This would indicate that fry production in the Dee is substantially lower than it could be, with potential consequences for future smolt production if the fry densities remain low over the next couple of years. Fry densities in 2016 were substantially lower than in 2012, which was a year of high production following a good spawning year in 2011, and also lower than in 2015.

This stock assessment has used a different benchmark to that used in 2015. This improvement has allowed a Dee specific reference to be used as the benchmark, as indications were that the national benchmark (used previously) 'set the bar' too low for maximum production in the Dee. The use of the new Dee benchmark (based on the national data, but with an upward adjustment for the Dee catchment) produced results comparable to those from the stock-recruitment data at the scale of the Girnock burn, leading Malcolm et al (2016) to suggest that at present, the status of Dee fry stocks is best assessed relative to the Dee Reference.

The reduction in fry densities since 2015 could be due to several reasons. Firstly, the flood caused by Storm Frank (30 December 2015) was the biggest flood since at least 1829, and had a huge impact on substrate at a time of year when salmon eggs were buried within the substrate. Therefore, this single event is likely to have had an impact on 2016 fry production. It is perhaps more surprising that the surveys suggest that parr densities in the tributaries and main stem were not significantly impacted by the flood, or otherwise that any flood-related reductions did not reduce parr numbers below 2015 levels. It may be that post-flood survival of parr was improved relative to 'normal' years, with parr perhaps even benefitting from a reduction in fry numbers.

Secondly, other rivers have reported low fry numbers in 2016, with unpublished reports from other large Scottish rivers suggesting low or patchy fry densities. Rivers in Wales, including the Clwyd, Usk and Tywi have also reported a severe decline in fry numbers in 2016, which is unprecedented since monitoring began 30 years ago (Natural Resources Wales 2016). These rivers did not suffer the magnitude of flooding that the Dee experienced following Storm Frank, suggesting that there is another factor influencing fry abundance at a wider scale. Natural Resources Wales is currently investigating whether warm winter temperatures (December 2015 was the hottest December on record) could have been a factor in poor fry survival.

A third factor is that rod catches indicate that 2015 had the poorest spawner abundance on the Dee on record. Therefore, reduced spawner abundance could well have contributed to low fry abundance, a relatively straight forward concept which has been demonstrated to occur on the Girnock burn, based on over 40 years of adult return and juvenile production data (Gurney et al 2010).

The likelihood is that a combination of factors such as those above have led to low fry abundance in 2016. Based on these possibilities, it is hoped that 2017 will see an improvement in fry densities, as spawner numbers appear improved from 2015 and low numbers of fry in 2016 may benefit the 2017 fry cohort by reducing competition for territory and food (Bacon et al 2015).

It is considered unlikely that the 2015 flood event will have a large impact on smolt production, due to compensatory increases in other juvenile age classes. For example, the River Derwent (England) experienced an extreme (1 in 1,000 year) flood event in November 2009, however, subsequent electrofishing surveys indicated that there was no significant impact on fry or parr numbers in the river, and anecdotal evidence suggested that the smolt run in 2010 was relatively strong (CEFAS, EA, NRW 2015). Modelling work on the River Carron stocks has shown that single flood events that remove up to 95% of eggs from the gravels had no noticeable effect on rod catches, due to the population's ability to compensate through improved juvenile survival and the variety of age groups comprising smolt/adult year classes (Curran et al 2015).

The juvenile stock assessment appears to reach a different conclusion to the adult stock assessment based on Conservation Limits (Marine Scotland Science 2016b). However, these two assessments are not fairly comparable, as (1) the adult stock assessment is based on stocks over the period 2011-2015 whilst the juvenile stocks are for the 2016 season only, and (2) the juvenile stock assessment uses a benchmark based on maximising fish production, whereas the adult assessment uses a benchmark based on maximising harvest from the stock. The juvenile assessment is therefore based on a higher benchmark than the adult assessment. Additionally, a benefit of the juvenile assessment approach used here is that it allows for variability in fish production within the catchment, as local habitat effects and local fry levels can be incorporated. In the case of the adult stock assessment, it is based on a national average egg deposition requirement and it is therefore possible that the target is lower than required for a salmon river like the Dee which is thought to be characterised by higher than average productivity. Hence, there is a possibility that the adult stock assessment using the national data also sets the bar too low.

Although there appears to be fairly strong evidence suggesting that fry production in the Dee is substantially below carrying capacity, the underlying limitations of the models, reference benchmarks, model input data and monitoring data should also be considered: This assessment uses capture probability and density models developed for salmon fry (Millar et al 2015). However, since then there has been further quality control of the underlying datasets and improvements to the capture probability model (Millar et al 2016). Work is now underway by MSS to improve the juvenile density model. MSS are also exploring electrofishing survey designs to ensure unbiased monitoring strategies. For example, if data coverage has been inadvertently located in good or poor areas this could result in biased assessments of overall catchment performance. Such bias is possible given that, with the exception of the catchment health monitoring sites, other survey sites were chosen to meet other objectives. This could also affect the Dee Reference benchmark, in that if all historic electrofishing sites in the Dee were chosen in good sites, this would bias the benchmark (i.e. set the bar too high). A specifically designed monitoring plan for assessing catchment health may be introduced in the future (2017 or 2018) if juvenile assessment is incorporated into assessments that underpin Conservation Regulations.

A further limitation of the current juvenile models is their dependence on electrofishing data that is obtained only on wadeable rivers. This means that quantitative assessments cannot be obtained for larger rivers (see grey shading Fig. 2) that include much of the main stem. The development of methods for assessing larger rivers is unlikely to become available soon. Given this constraint, juvenile assessments in the short term will probably need to be focussed on rivers where electrofishing is possible.

Next steps

Juvenile assessments offer a potentially valuable complimentary approach to adult based assessment methods for the Conservation Regulations. Therefore, MSS are working to develop this approach used on the Dee catchment for national assessments so that, in the longer term, assessments of catchment health use both adult and juvenile assessment methods. Therefore, the annual electrofishing programme on the Dee, which already provides information for local management decisions, may also be fed into the national Conservation Regulations. This may require the survey programme to be updated in due course.

This report focuses on the earlier work reported by Millar et al (2015) and is likely to be superseded in due course, with work already underway to refit the capture probability model and to develop a juvenile salmon density model that incorporates both fry and parr life stages in a single model. This should provide a more robust estimate of catchment health from juvenile data.

Acknowledgements

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