About sustaining wild salmon populations in Wester Ross: are smolt production and quality declining due to lack of food?

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February 2024

About sustaining wild salmon populations in Wester Ross: are smolt production and smolt quality declining because of a lack of food for juvenile salmon in some rivers?

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Summary and need for actions

This document summarises the main findings of juvenile salmon surveys in Wester Ross (Northwest Scotland) in 2023 and discusses potential actions available for important wild salmon populations.

It focusses on differences in the sizes of salmon fry and salmon parr and juvenile salmon biomass per unit area between rivers and survey sites; and considers what this means in terms of juvenile salmon growth, salmon smolt production and smolt 'quality', at a time when rates of marine survival of smolts are low.

Results varied. For sites surveyed in the River Canaird (below Langwell falls and in River Runie), Ullapool River and Dundonnell River, density estimates for both salmon fry and salmon parr were mostly high. At sites surveyed in the Runie and Dundonnell rivers, parr densities and sizes suggested production of **>20 smolts per 100m^2 of wetted habitat per year** for some areas. These rivers already have areas of good or improving habitat for production of juvenile salmon, partly as a result of recent riparian habitat revival projects.

In contrast, at some sites in the Gruinard River and Little Gruinard River [Special Area of Conservation for Wild Atlantic Salmon], juvenile salmon were particularly small for their age. Some fish appeared to be 'stunted' with a disproportionately large head, possibly having shrunk for lack of food (c. Huusko et al 2011). Projected smolt production at a main Gruinard River site **was less than 5 smolts per 100m^2 per year**. Malnourished parr and smolts will be easier targets for fish-eating birds and other predators.

However, at the loch outflow at the top of the Little Gruinard River, salmon fry and parr were much larger for their age, demonstrating a response to elevated feeding opportunities and the potential for faster growth of salmon parr and for increasing levels of smolt production and smolt quality elsewhere.

Rod catches of salmon in rivers in Wester Ross in 2023, reported to date, were low. Many wild salmon populations in Wester Ross may now be sustained by fewer than the recommended 150 breeding fish (adult salmon) to maintain genetic health (Consuegra and Nielsen, 2007).

Actions are needed to support and increase smolt output from parts of the Gruinard and Little Gruinard rivers where juvenile salmon appear to be increasingly malnourished because of a decline in marine derived nutrient [MDN] transfer from adult salmon to juvenile salmon; a lack of terrestrial sources of food for juvenile salmon; and rising water temperatures. Such actions are required to secure and strengthen the genetic base for core wild salmon populations in these rivers to make them as resilient as possible and better able to adapt to a changing environment as climate change progresses.

Until the 1980s, much larger numbers of salmon carcasses and surplus 'washed out' salmon eggs would have provided an additional, possibly vital, source of nutrition for juvenile salmon, particularly in winter months. Nutrient addition, at scales designed to mitigate for loss of marine derived nutrient [MDN] transfer via salmon carcasses, has been shown to support higher productivity and higher genetic diversity of juvenile salmon populations as a result of more salmon families having surviving representatives (McLennan et al, 2019; Bernthal et al, 2022).

To support declining wild salmon populations, methods of providing supplementary food for wild juvenile salmon should be explored, for similar reasons to why wild birds are provided with supplementary food where human activities have contributed to depletion of natural food sources.

Sustaining wild salmon populations in Wester Ross

1. Introduction

1.1 Background

This document presents a summary of the results of juvenile fish surveys of sites in rivers within the Wester Ross area in 2023, focussing on Atlantic salmon (*Salmo salar*).

In addition to estimates of numbers of salmon fry and salmon parr per unit effort and unit area, the sizes of juvenile salmon and estimates of salmon biomass per unit area, and salmon smolt production are considered for some survey sites.

This report follows on from other recent reports. In 2022, the status of wild juvenile salmon populations in Wester Ross was reviewed; comparing juvenile salmon abundance with information describing conservation status (based on rod catches) and genetic integrity. The WRFT Review April 2023 provided an update of juvenile salmon distribution and relative abundance following juvenile fish surveys in the summer of 2022 https://www.wrft.org.uk/files/WRFTReviewApril2023_final.pdf.

This report is based on the results of surveys of National Electrofishing Programme of Scotland [NEPS] sites and other sites surveyed in Wester Ross in 2023; with some sites surveyed in previous years for comparison.

1.2 Wild salmon population decline and loss of genetic diversity

In December 2023, the Atlantic salmon was added to the IUCN Red List as an endangered species in Great Britain https://www.iucnredlist.org/species/213546282/213546288#geographic-range because of a long term decline in the overall numbers of returning adult fish. For the Wester Ross area, reported rod catches suggest that, overall, 2023 was the poorest year on record for numbers of returning adult salmon.

Wild Atlantic salmon have one of the most complex life-cycles of any vertebrate animal, requiring an ability to cope with many challenges in freshwater and at sea. Most wild salmon 'home' back to their river of natal origin. Through natural selection, salmon populations become adapted to the environmental challenges of where and how they live, maximising survival. For a wild salmon population to remain healthy and able to cope with environmental changes, the number of breeders that has been recommended is 'not less than 150 per year' (Consuegara and Nielsen, 2007).

The three largest river systems in the Wester Ross area (rivers Ewe, Gruinard and Little Gruinard) may have retained runs of returning adult salmon well in excess of 150 fish per year (so 75 adult female salmon assuming close to 1:1 sex ratio), to 2023 at least. However, even in these river systems, salmon are likely to belong to several locally-adapted populations with life-cycle challenges that vary according to which part of the river system they belong. Salmon populations living above or below major freshwater lochs (e.g. Loch na Sealga, the Fionn Loch, Loch Maree), or above or below major waterfalls (e.g. on rivers Runie (Canaird) and Ullapool River) may differ in size at maturity, time of spawning, time of smolt migration to sea, and in other ways. For the River Ewe system, some of the life-cycle challenges of the salmon population adapted for life in the big river below Loch Maree, close to the top of the tide, are different from those of the salmon population in the Coulin River in the shallow headwaters above three freshwater lochs.

Other rivers which have supported salmon fisheries where the number of adult female salmon returning from the sea may now be close to or less than 75 include the rivers Canaird, Ullapool, Broom, Dundonnell, Kerry, Badachro and all Wester Ross rivers to the south of Gairloch. In some areas, salmon may stray between nearby rivers more often as part of a 'metapopulation', maintaining greater genetic diversity within the population. Also, male salmon can mature in freshwater as 'precocious parr', so there will usually be many more mature males than females in a population. However, some salmon metapopulations may also now be sustained by less than 75 breeding female salmon each year (e.g. rivers flowing into Loch Gairloch?).

As the gene pool of a wild salmon population shrinks, the overall fitness of the population (i.e. its ability to survive) declines. Since the 1990s salmon populations have been lost in the Wester Ross area from above the Bruachaig falls (River Ewe system) and in headwaters of the River Balgy above Loch an Loin. Where next?

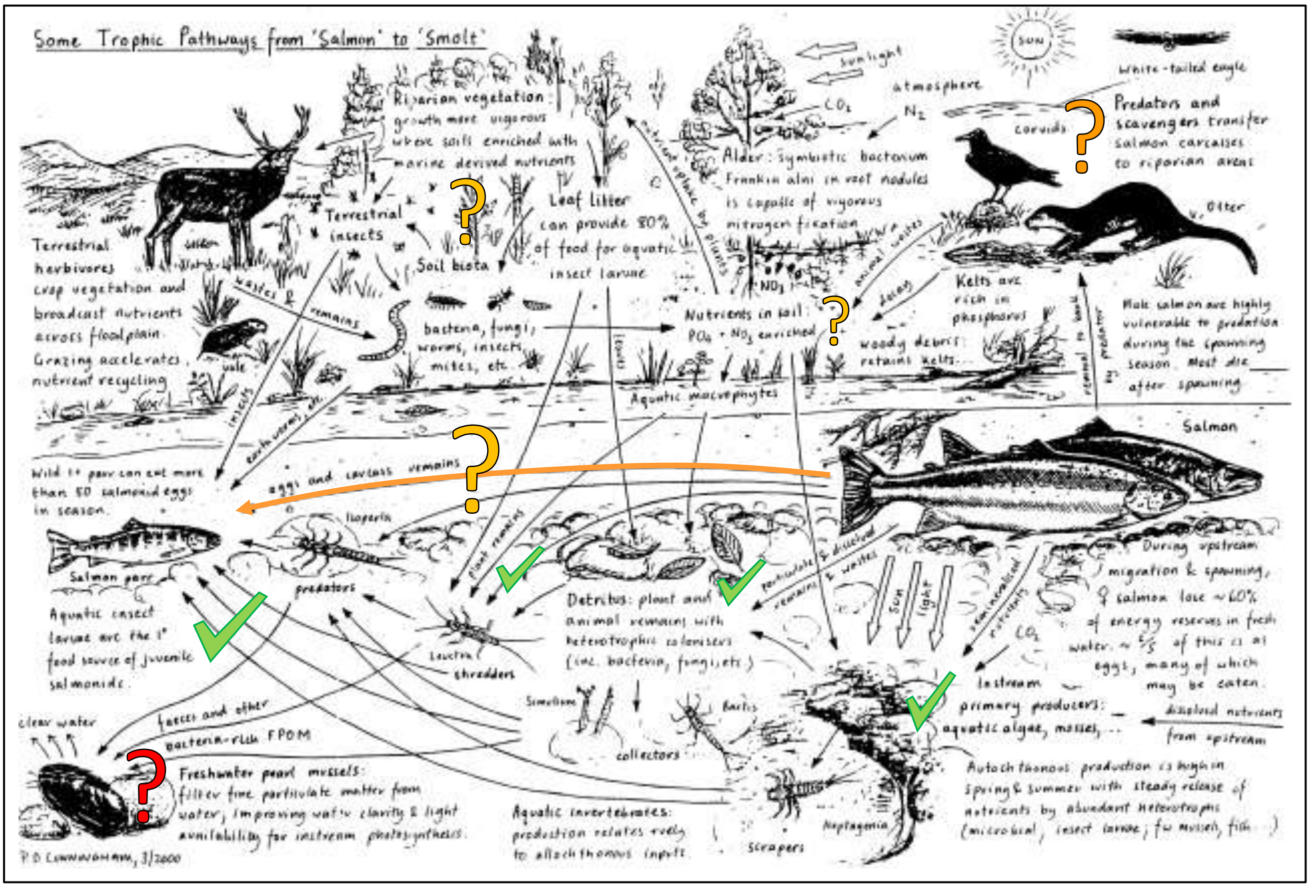
Salmon populations may disappear from other areas if their ability to adapt to future environmental challenges is eroded further. Is it time to provide additional support to wild salmon populations in Wester Ross?

1.3 How has the loss of wild salmon derived marine nutrient transfer affected ecosystems in Wester Ross?

For some river systems the reduction in numbers of adult fish returning from the sea may have a disproportionate impact upon subsequent recruitment of juvenile salmon, because of the importance of salmon carcasses and surplus salmon (and sea trout) eggs as a source of nutrition for juvenile salmon.

Figure 1 shows some of the trophic pathways through which nutrition from adult salmon returning from the sea can contribute to growth of salmon parr and production of smolts, and potentially also to the growth and reproduction of freshwater pearl mussels.

Figure 1. Some trophic pathways from adult salmon to salmon smolts. Since this figure was drawn in 2000, research has focussed on how juvenile salmon respond to placement of salmon carcasses or salmon carcass analogue pellets in stream habitats (green ticks). The importance of: (1) trophic pathways via riparian ecosystems; (2) salmon eggs as parr food in salmon river systems in Scotland; and (3) marine derived nutrients for freshwater pearl mussels require further research (question marks).



Since Figure 1 was drawn in 2000, studies by Williams et al (2010), Auer et al (2018) and Maclennan et al (2019) have investigated responses of juvenile salmon (stocked into nursery streams within the River Conon catchment) to additions of salmon carcasses and salmon carcass analogues. The main findings were discussed by Bernthal, et al (2022) who reported that in some situations, growth and biomass of juvenile salmon can be increased via additions of marine nutrient analogues, offering potential as a conservation tool.

Studies in Scotland over the past 20 years have focussed on learning more about ***indirect instream trophic pathways*** from adult salmon to smolt via a trophic web that includes periphyton (algae, bacteria and other primary producers and decomposers) and instream invertebrates (shown by green ticks in Figure 1).

However, other trophic pathways have received less attention. ***Terrestrial trophic pathways*** from adult salmon to smolt may sometimes be as important as instream pathways (Figure 1, question marks). A majority of dead or dying salmon in spawning streams can be transferred onto river banks by scavengers and predators rather than decomposing within the river (Cunningham, Brown & Harwood, 2002) enhancing the productivity of riparian habitats from which insects and leaves fall into to the river.

Salmon eggs and alevins can also be eaten directly by salmon fry and parr (Figure 1, question mark). Alan Youngson (*pers comm* 2014) found that salmon parr of >70mm in length taken from the Girnock Burn (Aberdeenshire River Dee) in the autumn prior to salmon spawning, in captivity would eat salmon eggs but nothing else. A large parr of 120mm length was able to consume 12-15 eggs. They stopped eating eggs because digestion of eggs was slow and they couldn't hold any more eggs.

Youngson attempted to quantify the contribution of marine nutrients from the eggs to the parr through analyses of fatty acids and isotopes. However, the parr were found to already have had a marine nutrient signature prior to capture and consumption of salmon eggs in captivity. This implied that the parr had already fed upon salmon eggs the previous year or upon salmon alevins in the spring; further evidence of the importance of marine derived nutrition.

It is not difficult to imagine how salmon eggs could provide vital nutrition to larger parr and especially pre-smolt salmon in the early winter in oligotrophic rivers, by providing lipids that would increase rates of overwinter survival and the condition of smolts prior to emigration the following spring. In turn, this would enhance rates of marine survival and subsequent return to freshwater as adult fish.

Where there is insufficient food for juvenile salmon, there can also be more competition between juvenile fish, reducing the genetic diversity of juvenile salmon populations in addition to reductions in the numbers of smolts produced and reductions in the size and condition ('quality') of smolts (McLennan et al, 2019; Bernthal et al, 2022).

In response to declining numbers of returning adult salmon, there is a need to secure and strengthen 'core' wild salmon populations. The largest and most important salmon rivers in Wester Ross area discharge into the Wester Ross Marine Protected Area [Wester Ross MPA]. One of these rivers, the Little Gruinard River system is a Special Area of Conservation [SAC] for the Atlantic salmon.

Evidence strongly points towards the importance of nutrition and smolt size in sustaining viable salmon populations. Hence the focus of this report on consideration of the size of salmon parr and biomass of juvenile salmon at electro-fishing sites. Nutrition and smolt-size matter (Armstrong et al, 2018)!

The remainder of this report is divided into the following sections:

(1) Summary results for the distribution and relative abundance of juvenile salmon in Wester Ross (Part 2).

(2) Site-specific results focusing on juvenile salmon size and estimates of juvenile salmon biomass per unit area (Part 2)

(3) Discussion; challenges for salmon smolt production in Wester Ross? (Part 3)

(4) Recommendations; responding to malnutrition of juvenile salmon (Part 4)

This report has been prepared for all interested in protecting and reviving wild Atlantic salmon populations in northwest Scotland, and especially those with responsibility for their conservation and management, including river proprietors, fisheries managers, Nature Scot staff (for Little Gruinard River SAC especially), SEPA staff (Water Frameworks Directive), WRASFB members (Salmon Fisheries) and anglers.

2. Juvenile fish survey

supported by the Scottish Government, WRASFB & hydropower businesses

2.1 Introduction

Electro-fishing using purpose designed equipment provides the means for monitoring the distribution and relative abundance of juvenile fish. The equipment and protocols used are designed so that all the fish that are captured during a survey can be returned unharmed to where they came from following a period of recovery. Using this method, since 2020, juvenile salmon have been recorded within 20 river or small stream systems within the Wester Ross Area Salmon Fishery Board area (rivers from the Canaird to Applecross).

In 2018, the collaborative National Electro-fishing Programme of Scotland **[NEPS]** was launched by the Scottish Government's Marine Scotland Science [MSS] (now the Marine Directorate) to provide data on the occurrence of juvenile salmon from which trends in the abundance of juvenile salmon can be assessed at the regional level. Some of the results of previous NEPS surveys can be found here https://scotland.shinyapps.io/sg-national-electrofishing-programme-scotland/ .

NEPS electro-fishing survey sites were randomly selected by the Marine Directorate and widely spread across Scotland. On their own, a survey of these sites is not adequate to provide an assessment of the status of wild salmon at individual river or salmon population levels. However, NEPS has been a useful step forward by the Scottish Government in support of wild salmon.

The main aim of the WRFT juvenile fish survey in 2023 was to visit as many of the salmon rivers within the Wester Ross area as possible to assess the distribution and abundance of juvenile salmon. Juvenile trout, eels and other fish species were also recorded; however, site selection was focussed on learning about salmon.

To complement the NEPS survey and to maintain our own information base for local conservation and fisheries management purposes, additional sites were surveyed in many rivers. This was possible only through the support of river proprietors, estate staff and the Wester Ross Area Salmon Fishery Board. Additional surveys were carried out to fulfil monitoring contracts for hydropower companies.

Surveys were carried out by the WRFT electro-fishing team of Peter Cunningham, Dr Shraveena Venkatesh (both SFCC qualified) Nic Butler and Dr Sue Ward in July, August and September 2023.

Water levels were low throughout most of this period, and progress was good. By the end of the field season (July to end September 2023) over 65 sites in 14 different river or coastal stream systems had been surveyed.

Further background information and summaries of the results of juvenile fish surveys in earlier years can be found in the Status of wild juvenile salmon populations in Wester Ross and other reports on the WRFT website.

2.2 Results

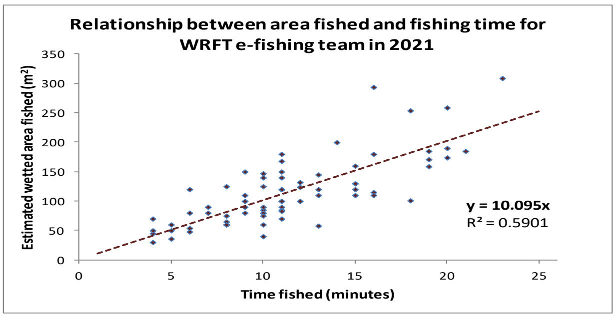
2.2.1 Summary

The main findings of the 2023 survey included the following (see also Figure 3):

- Juvenile wild salmon of wild origin remained widely distributed within most of the major salmon rivers of the Wester Ross area.
- High densities of juvenile salmon (fry and parr) were recorded at some sites within the rivers Canaird, Ullapool (Rhidorroch River), Dundonnell, Little Gruinard, Gruinard, Allt Beith some tributaries of the River Ewe above Loch Maree, including at one site above the Bruachaig falls) and Kerry.
- Salmon fry were recorded at low densities or were absent at sites surveyed in the Kernsary sub-catchment (Ewe); and in the rivers Tournaig, Sguod, Sand and Cuaig rivers (all smaller rivers).
- Fast growing salmon fry were recorded in the Kinlochewe River, 500m downstream from the Kinlochewe sewage works outflow.
- Salmon parr densities were very low at sites surveyed in the River Kerry (SAC for freshwater pearl mussels), possibly indicative of a weak fry year class in 2022 (few spawning salmon in 2021?).
- Very small salmon fry and parr were once again found at sites in the big Gruinard River, Little Gruinard River and Coulin River, as in previous years. This is further explored in part 2.2.2.

Results in terms of fish numbers at respective sites are expressed as numbers of fish per unit fishing time (Catch per Unit Effort [CPUE]) or numbers of fish per unit area or minimum density estimates (numbers of fish per 100m^2). Figure 2 shows the relationship between the area fished and the time fished for sites surveyed by the WRFT electrofishing team in 2021. Conveniently, the team (led by Peter Cunningham) fished at a fairly consistent rate of close to 10 m^2 per minute. Thus, for example, a catch rate of 1 fish per minute is usually close to a catch rate of 10 fish per 100m^2. Three-run (fully quantitative) electro-fishing surveys have indicated that actual fish densities are typically around 50% - 100% higher than the catch rate recorded in the one-run surveys.

Figure 2 Relationship between the area fished and the fishing time for electro-fishing sites surveyed by the WRFT electro-fishing team in 2021.



The distribution and relative abundance of salmon fry and salmon parr are shown in Figure 3a and Figure 3b. Note that these maps present relative abundance as numbers of fish caught per minute (so catch per unit effort, CPUE). The area of each survey site was also estimated to enable minimum estimates of fish density (numbers of fish per square metre).

However, smolt production, and the health and productivity of wild salmon populations is not just about fry and parr densities. Growth rates and thus size-at-age are important. The next section considers size-at-age of juvenile salmon and estimated smolt production for a sub-set of different sites in different rivers.

The methodology is based on the relationship between individual fish length and fish mass. Fish mass has been estimated using the formula: fish mass (g) = ((measured fish length in cm)^3/100) x 1.1. The values obtained are close to those where juvenile salmon have been length-measured (to nearest mm) and weighed (to 0.1g) previously in Wester Ross. Appendix 1 provides further background to this approach.

Figure 3a. Distribution and relative abundance of salmon fry at sites surveyed in 2023.

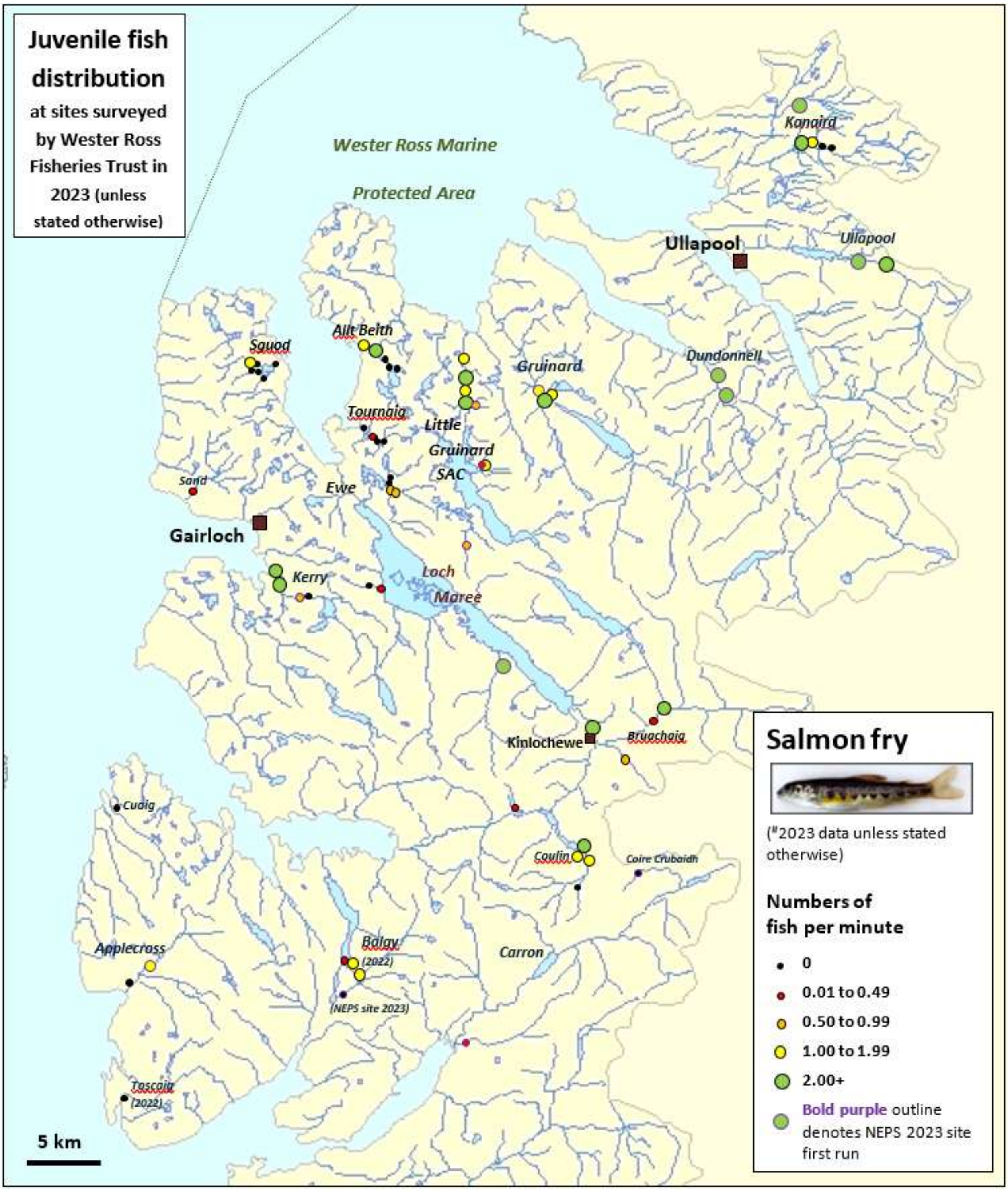
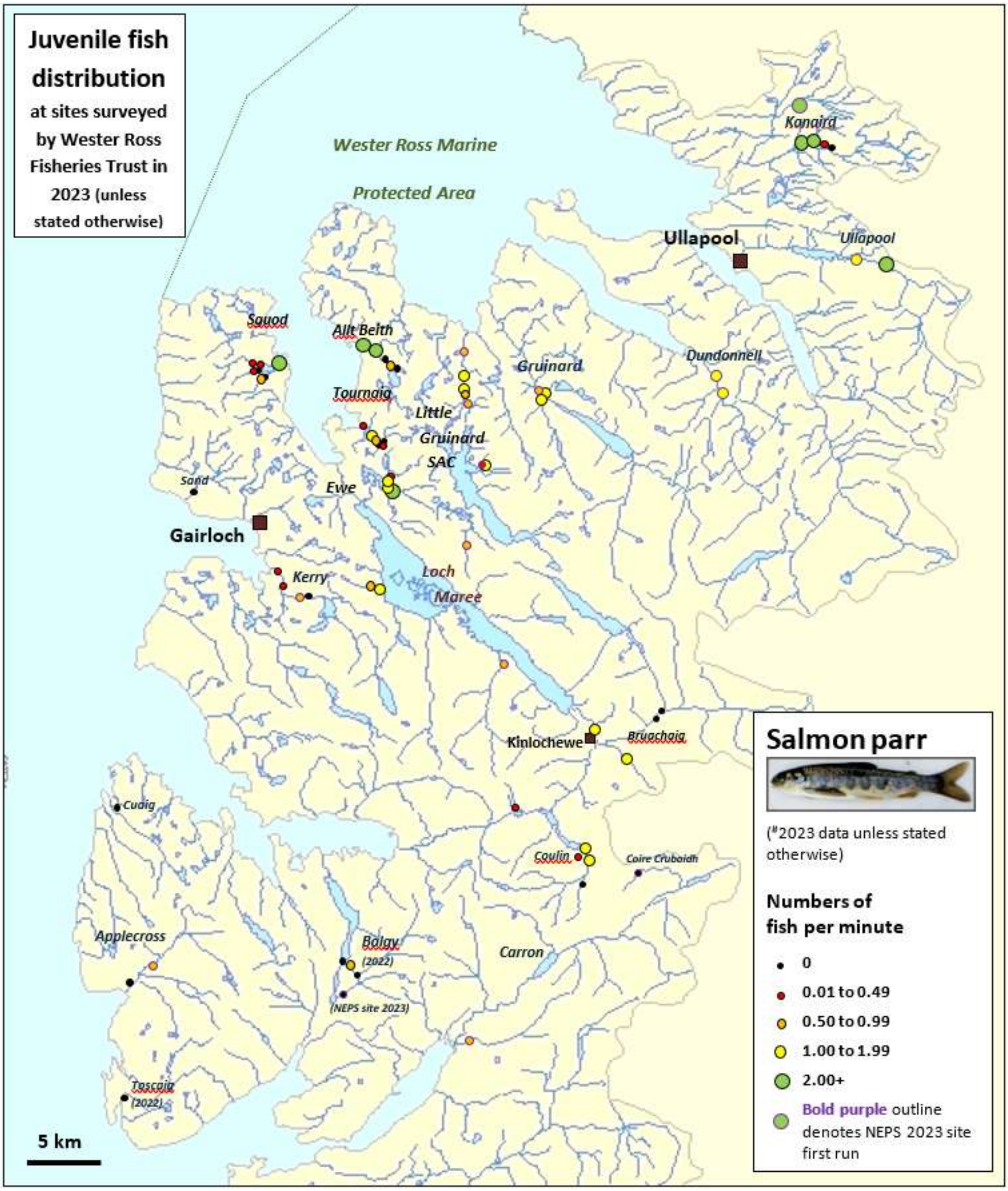


Figure 3b. Distribution and relative abundance of salmon parr at sites surveyed in 2023.



2.2.2 River Canaird (Kanaird) and River Runie

The River Canaird (Kanaird) and its fisheries are described in the WRFT River Kanaird Fisheries Management Plan (available on request). The river enters the sea in Loch Kanaird, about 6km north east of Ullapool, and 3km from the Wester Ross Fisheries (owned by MOWI) Ardmair salmon farm. There is some limestone within the catchment area, and several riparian woodland restoration schemes along sections of both the mainstem River Kanaird and the main tributary, the River Runie, which joins the River Canaird just downstream from the Blughasary falls, about 2km above the top of the tide.

Five sites were surveyed by the WRFT e-fish team on 24th August 2023, four in the River Canaird for the Langwell falls hydropower contract, and one in the River Runie for NEPS. Water levels at sites surveyed were low on the survey day and estimated fish densities (per unit wetted area) at some sites may therefore partly relate to some crowding of fish into available wetted habitat.

At the top site (Kan1) by Glen Cottage, very low densities of trout fry and trout parr (assumed to be 1+ fish, based on previous results), and eight eels were recorded. No possible juvenile salmon were seen. The trout fry and trout parr were large for their age (fry lengths: 78mm & 81mm; [c. 72mm – 85mm in 2021]; 1+ trout: 122mm-141mm [c. 110mm to 120mm in 2021]. Eight eels of lengths 180mm – 280mm were also recorded.

At site Kan 2, approximately 400m above the Langwell falls, no salmon fry were recorded. A large salmon parr of 132mm in length was caught in the section fished. 12 trout fry (62mm – 82mm) and 1 older trout (185mm) were recorded [; in 2021 no salmon fry were recorded here, however 15 salmon parr from 88mm to 114mm in length were recorded and shown from subsequent scale reading to be 1 year old parr]. The 132mm parr caught in 2023 is assumed to be a 3-year-old parr, belonging to the same year class as those recorded in 2021.

Riparian habitat improvement enclosure above the Langwell Falls (established in 2000s). For wild salmon, the River Kanaird is potentially very productive here. However, we have found no evidence that adult salmon have been able to ascend the Langwell falls and spawn in this section of river since 2019.

Below the falls, at sites Kan 3, many juvenile salmon were recorded belonging to at least 3 year-classes. Minimum density estimates were 8 salmon fry per 100m^2 and 37 salmon parr per 100m^2.

At site Kan 4, between the fields below Langwell Lodge and the SEPA river monitoring station, high minimum densities of salmon fry were recorded (26 fry per 100m^2), and salmon parr at moderate density (14 fry per 100m^2). Six eels (130mm-260mm) were also caught at this site within 117m^2 of wetted area habitat surveyed.

(below) Salmon parr and trout from site Kan2, above the Langwell falls. The salmon parr, assumed to be a 3+ fish was the only juvenile salmon found above the Langwell falls. Note how fat it is compared to juvenile salmon in picture below . . .!

(below) Three-year classes of juvenile salmon, fry (0+) and parr (1+ and 2+ year old fish) from site Kan 3 in the River Canaird about 100m downstream from the Langwell falls on 24th August 2023. The picture below is shown at the same scale as the picture above with the larger 'fatter' (higher condition factor) parr at site Kan 2, just a few hundred metres above the Langwell falls, within a riparian woodland scheme shown above. Contrast the size and shape of the fish in the picture below with the parr in the picture above (the scale is in cm) . . .

So, in summary, on 24th August 2023, no 0+, 1+ or 2+ year old juvenile salmon were recorded at either of the sites above the Langwell falls; just one large 3+ year old parr, trout and eels. However, in contrast, below the falls there were high numbers of salmon fry and salmon parr.

(right) WRFT electro-fishing team (Peter Cunningham and Nic Butler) at site Kan 3 below the Langwell falls, River Kanaird on 24th August 2023.

Photo by Sue Ward

Regulation of flows associated with the Langwell Falls hydropower scheme may have made it harder salmon to ascend the falls and inhabit an extensive area of good nursery habitat for juvenile salmon above the falls. The falls have been modified in the past; they are not a natural feature. To support the wild salmon population in the River Kanaird the Langwell Falls could and should be eased further (see page 9 of the Status of Salmon in Wester Ross Report 2022).

The NEPS site River Runie (NEPS23_03714) was fished as a three-run site between stop nets (see picture below) and provides a useful estimate of actual fish densities at this site. Habitat was good with a stable boulder streambed. The river drains a catchment with some limestone; water conductivity was 79µs.

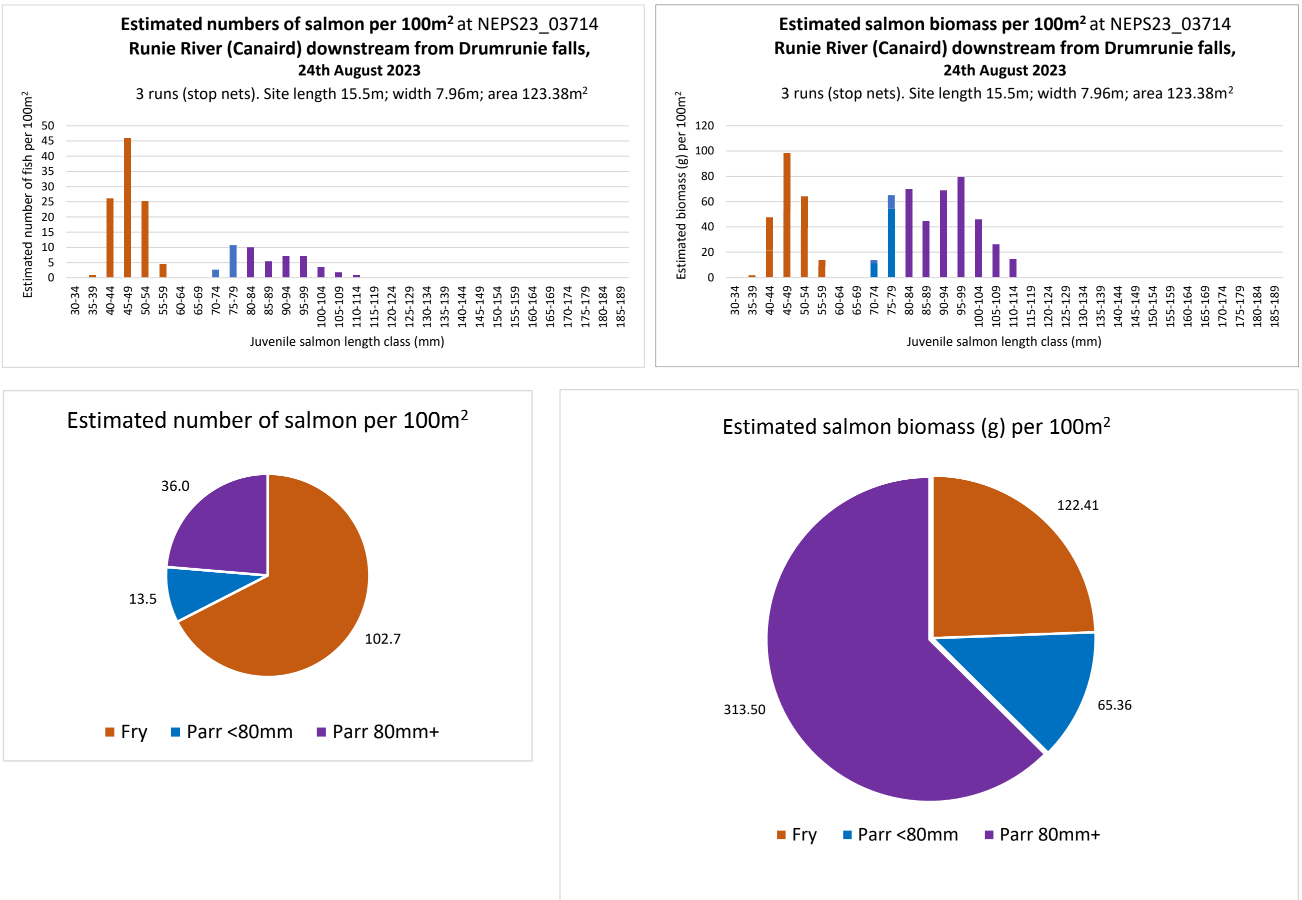
(right) Near perfect parr habitat?

WRFT electro-fishing team (Peter Cunningham and Nic Butler) at site NEPS23_03714 in the River Runie (Canaird system) on 24th August 2023. Photo by Sue Ward

High densities of both salmon fry and salmon parr were recorded at this site. These have been worked up into a series of graphs, shown on the next page (Figure 4).

The minimum density (after three runs) was 152 juvenile salmon per 100m^2, with over 100 fry per 100m^2 and almost 50 parr per 100m^2 (Figures 4a and 4b). In addition to salmon, two trout were caught (of lengths 170mm and 110mm). For juvenile salmon, these are high figures for any site in Wester Ross (apart from the rain and midges, we were happy!). When converted to biomass estimates (Figures 4c and 4d), the figures look even better: many of the parr were over 80mm in length by late August (36 large parr per 100^2) so likely to be big enough to become smolts the following spring. Well over half the biomass of juvenile salmon at this site was of larger (>80mm) parr (Figure 4d), so most of the food and energy would have been going into fish potentially destined to become salmon smolts the following year. Good site for juvenile salmon!

Figure 4. Results for e-fish site NEPS23_03714 in River Runie (Canaird) on 24th August 2023. (a, top left) Estimated numbers of fish for each size-class per 100m²; (b, bottom left) estimated numbers of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m²; (c, top right) estimated biomass (g) of fish for each size-class per 100m²; (d, bottom right) estimated biomass (g) of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m². Pie charts have been scaled for ease of comparison with figures for sites in other rivers reported below.



The combined minimum density of juvenile salmon at this site (NEPS23_03711, River Runie) on 24th August 2023 was **152.2 juvenile salmon / 100m², with an estimated total biomass of 501.27grams / 100m²**.

These figures are much higher than for some sites in other rivers in Wester Ross, including sites in the Gruinard and Little Gruinard River reported below.

In previous years the River Runie was subject to a stocking programme; but not in recent years. In 2023, the River Runie retained a healthy population of wild salmon demonstrating that adult salmon were able to ascend the Blughasary falls in sufficient numbers to maintain high densities of both fry and parr.

In summary: the River Canaird - Runie system still supports important wild salmon populations. I use the plural, as the falls by Blughasary may represent a biogeographic barrier separating salmon which spawn below the falls and upstream to Langwell, from those that ascend the falls and inhabit the River Runie. The Canaird has maintained a spring run of salmon; there is some evidence that these fish ascend the River Runie based on discovery of fresh salmon remains (otter predated) in by the falls in early June around 2005.

Thank you to Rob Cooper and Langwell estate for permissions and support, and to Kaenchullish estate for permission to survey respective sites. Sites on the Canaird by Langwell were surveyed as part of a contract for the Canaird River Company Limited (which is a subsidiary of DHG).

2.2.3 Ullapool River

The Ullapool River and its fisheries are described in the Ullapool River Fisheries Management Plan.

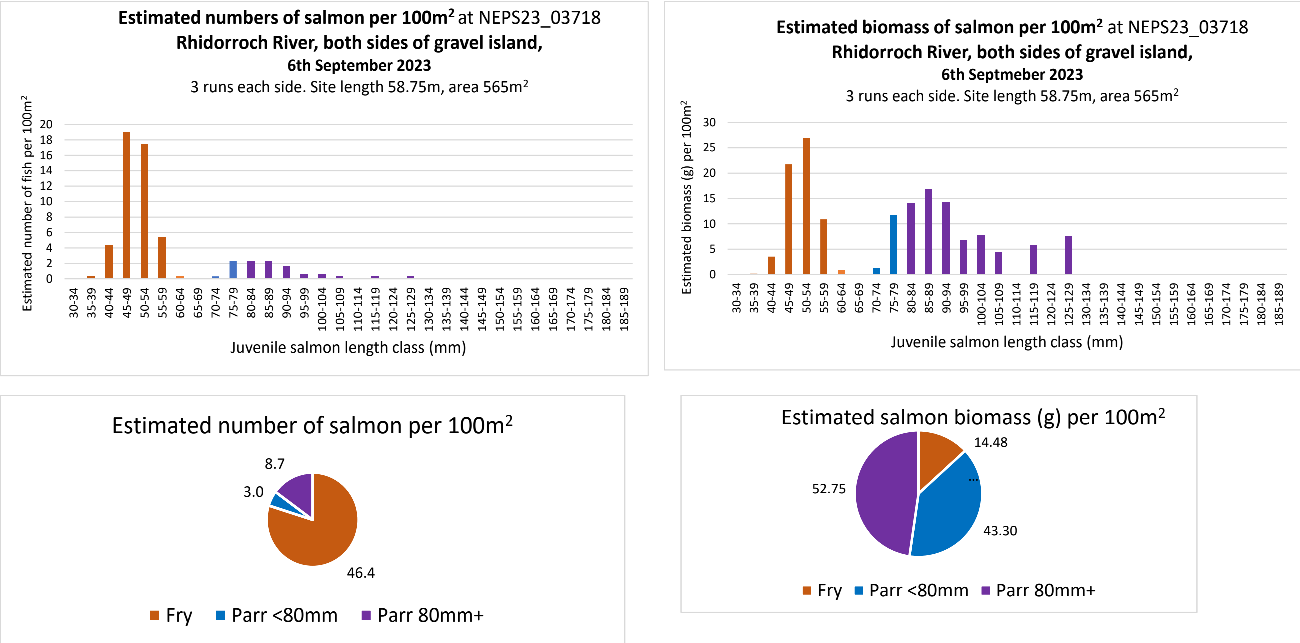
For wild salmon, the Ullapool River salmon populations may be split into three. Some salmon spawn below the Ness falls. Salmon which ascend these falls may spawn at the outflow of Loch Achall where there is an extensive area of stable spawning and nursery habitat for juvenile salmon. The main area of spawning habitat upstream from Loch Achall is in the Rhidorroch River. The Rhidorroch River has been unstable over at least the past 30 years because of much sediment movement associated with land use practices in the upper catchment and large erosive spate events. For further information about the river and its challenges, see https://www.wrft.org.uk/files/CatchmentVegetation&SalmonHabitat26Apr23.pdf (from slide 9).

Two sites were surveyed on 6th September 2023 in the Rhidorroch River. These included NEPS23_03718, fished as a three-run site. This was a particularly interesting site where the river was split around a 'dry island' (an island which would be submerged at high flows; see picture below). A stop net was put in at the bottom of the island, and a string across the top. Channels on both sides of the island were fished.

Results for the site (combined) are presented in Figure 5. Of interest was that the majority of juvenile salmon including most of the larger parr, and the highest densities, were found on the right side (facing downstream) of the gravel island, despite the observation that most of the water flowed down the shorter route over mobile gravel on the left side of island. Thus, the site provided a useful demonstration of the importance of habitat (substrate and river bank vegetation) for supporting juvenile salmon; smaller river channels with less water flowing through them can sometimes support higher densities and higher production of juvenile salmon than bigger channels!

NEPS23_03718, Rhidorroch River on 6th September 2023. The site included both sides of the gravel island from the stop net, up to a string across the top of island (indicated with dashed line). Many more fish were found in the right (facing downstream) side of the island than on the channel on the left side.

Figure 5. Results for e-fish site NEPS23_03718 Rhidorroch River on 6th September 2023. (a, top left) Estimated numbers of fish for each size class per 100m²; (b, bottom left) estimated numbers of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m²; (c, top right) estimated biomass (g) of fish for each size class per 100m²; (d, bottom right) estimated biomass (g) of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m².

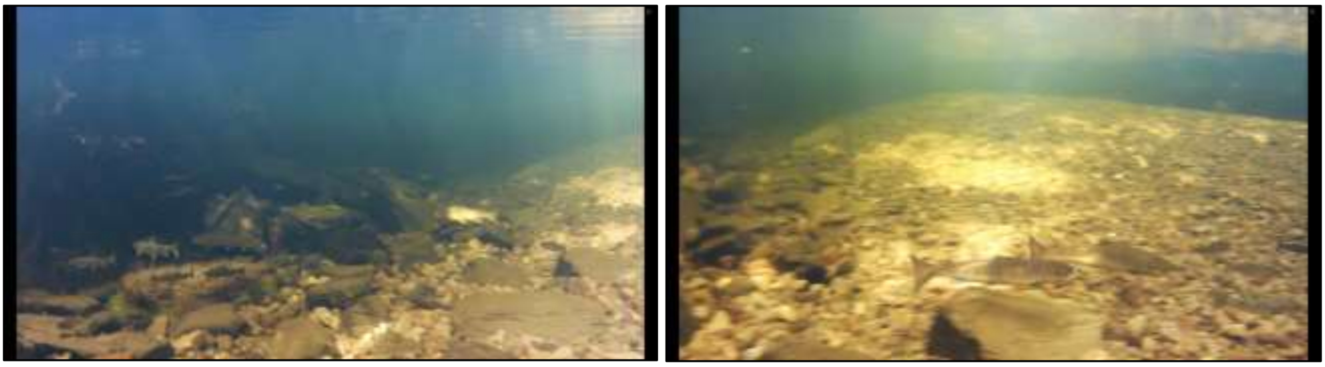


The combined minimum density of juvenile salmon at this site NEPS23_03718 in the Rhidorroch River on 6th September 2023 was **58 juvenile salmon / 100m², with an estimated total biomass of 155 grams of juvenile salmon / 100m²**. In addition to juvenile salmon, juvenile trout and eels were recorded at approximately 6 trout and 1.5 eels per 100m².

The overall biomass and growth rates of juvenile salmon were lower at this site than at NEPS23_03714 in River Runie (Canaird) [see part 2.2.2]. Just less than 50% of the estimated biomass was of larger parr that may have been big enough to smoltify and go to sea in 2024; so perhaps 8 smolts per 100m² per year. The streambed was of smaller stones (pebbles) and less stable than the site in the River Runie; larger parr may have been in the deeper water elsewhere in the river nearby.

When snorkelling in the pool above the electrofishing site following the survey, two adult salmon were seen with larger trout (estimated lengths of up to 30cm); these are shown in GoPro video stills below.

(below) Larger trout and adult salmon in the Rhidorroch River in pool just above site NEPS23_03718, 6th September 2023. GoPro video stills, recorded by snorkelling.

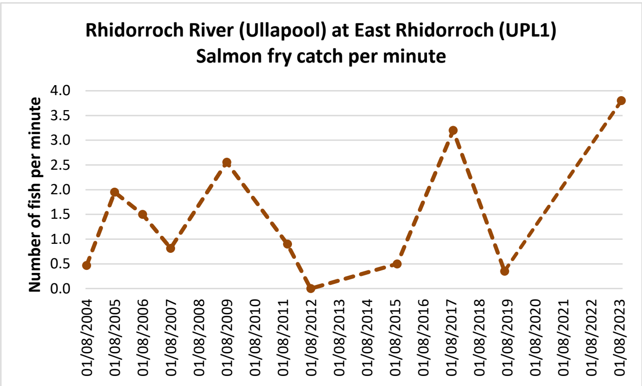


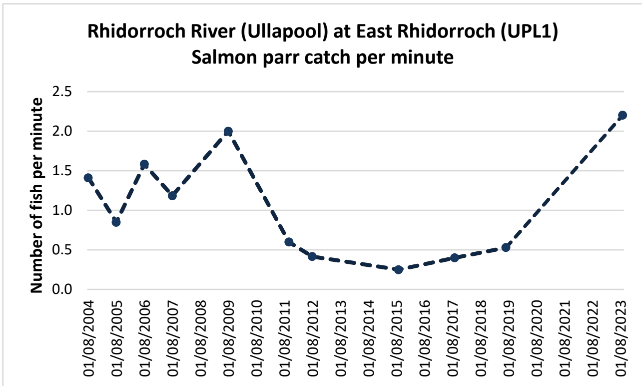
A second site, UPL1, was fished just below the swing bridge at East Rhidorroch *(right; note regenerating alder)*. This site has changed over many years as a result of erosion, bank collapse and mobilisation of sediment on the stream bed during big spate flows. Some years hardly any juvenile salmon were found here (Figure 6).

On 6th September, 2023, two channels were fished on either side of a dry island. The overall results were good with high CPUE for salmon fry in both channels, and high CPUE for salmon parr when averaged out.

Figure 6 shows catch per minute graphs for salmon fry and salmon parr recorded at this site since 2004.

Figure 6. Graphs of catch per unit effort [CPUE] for salmon fry (left) and salmon parr (right) at electro-fishing site UPL1 by East Rhidorroch, from 2004 to 2023. Note that on 6th September 2023, the CPUE for both salmon fry and salmon parr were the highest on record. Although this can be partly explained by the low water at the time of survey, the combined results for fry and parr are exactly what one would hope to see in response to the on-going sediment management and riparian habitat enhancement project.





The upper part of the Rhidorroch River, from just downstream from the swing bridge at East Rhidorroch upstream, has been enclosed to keep the deer out so far as possible. Alder trees could be seen regenerating along the river bank (*above photo*); these trees will help to stabilise the river bank, provide additional nutrition to the river ecosystem and may help to provide some shade keeping the river a bit cooler in future year. Electro-fishing results in 2023 were very encouraging, habitat and fish numbers are improving!

Next time we can compare the biomass by doing three runs at East Rhidorroch.

Tree planting was supported by the Rhidorroch River sediment management project, supported by the Wild Salmonid Fund. Thank you to Julien and Iona Legrand (Scobie) and family (East Rhidorroch estate); well done everyone!

2.2.4 Dundonnell River

The Dundonnell River is accessible to salmon for only 5km upstream from the top of the tide to a waterfall in the gorge upstream of Coire Hallie. However, the river flows through a relatively fertile valley with tree-lined riparian corridor; so overall, good habitat for the production of juvenile salmon.

On 8th September 2023 two NEPS sites were surveyed, including a three-run site NEPS23_03710 by the new shed (*shown below*).

(below) Nic Butler and Dr Shraveena Venkatesh returning juvenile salmon to site NEPS23_03710 in the Dundonnell River on 8th September 2023.

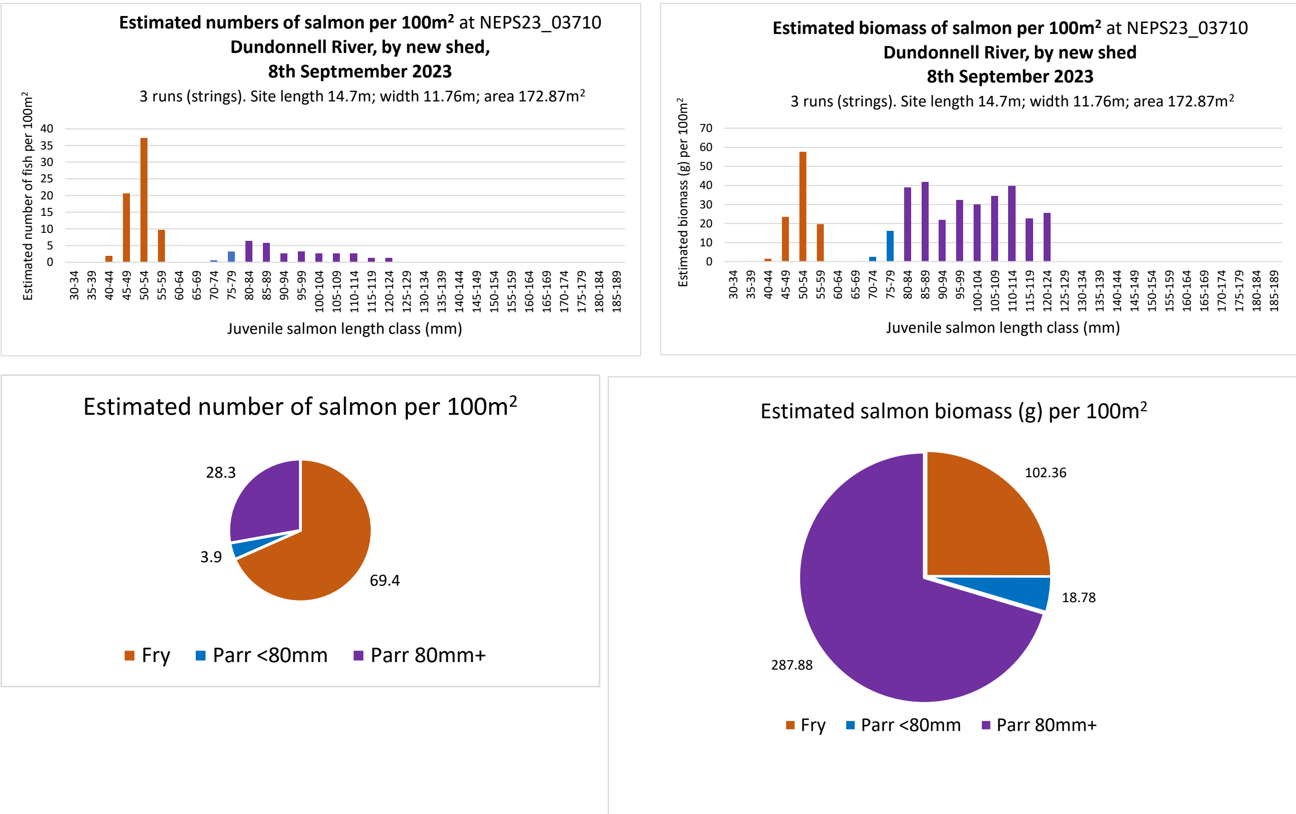
Results for juvenile salmon were good with high densities of both salmon fry and salmon parr recorded.

The estimated salmon fry density of almost 70 fish per 100m^2 is high for a site in Wester Ross (Figure 7). The estimated parr density of over 30 fish per 100m^2 is also especially good because most of the parr were larger than 80mm in length, so big enough to smoltify in 2024. Most of the juvenile salmon biomass was of larger parr, so potentially most of the salmon food going into fish which would emigrate to sea the following spring.

Many eels were seen. Most of the eels could not be caught because they did not more away from beneath the stones on the streambed to where they could be netted. Eels are likely to feed on unhealthy salmon fry and parr and other small fishes and invertebrates.

It's tempting to think that there could have been even higher densities of juvenile salmon without so many eels. However, eels are critically endangered (IUCN Red List) having declined across their range in recent decades. For salmon, what matters most is that salmon smolts are in good condition when they go to sea. Salmon need to be good at avoiding predators if they are to survive at sea; eels could possibly be regarded as part of the ecosystems 'quality control' system!

Figure 7. Results for e-fish site NEPS23_03710 in Dundonnell River on 8th September 2023. (a, top left) Estimated numbers of fish for each size class per 100m^2; (b, bottom left) estimated numbers of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2; (c, top right) estimated biomass (g) of fish for each size class per 100m^2; (d, bottom right) estimated biomass (g) of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2. Pie charts have been scaled for ease of comparison with figures for sites in other rivers reported.



The combined minimum density of juvenile salmon at this site NEPS23_03710 in the Dundonnell River on 8th September 2023 was **101 juvenile salmon / 100m^2, with a total estimated biomass of 409 grams of juvenile salmon / 100m^2**. In addition to juvenile salmon, juvenile trout and many eels were recorded at estimated densities of 3 small trout and 8 eels per 100m^2 (lengths 92mm – 380mm). Many other eels were seen but not caught; the biomass of eels may have been as high or higher than that of juvenile salmon at this site.

Projected smolt production of 20-25 smolts per 100m^2 in 2024 from this site. That's relatively good!

At a second more bouldery one-run site further upstream near Coire Hallie, salmon fry were found at high CPUE and large parr at moderate CPUE.

Thank you to Alasdair Macdonald and Dundonnell estate for permissions and help with the survey. The Dundonnell River is doing much to support conservation of both the endangered wild Atlantic salmon and the critically endangered European eel.

2.2.5 Gruinard River

The Gruinard River is one of the largest and most important for Atlantic salmon within the Wester Ross area. It has much in common with the neighbouring Little Gruinard (see next section), with a large loch at the top of the river, Loch na Sealga, from which the main river flows for about 8km to the sea. Above Loch na Sealga there is a large area of riverine habitat accessible to salmon in the Abhainn Loch an Nid and the Abhainn Gleann na Muice. Within living memory, large numbers of salmon and sea trout ran the river, with hundreds of fish seen at spawning time at the top of the river, just below the loch (Eric Ross, 2021, pers comm).

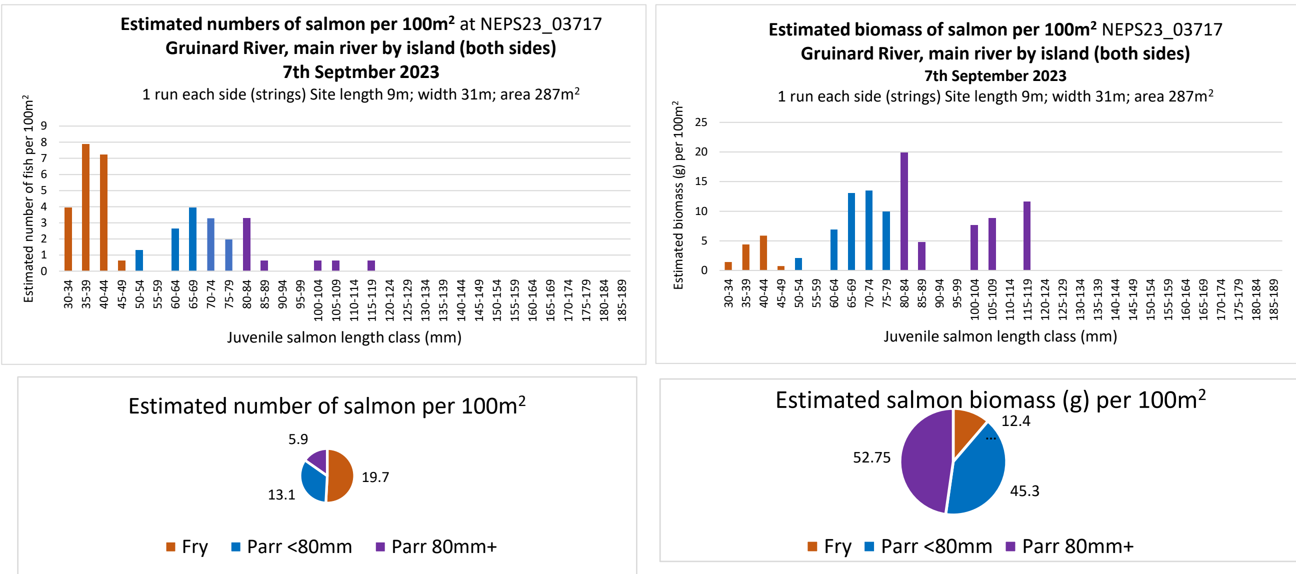
On 7th September 2023, four sites were fished, two in the main river, including site NEPS23_03717, and two (close together) in the Allt loch Ghuibhsachain just upstream from the pipe bridge. The day was very warm (water temperature 18C) and it's possible that the numbers of fish recorded especially at main river sites were slightly less than would have been recorded when the river is cooler, as juvenile salmon can escape from the electric field around the anode more easily at high water temperature, and water depths were just a bit on the high side in the middle of the NEPS site.

Salmon fry were recorded at high CPUE only at the lower 'run-riffle' site in the Ghuibhsachain burn, salmon parr at only low to moderate CPUE. The main concern was of the small size of salmon fry and parr (Figure 8).

Site NEPS23_03717, 7th September 2023 looking from track towards site, and from the 'far side'. Sections, demarcated by strings across the river, were surveyed on both sides of the island (roughly where indicated).

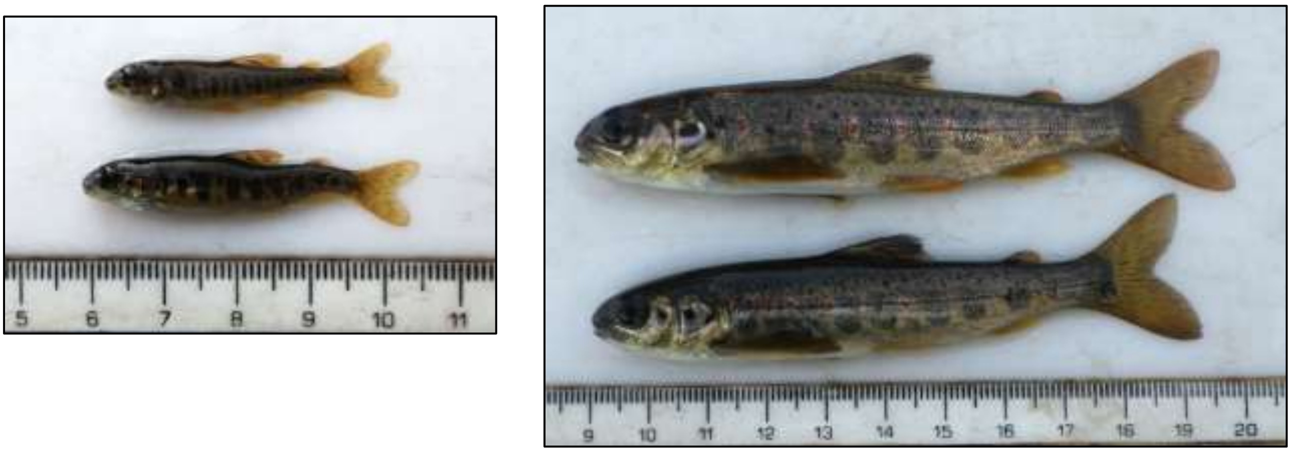
Figure 8. Results for e-fish site NEPS23_03717 in Gruinard River on 7th September 2023. This site was fished as a one-run site; density estimates are based on an estimated capture rates of 53% of fish present in the 1st run. The water depth was up to 30cm and water temperature up to over 18C by end of survey (that's high for e-fishing), so figures may slightly underestimate the numbers of fish present. Physical habitat (substrate and flow) was good for both salmon fry and parr.

(a, top left) Estimated numbers of fish for each size class per 100m^2; (b, bottom left) estimated numbers of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2; (c, top right) estimated biomass (g) of fish for each size class per 100m^2; (d, bottom right) estimated biomass (g) of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2. Pie charts have been scaled according to relative fish density and biomass density for ease of comparison with other sites.



The combined estimated minimum density of juvenile salmon at this site NEPS23_03717 in the Gruinard River on 7th September 2023 was **39 juvenile salmon / 100m^2, with a total estimated biomass of 110 grams of juvenile salmon / 100m^2**. In addition to juvenile salmon, two juvenile trout and two eels were recorded. Note that most salmon fry were unusually small at this Gruinard River site compared to salmon fry in the Runie, Rhidorroch and Dundonnell rivers at around the same time of year in 2023; and most of the parr were still less than 80mm in length, so not big enough to become smolts the following year. Projected smolt production of just five small smolts per 100m^2 in 2024 from this Gruinard River site. Inadequate nutrition!

(below) Salmon fry and parr from Gruinard River site NEPS23_03717 on 7th September 2023



(right) Malnourished juvenile salmon?

Four more juvenile salmon from the Gruinard River, from site NEPS23_0317 on 7th September 2023.

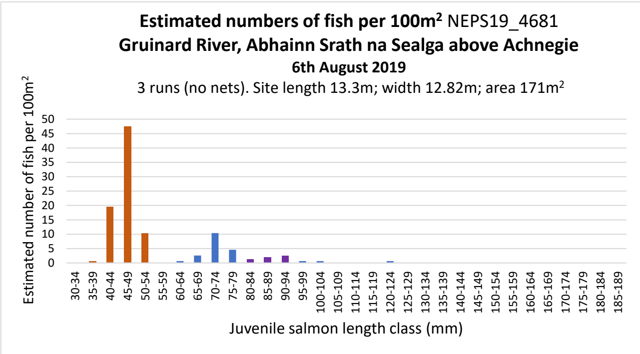
The two fish at the top are parr, note the large head and relatively small body of these fish. Both these parr are very small and thin for their age; juvenile salmon may shrink if there is not enough food to maintain themselves.

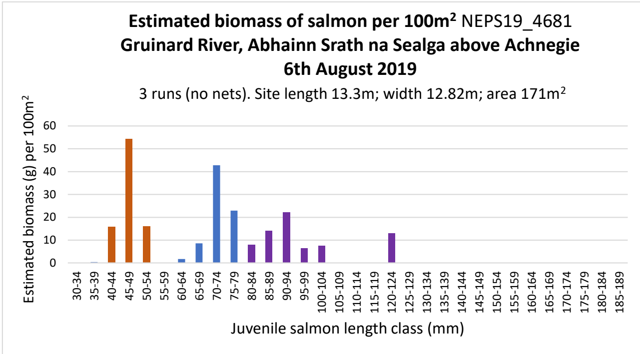
The top fish has a clipped caudal fin; the NEPS survey included collection of samples from salmon parr for genetic analyses to learn more about many things.

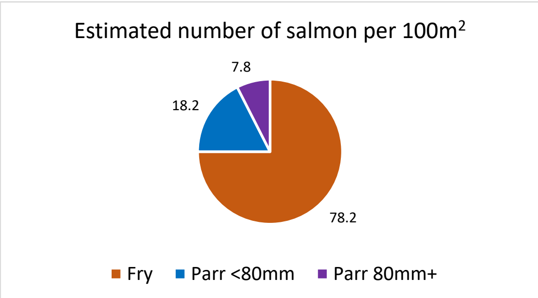
We were unable to survey sites above Loch na Sealga in summer 2023. However, for the purposes of learning more about juvenile salmon carrying capacity and smolt production in different parts of the Gruinard River catchment area, the results of site NEPS19_4681 fished as a three-run site on in the Abhainn Srath na Sealga on 6th August 2019 have been reworked *(shown below)*. The in-stream habitat at this site was good for salmon with a streambed of cobbles and boulders. Results are shown in Figure 9.

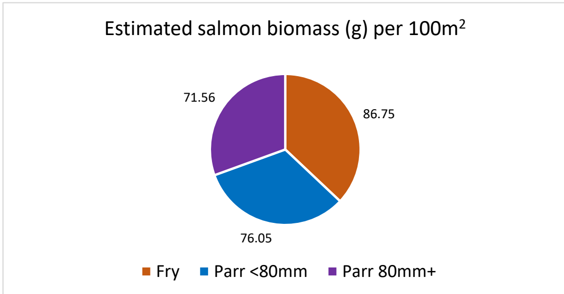
(below) site NEPS19_4681 fished as a three-run site on in the Abhainn Srath na Sealga on 6th August 2019

Figure 9. Results for e-fish site NEPS19_4681 in Abhainn Srath na Sealga on 6th August 2019. (a, top left) Estimated numbers of fish for each size class per 100m^2; (b, bottom left) estimated numbers of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2; (c, top right) estimated biomass (g) of fish for each size class per 100m^2; (d, bottom right) estimated biomass (g) of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2. Pie charts have been scaled for ease of comparison with figures for sites in other rivers in this report.









The combined estimated minimum density of juvenile salmon at this site NEPS19_4681 in the Abhainn Srath na Sealga on 6th August 2019 **was 104 juvenile salmon / 100m^2, with a total estimated biomass of 234 grams of juvenile salmon / 100m^2**. The biomass was evenly divided between fry, small parr and larger parr, big enough to go to sea the following year. The number of pre-smolt-sized salmon was around 7 per 100m^2.

Estimates for smolt production from the Gruinard River per unit wetted area of river habitat per year are mostly much less than for rivers where there is more food for juvenile salmon. Even if projected smolt production per unit areas were doubled from sites reported here, they would still be less than for sites in the Dundonnell River and River Runie.

For the Gruinard River, some larger smolts may be produced in loch habitat. However, in July 2008, a gill netting team led by Prof Eric Verspoor and Ron Greer, using 8 benthic nets and a pelagic net recorded trout, arctic charr and minnow, but no juvenile salmon (report to WRFT, 2008). Eels also inhabit the system.

(below) eels from electro-fishing site in the Allt Loch Ghuibhsachain just above the pipe bridge on 7th September 2023. The lower eel has turned silver in preparation for emigration to the sea.

2.2.6 Little Gruinard River

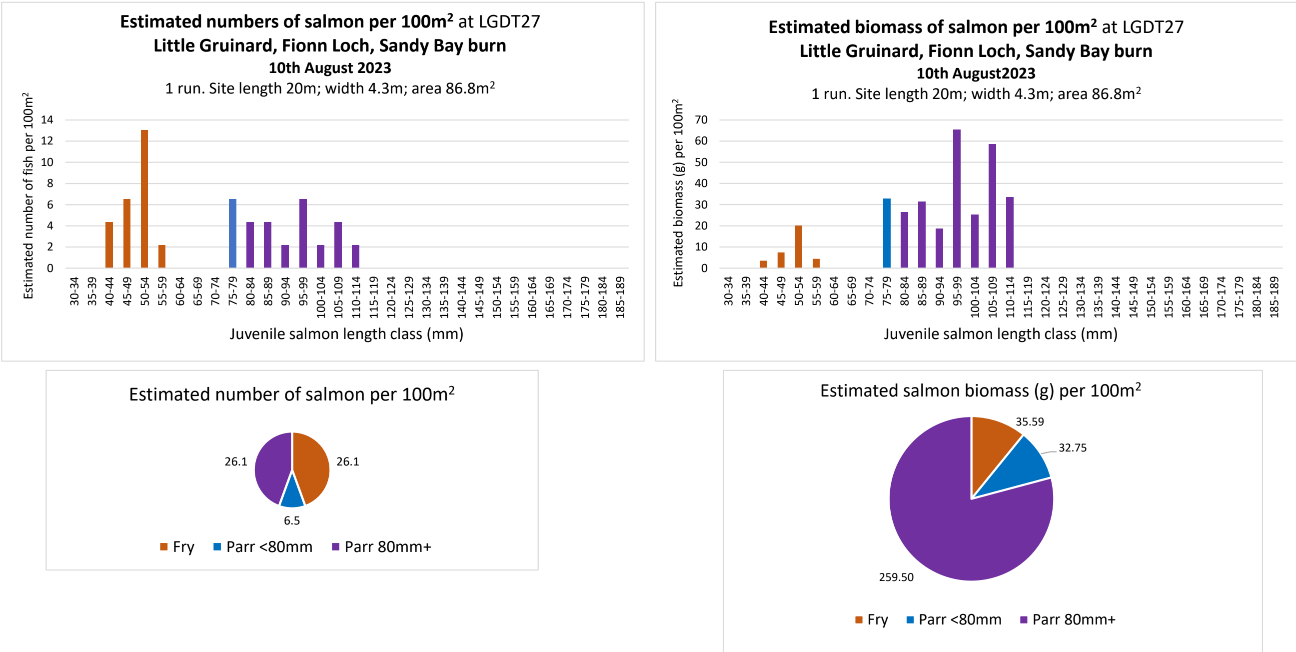
Like the big Gruinard River, the Little Gruinard River drains a catchment area with very little human habitation. The main river flows for 6km from a series of lochs including the Fionn Loch to the sea. To reach the Fionn Loch, adult salmon have to ascend a series of falls and rapids. Some fish continue to headwater streams around the Dubh Loch to spawn or enter the Beannach lochs system on the south west side of the Fionn Loch. Most of the catchment area is denuded and nutrient poor.

The Little Gruinard River was the first in Scotland to go 100% catch and release, a far-sighted policy introduced by proprietor Paul van Vlissengen in 1990. To test whether salmon that were caught and released would survive to spawn, Dr Andy Walker carried out a radio-tracking study in 1990. Of 13 rod caught salmon that retained their radio tags following capture in the Little Gruinard River, 8 fish entered the Fionn Loch, presumably en route to spawning areas above the loch. In March 2005, the Little Gruinard River system was designated as a Special Area for Conservation [SAC] for the Atlantic salmon on account of its high-quality salmon population. Further back ground information can be found in the WRFT Little Gruinard Fisheries Management Plan.

In 2023, eight electrofishing sites were surveyed around the Little Gruinard River catchment, three above the Fionn Loch (including two NEPS sites), four in the main river, and one (another NEPS site) in tributary burn which flows into the main river. Salmon fry and parr were found at all sites. The two NEPS sites above the Fionn Loch were in suboptimal habitat for juvenile salmon, so density estimates for these sites underestimate the numbers of juvenile salmon that may have been present in better quality habitat areas nearby. Site LGDT27 *(shown below)* is located close to one of the NEPS sites in the larger of two burns (Allt Feith a' Chaisgean) which flows into Sandy Bay on the east side of the Fionn Loch. Habitat is good for salmon parr. Figure 10 presents the results of survey of LGDT27 on 10th August 2023.

(below) Site LDGT27, Allt Feith a Chaisgean, 10th August 2023.

Figure 10. Results for e-fish site LDGT27, Allt Feith a' Chaisgean, above the Fionn Loch, 10th August 2023. (a, top left) Estimated numbers of fish for each size class per 100m^2; (b, bottom left) estimated numbers of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2; (c, top right) estimated biomass (g) of fish for each size class per 100m^2; (d, bottom right) estimated biomass (g) of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2. Pie charts have been scaled for ease of comparison with figures for sites in other rivers in this report.



The combined estimated minimum density of juvenile salmon at this site LDGT27 in the Allt Feith a' Chaisgean, above the Fionn Loch, on 10th August 2023 **was 59 juvenile salmon / 100m^2, with a total estimated biomass of 328 grams of juvenile salmon / 100m^2**. The biomass was mostly of larger parr (>80mm in length), so likely to migrate to sea in 2024. Estimated smolt production from this site was 20 to 25 smolts per 100m^2. That's good for a relatively high-altitude site!

For help with surveys in the Gruinard River and Little Gruinard, thank you to Eilean Darach Estate, Gruinard Estate, Letterewe Estate, and keepers, Gary Ross, Stuart Allison, Iain Allison and Andrew Oliver.

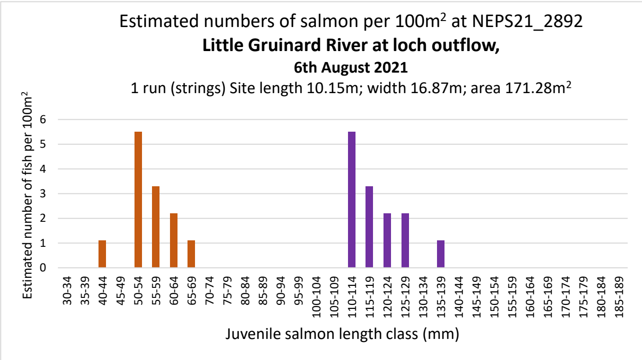
(below) Salmon parr from site LDGT27, Allt Feith a' Chaisgean, above the Fionn Loch, on 10th August 2023

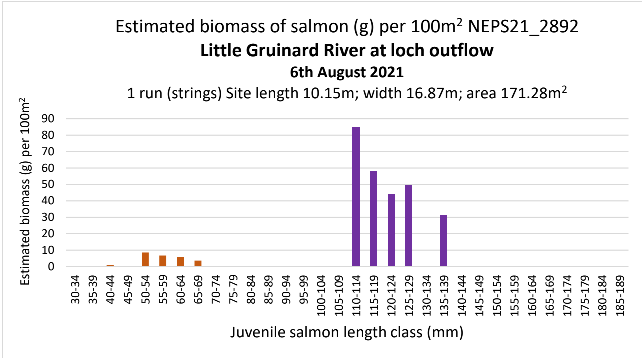
Some of the largest salmon parr in the Little Gruinard system recorded to date were at the top of the Little Gruinard River, at the outflow of Pait Fhearchair, at NEPS site NEPS21_2892 surveyed on 6th August 2021 (*shown below*). This site was rather deep and bouldery, so difficult to fish (just one crossing). The numbers of fish that were caught in just one run may have under represented the density of juvenile salmon present at this site.

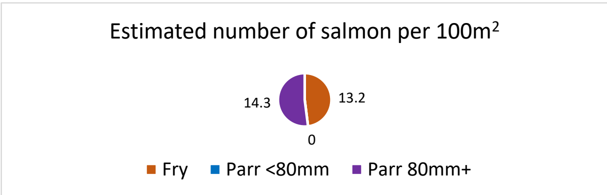
However, it is included here because it demonstrates how much faster juvenile salmon can grow at the top of the Little Gruinard River than further downstream. Figure 11 presents the results for this site.

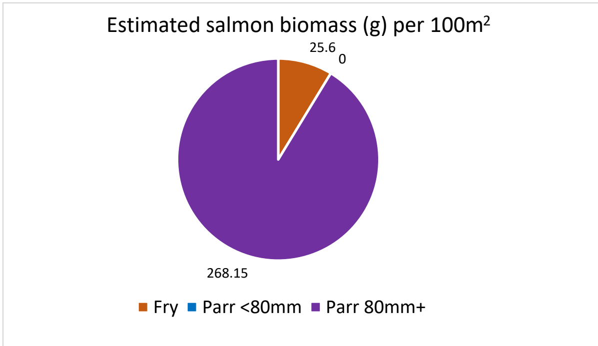
(below) NEPS site NEPS21_2892 at the top of the Little Gruinard River, at the outflow of Pait Fhearchair, on 6th August 2021. The site was fished as a one-run site using strings as markers (just about visible). Two of the large, relatively fat, parr recorded here are shown in picture below.

Figure 11. Results for e-fish site NEPS21_2892 at the top of the Little Gruinard River, at the outflow of Pait Fhearchair, on 6th August 2021. (a, top left) Estimated numbers of fish for each size class per 100m^2; (b, bottom left) estimated numbers of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2; (c, top right) estimated biomass (g) of fish for each size class per 100m^2; (d, bottom right) estimated biomass (g) of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2. Pie charts have been scaled for ease of comparison with figures for sites in other rivers in this report.









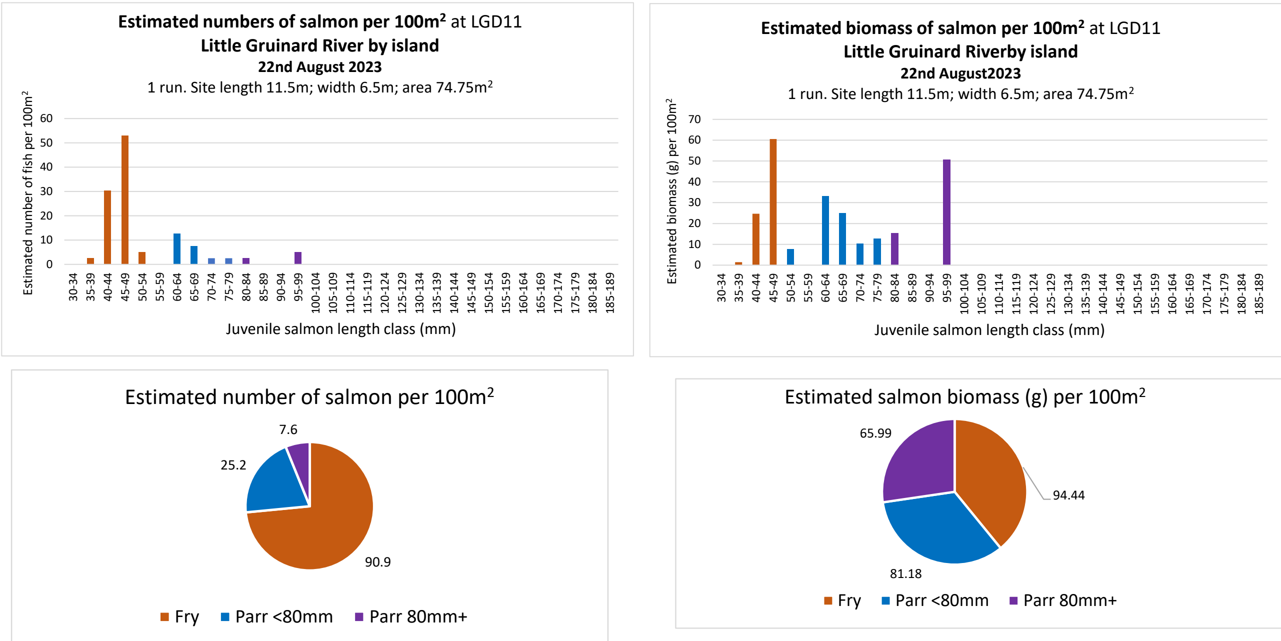
The combined estimated minimum density of juvenile salmon at this site NEPS21_2892 at the top of the Little Gruinard River, at the outflow of Pait Fhearchair, **on 6th August 2021 was just 29 juvenile salmon / 100m^2, with a total estimated biomass of 293 grams of juvenile salmon / 100m^2**. However, the biomass was nearly all of very large parr (>80mm in length), big enough to migrate to sea as large smolts in 2024. Estimated smolt production from this site was around 12 large smolts per 100m^2 (probably an underestimate); estimates of fish numbers may be a bit low, given the difficulty of fishing this site. But look how big the salmon fry and salmon parr (assumed to be fast growing 1+ year old parr) were!

In contrast, further down the Little Gruinard River, growth rates and size at age of juvenile salmon become much less. Site LGD11 by the First Flats has been surveyed many times in the past 20 years. It is close to an area of ancestral salmon redds (which can be seen in satellite photos), and has consistently produced high densities of salmon fry.

Figure 12 presents the results for a one-run survey of this site on 22nd August 2023.

(left) Nic Butler and Dr Shraveena Venkatesh by site LDG11, near the 1st Flats Little Gruinard River, 22nd August 2023

Figure 12. Results for e-fish site LGD11 in the Little Gruinard River channel by left bank, by island above the 1st Flats on 22nd August 2023. (a, top left) Estimated numbers of fish for each size class per 100m^2; (b, bottom left) estimated numbers of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2; (c, top right) Estimated biomass (g) of fish for each size class per 100m^2; (d, bottom right) estimated biomass (g) of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2. Pie charts have been scaled for ease of comparison with figures for sites in other rivers in this report.



The combined estimated minimum density of juvenile salmon at LGD11 in the Little Gruinard River channel by left bank, by island above the 1st Flats on 22nd August 2023 was **124 juvenile salmon / 100m^2, with a total estimated biomass of 241 grams of juvenile salmon / 100m^2**. The numbers and biomass of salmon were mostly of small salmon fry, with just a minor proportion of parr big enough to become smolts in 2024. Estimated smolt production from this site was around 6 smolts per 100m^2 in 2024, depending on over-winter survival.

(below) Thin salmon fry and parr from LGD11, Little Gruinard River on 22nd August 2023. Malnourished?

The fish at the top of the picture is one of few salmon parr long enough to become a smolt in 2024; but look how thin it is! How will it find enough food before smolt emigration time in 2024?

2.2.7 River Ewe

The River Ewe – Loch Maree system is the largest river system within the Wester Ross area. Most of the juvenile salmon habitat is in the Kinlochewe River and tributaries. Several other stream systems that discharge into Loch Maree also support juvenile salmon, including the Inveran River (and Kernsary river system), Grudie River, Talladale River and Slattadale burn.

In 2023, electro-fishing sites were surveyed in the Kinlochewe River and tributaries (Bruachaig, Docherty Burn, Coulin River, Bharranch burn), Grudie River and Slattadale burn. Fry densities were good in the Grudie River, Kinlochewe River (though few parr here), in the Bruachaig by the Heights of Kinlochewe (no parr here), and at one site in the Coulin River. However, salmon fry CPUE figures (Figure 3) were low in the Slattadale burn and Kernsary River (though parr CPUE good – see below), lower than recorded in earlier years.

The accessible part of the Kernsary River (and tributaries) represents quite a small area of wetted riverine habitat for supporting a salmon population, estimated at less than 10,000m^2. The river is separated by Loch Kernsary from the next nearest salmon habitat in the Inveran River and then by Loch Maree from other salmon nursery areas. Loch Kernsary is inhabited by large piscivorous trout; wild salmon smolts have to be able to find the outflow (not easy to find) before they are eaten by a large trout!

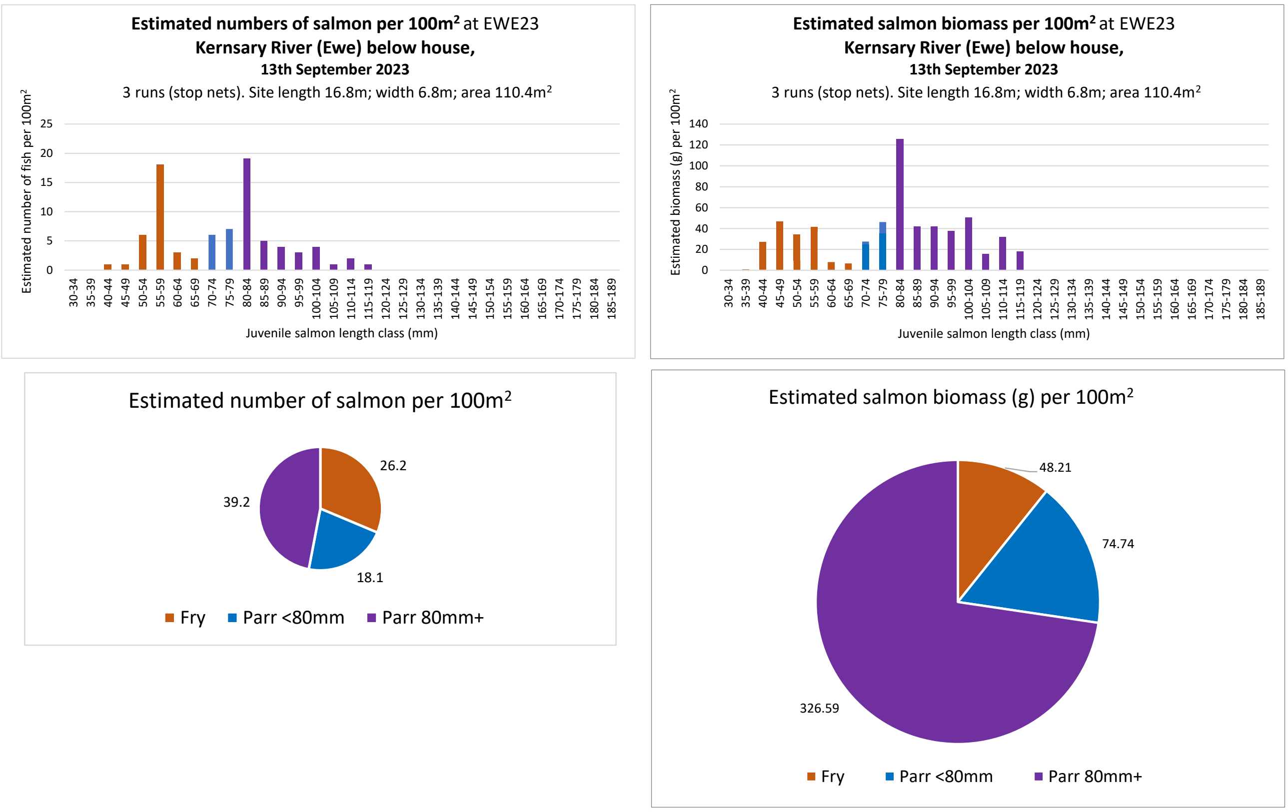
On 13th September 2023, site EWE23 in the Kernsary River was surveyed as a three-run site, using the same protocol as for a NEPS site; using stop nets (*right*). This site has been surveyed as a three-run site once every two or three years since the 1990s; the site has a stable streambed so few changes in habitat between years.

Results for this site (EWE23) on 13th September 2023 are presented in Figure 12.

Consistently, the WRFT e-fish team has recorded quite high densities of juvenile salmon here. In addition to juvenile salmon, the site supports juvenile trout and eels, some of which are large (over 500mm in some previous years).

Trout and a salmon parr from site EWE23 on 13th September. The river was at a moderate flow, the larger trout are likely to have been moving through the area; pre-spawning trout.

Figure 12. Results for e-fish site EWE23, Kernsary River (Ewe system) on 13th September 2023. (a, top left) Estimated numbers of fish for each size class per 100m^2; (b, bottom left) estimated numbers of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2; (c, top right) estimated biomass (g) of fish for each size class per 100m^2; (d, bottom right) estimated biomass (g) of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2. Pie charts have been scaled for ease of comparison with figures for other sites in this report.



The combined estimated minimum density of juvenile salmon at EWE23 in the Kernsary River on 13th September 2023, was **83 juvenile salmon / 100m^2, with a total estimated biomass 449 grams of juvenile salmon / 100m^2.** The numbers and biomass of salmon were mostly of salmon parr, the majority of which were big enough (>80mm) to become smolts in 2024. Estimated smolt production from this site was around 25 - 30 smolts per 100m^2 in 2024, depending on over-winter survival. In addition to juvenile salmon, eels (to 325mm; a larger eel of 500mm+ was seen), trout (to 230mm) and minnows (to 72mm) were caught at densities of approximately 9 eels, 18 minnows and 8 trout (respectively) per 100m^2. The biomass of juvenile salmon may have been only around half of the total fish biomass at this site, because of the number of large eels present; this can be explored further another day. The high overall fish biomass at this site may be due to a relatively fertile, well-wooded and stable catchment area, and to seepage from a septic tank soakaway.

If the larger parr survive, and the recorded density of larger parr is similar in other parts of the system, then the potentially production of salmon smolts from the Kernsary River sub-catchment may be around 2000 to 3000 salmon smolts per year (= 25 smolts x (10,000m^2/ 100m^2)). To maintain a genetically healthy breeding population of over 150 adult fish (with 75 adult female salmon; c. Consuegara and Nielsen, 2007) would require survival of around 5% of 3000 smolts. That may be rather more female salmon than have spawned in recent years?

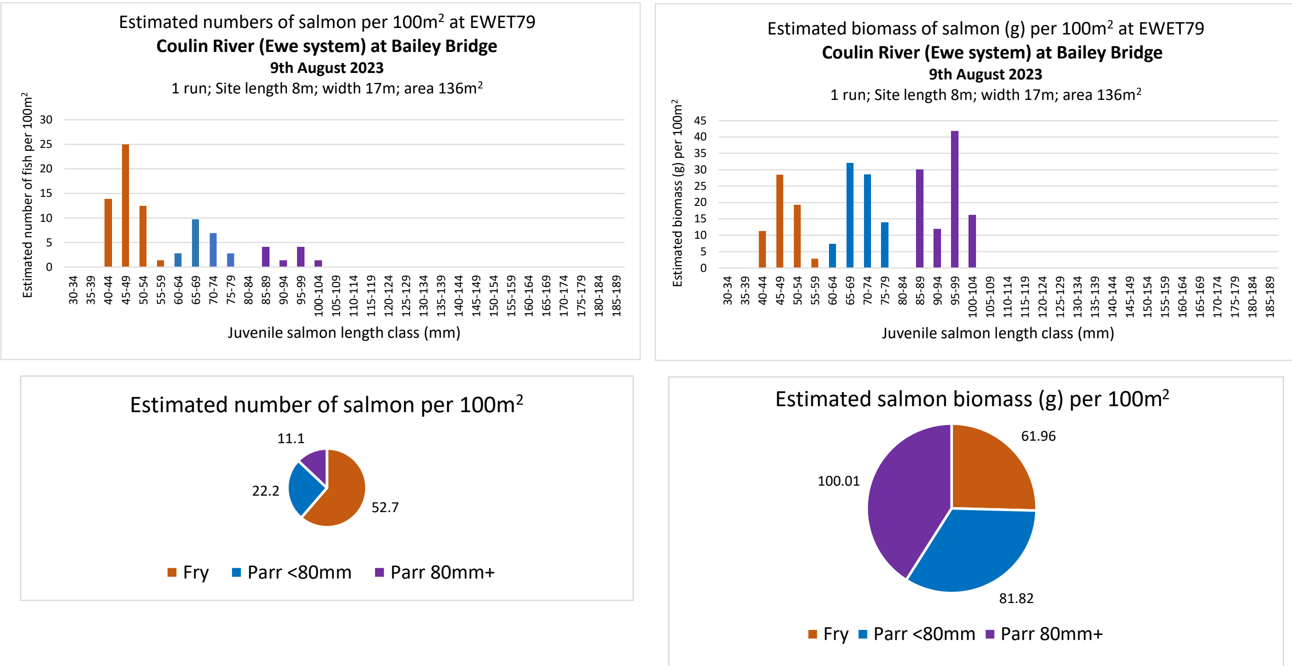
The Coulin River which flows into Loch Coulin is one of the most important spawning streams for salmon in the River Ewe headwaters. However, much of the river is wide and shallow, unstable at times; vulnerable to redd washout. In recent years several woodland schemes have been planted nearby, enhancing the valley; there is also a run-of-the-river hydropower scheme at the top of the river.

The river has few riparian trees and water temperatures of over 20C have been recorded in July in some previous recent years.

Two sites were surveyed on the mainstem Coulin River on 9th August 2023, one by the pine trees towards the top of the river (EWET80) and the other by the Bailey bridge over the river, about 400m above the loch (EWET79). Results are shown in Figure 13 and Figure 14.

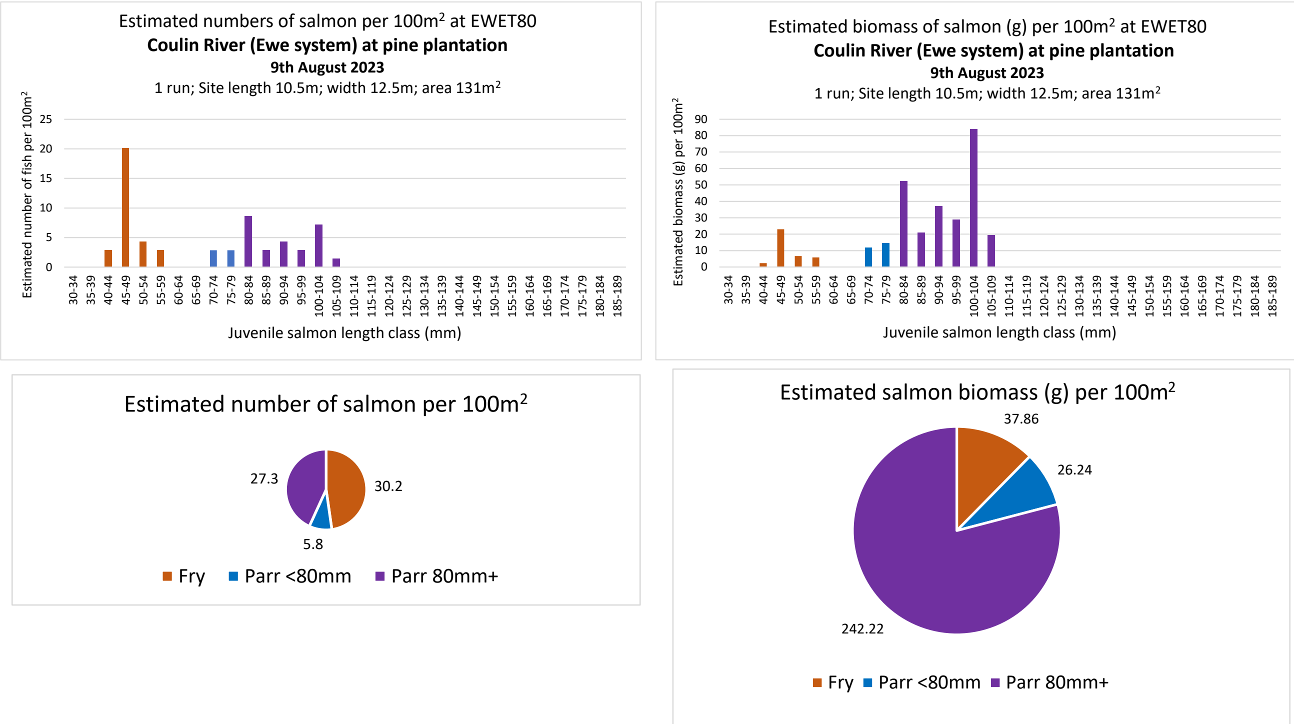
(below) Coulin River site EWET79 on 9th August 2023. The river is wide and shallow here; with nearby bank collapse, as shown in the lower picture looking upstream from just above this site.

Figure 13. Results for e-fish site EWET79, Coulin River (River Ewe system) on 9th August 2023. (a, top left) Estimated numbers of fish for each size class per 100m^2; (b, bottom left) estimated numbers of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2; (c, top right) estimated biomass (g) of fish for each size class per 100m^2; (d, bottom right) estimated biomass (g) of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2. Pie charts have been scaled for ease of comparison with figures for other sites in this report.



The combined estimated minimum density of juvenile salmon at EWET79, Coulin River (Ewe system) at the Bailey Bridge on 9th August 2023 was **86 juvenile salmon / 100m^2, with a total estimated biomass of 243 grams of juvenile salmon / 100m^2**. The numbers and biomass of salmon were mostly of salmon fry and parr of less than 80mm in length, with just a minor proportion of parr big enough (80mm +) to become smolts in 2024. Estimated salmon smolt production from this site was around 9 smolts per 100m^2 in 2024, depending (as elsewhere) on over-winter survival.

Figure 14. Results for e-fish site EWET80, Coulin River (River Ewe system) by the Pine trees (about 2km upstream from Loch Coulin) on 9th August 2023. (a, top left) Estimated numbers of fish for each size class per 100m^2; (b, bottom left) estimated numbers of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2; (c, top right) estimated biomass (g) of fish for each size class per 100m^2; (d, bottom right) estimated biomass (g) of salmon fry, smaller salmon parr [<80mm] and larger salmon parr [=/>80mm] per 100m^2. Pie charts have been scaled for ease of comparison with figures for other sites in this report.



The combined estimated minimum density of juvenile salmon at EWET80, Coulin River (Ewe system) at the Pine trees on 9th August 2023 was **63 juvenile salmon / 100m^2, with a total estimated biomass of 306 grams of juvenile salmon / 100m^2**. The numbers and biomass of salmon were mostly of salmon parr big enough to become smolts in 2024. Estimated smolt production from this site was around 24 smolts per 100m^2 in 2024, depending on over-winter survival.

2.2.8 Other rivers in Wester Ross area where sites were surveyed in 2023

Small numbers of adult salmon spawn in several smaller stream systems which flow into Loch Ewe. In 2023, sites were surveyed in the Allt Beith River (high CPUE of salmon fry and parr at some sites), in the Tournaig burn system (parr widely distributed; fry at only one site); River Sguod system (more salmon parr than fry).

Four sites were surveyed in the River Kerry [SAC]. Reasonable fry densities were recorded at two sites; however fewer parr were recorded than usual. This is an important river for juvenile salmon as they are the principal host fish for freshwater pearl mussel glochidia (larvae). Sites should be surveyed in the River Kerry in 2024 as it is possible that in some years very few salmon enter the river and survive to spawn.

A NEPS site was surveyed in the Applecross River where moderate densities of salmon fry and low densities of some parr were recorded; no salmon were recorded at a site in a small tributary drain.

A NEPS site was surveyed in the Taodail River (River Carron), near Strathcarron station: low numbers of both salmon fry and salmon parr were recorded. River Carron has had a long-term stocking programme; some of the salmon parr may have been of stocked origin.

3. Discussion

Table 1 provides a summary of the main findings from Part 2 of this report. The examples presented show much variation in the size at age of juvenile salmon, in the biomass of juvenile salmon per unit area of nursery habitat, and in potential smolt production per unit area per year within and between river systems in Wester Ross. Some of these are shown in sketches in Figure 15.

The highest estimates of smolt output were close to 30 smolts per 100m^2 habitat area per year (for sites in the Runie and Dundonnell rivers). The lowest estimates of smolt output for areas of comparable physical habitat with stable cobbly streambed, were less than 10 small thin smolts per 100m^2 per year (for sites in the Gruinard River and Little Gruinard River). Do these estimates provide a realistic indication of actual variation in potential smolt production?

Parr size and potential smolt production?

An argument can be made that looking at just a few sites provides an unrepresentative overview for comparison of smolt production potential from respective river systems. Juvenile salmon are known to disperse both upstream and downstream from where they hatch as they seek out better habitat and feeding opportunities. Larger faster growing parr migrate away from some sites to deeper water, including freshwater lochs where present, where feeding opportunities are better. Electro-fishing survey using a back-pack is only effective in water less than about 40cm deep; larger parr are often found in deeper water.

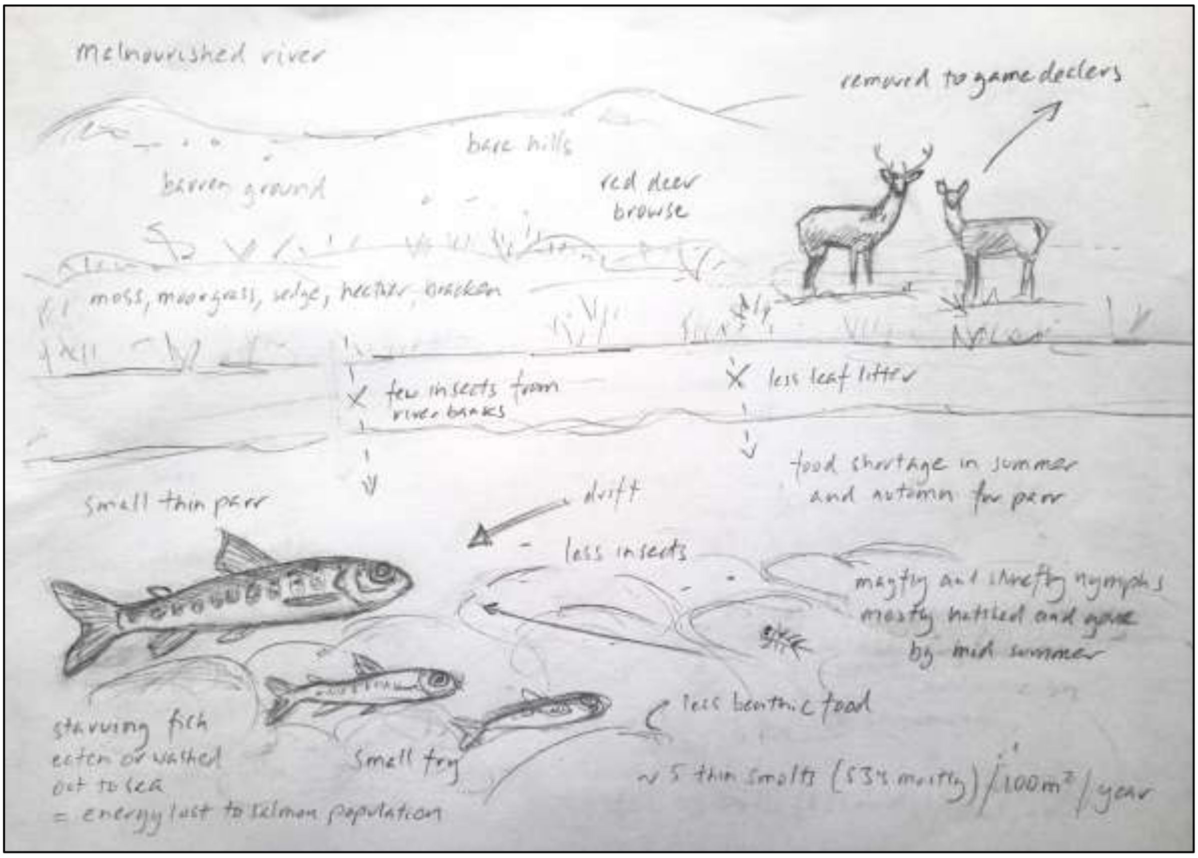
Some river systems have relatively large areas of riverine habitat deeper than 40cm, including the Gruinard and Little Gruinard Rivers which include loch habitat. Juvenile salmon are well adapted for living in deeper water where the current remains strong. However, brown trout, which eat juvenile salmon are better adapted for life in deeper water where the current is slower; trout eat juvenile salmon.

Furthermore, where there are large areas of still water (loch) habitat within the river system, significant number of parr may be able to grow on during winter months to reach larger sizes and conditions. A Nordic multi-mesh size netting study of Loch Maree by Ron Greer in July 2006 recorded 8 juvenile salmon out of a total catch of 221 fish (summary in Cunningham et al, 2007). These parr were of average weight 30g, over 130mm in length. No salmon parr were recorded in a similar Nordic multi-mesh netting study of Loch na Sealga led by Ron Greer in July 2008, just trout and arctic charr. Similar netting studies of the Fionn Loch and other lochs within the Little Gruinard River system could provide much information about fish diversity and utilisation of loch habitat by juvenile salmon. Some salmon parr are known to migrate downstream into deeper water during the autumn; netting studies during winter months may produce higher numbers of salmon parr from loch habitat.

In April and May 2021, a smolt trap was operated at the top of the Badachro River below the outflow of Loch Bad a' Chrotha (Cunningham, 2021). 220 salmon smolts ranging in size from 110mm to over 190mm were recorded. The highest number of smolts was in the 120mm-130mm size class. However over 100 smolts were over 140mm in length, and these were interpreted as having grown on within the loch during the winter months prior to emigration to sea.

Salmon smolt size data has also been recorded at the Tournaig trap since 1999. Since recolonisation by straying salmon in 2003 and 2004, numbers of smolts recorded emigrating to sea have varied from less than 50 (most recent years) to over 600 smolts in 2007. There has been much variation in smolt size. Figure 16, reproduced from the WRFT Review 2016, contrasts the size of smolts recorded in the Tournaig trap in 2007 with those recorded in 2015. The difference in size was attributed to a higher proportion of smolts growing on within the loch at Tournaig (Loch nan Dailthean) in winter 2014-2015, following a huge spate in August 2014 (Hurricane Bertha) which may have swept many of them into the loch from the nursery stream above

Figure 15. Sketches to show some differences in productivity of sites for juvenile salmon in Wester Ross



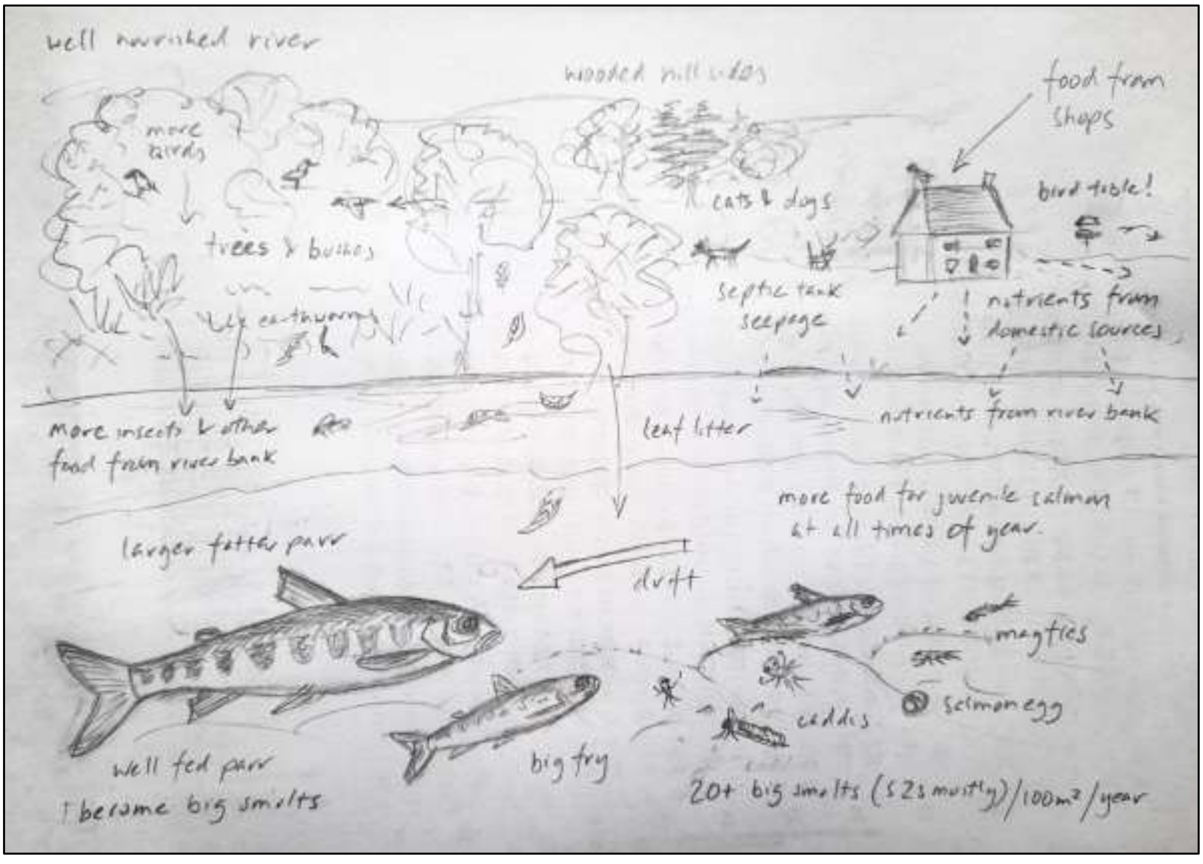


Table 1. Summary of results for estimates of juvenile salmon present at the subset of sites described in section 2, expressed in densities per 100m^2 for salmon fry, salmon parr of less than 80mm in length, salmon parr of greater than 80mm in length, and for respective biomass, including combined totals. (a) results expressed for rivers listed north to south. (b) below, the same data sorted out according to ranking for estimated densities of larger parr of ≥80mm in length (in order of lowest to highest)

Date	River system	River	location	code	fry density (fish/100^2)	fry biomass (g/100m^2)	parr <80mm density (fish/100^2)	parr <80mm biomass (g/100m^2)	parr =/>80mm density (fish/100^2)	parr =/>80mm biomass (g/100m^2)	total juv salmon density (fish/100^2)	total salmon biomass (g/100m^2)	other fish
24-Aug-23	Canaird	Runie	bouldery run	NEPS23_03714	36	122.4	13.5	65.3	36	313.5	152	501	2 trout
06-Sep-23	Ullapool	Rhidorroch	gravel island	NEPS23_03718	46.4	14.5	3	43.3	8.7	52.8	58	155	6 trout, 2 eels
08-Sep-23	Dundonnell	Dundonnell	by green shed	NEPS23_03710	69.4	102.4	3.9	18.8	28.3	287.9	101	409	3 trout, 8 eels (many seen)
07-Sep-23	Gruinard	Gruinard	by island	NEPS23_03717	19.7	12.4	13.1	45.3	13.1	52.75	39	110	2 trout, 2 eels
06-Aug-19	Gruinard	A. Srath na Seaga	above Achneigie	NEPS19_4681	78.2	86.8	18.2	76	7.8	71.56	101	234	
10-Aug-23	Little Gruinard	Allt F' a' Chaisgean	above confluence	LGDT27	26.1	35.6	6.5	32.8	26.1	259.5	59	328	
06-Aug-23	Little Gruinard	Little Gruinard	top of river	NEPS21_2892	13.2	25.6	0	0	14.3	268.1	29	293	
22-Aug-23	Little Gruinard	Little Gruinard	island by 1st flats	LGD11	91	94.4	25.2	81.2	7.6	66	124	241	
13-Sep-23	Ewe	Kernsary	below house	EWE23	26.2	48.2	18.1	74.4	39.2	326.6	83	449	9 eels, 8 trout, 18 minnows
09-Aug-23	Ewe	Coulin	by Bailey Bridge	EWET79	52.7	61.96	22.2	81.2	11.1	100	86	243	2 minnows
09-Aug-23	Ewe	Coulin	by Pine wood	EWET80	30.2	37.9	5.8	26.2	27.3	242.22	63	306	4 trout, 13 minnows

Date	River system	River	location	code	fry density (fish/100^2)	fry biomass (g/100m^2)	parr <80mm density (fish/100^2)	parr <80mm biomass (g/100m^2)	parr =/>80mm density (fish/100^2)	parr =/>80mm biomass (g/100m^2)	total juv salmon density (fish/100^2)	total salmon biomass (g/100m^2)	other fish
22-Aug-23	Little Gruinard	Little Gruinard	island by 1st flats	LGD11	91	94.4	25.2	81.2	**7.6**	66	124	241	
06-Aug-19	Gruinard	A. Srath na Seaga	above Achneigie	NEPS19_4681	78.2	86.8	18.2	76	**7.8**	71.56	101	234	
06-Sep-23	Ullapool	Rhidorroch	gravel island	NEPS23_03718	46.4	14.5	3	43.3	**8.7**	52.8	58	155	6 trout, 2 eels
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07-Sep-23	Gruinard	Gruinard	by island	NEPS23_03717	19.7	12.4	13.1	45.3	**13.1**	52.75	39	110	2 trout, 2 eels
06-Aug-23	Little Gruinard	Little Gruinard	top of river	NEPS21_2892	13.2	25.6	0	0	**14.3**	268.1	29	293	
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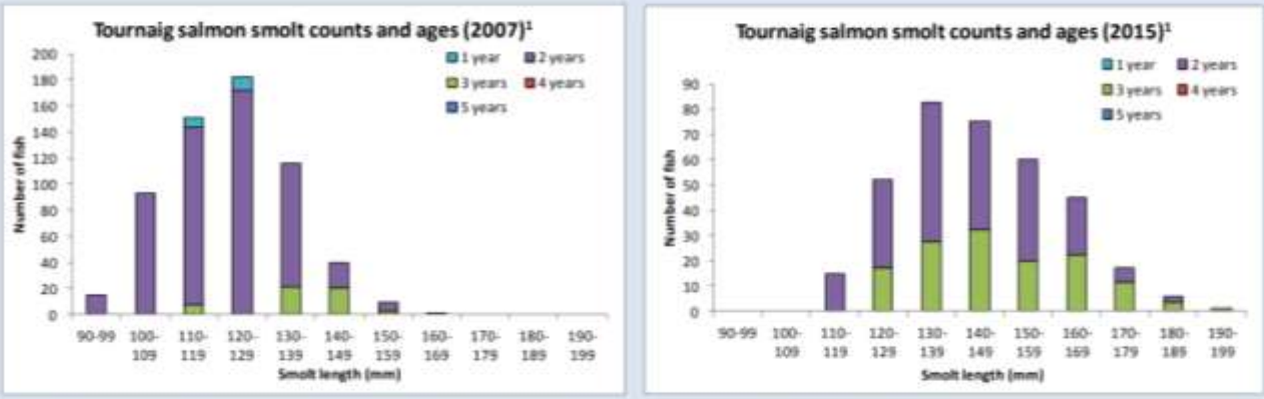
08-Sep-23	Dundonnell	Dundonnell	by green shed	NEPS23_03710	69.4	102.4	3.9	18.8	**28.3**	287.9	101	409	3 trout, 8 eels (many seen)
24-Aug-23	Canaird	Runie	bouldery run	NEPS23_03714	36	122.4	13.5	65.3	**36**	313.5	152	501	2 trout
13-Sep-23	Ewe	Kernsary	below house	EWE23	26.2	48.2	18.1	74.4	**39.2**	326.6	83	449	9 eels, 8 trout, 18 minnows

the loch. Scale reading supported the interpretation that many of the 2015 Tournaig smolts had grown on within loch habitat prior to emigration.

Figure 16. Contrasting salmon smolt sizes recorded at the WRFT Tournaig trap. Caption as in box. From WRFT Review 2016 https://www.wrft.org.uk/files/WRFT%20Review%20May%202016%20Final.pdf . Click on this link for more information and further discussion.

Figure 2.6 Contrasting years: salmon smolt runs compared. The 2007 smolt run of 607 is the maximum number of salmon smolts so far produced in the Tournaig system since the trap was set up in 1999. In 2015, 354 smolts were recorded.



[1] Smolt ages are based on readings of scales from sub-samples of smolts in respective years.

However, for some of the sites in this report and many other rivers, there is no accessible freshwater loch in the river catchment (e.g. rivers Runie, Dundonnell), or the freshwater loch habitat will not be accessible because of water falls (Little Gruinard River, by 1st flats).

In the Little Gruinard River below the falls just below the top of the river, juvenile salmon will not be able to access loch habitat. The best they can do for the winter is to drop into a large pool where feeding opportunities will be no better than in the shallower summer habitat. Likewise, for most of the mainstem Gruinard River. These are the river systems, two of the most important salmon river systems within the Wester Ross area, where malnutrition may be having the biggest negative impact on salmon smolt production.

Problems with degraded riverside habitat and reduced terrestrial origin food availability

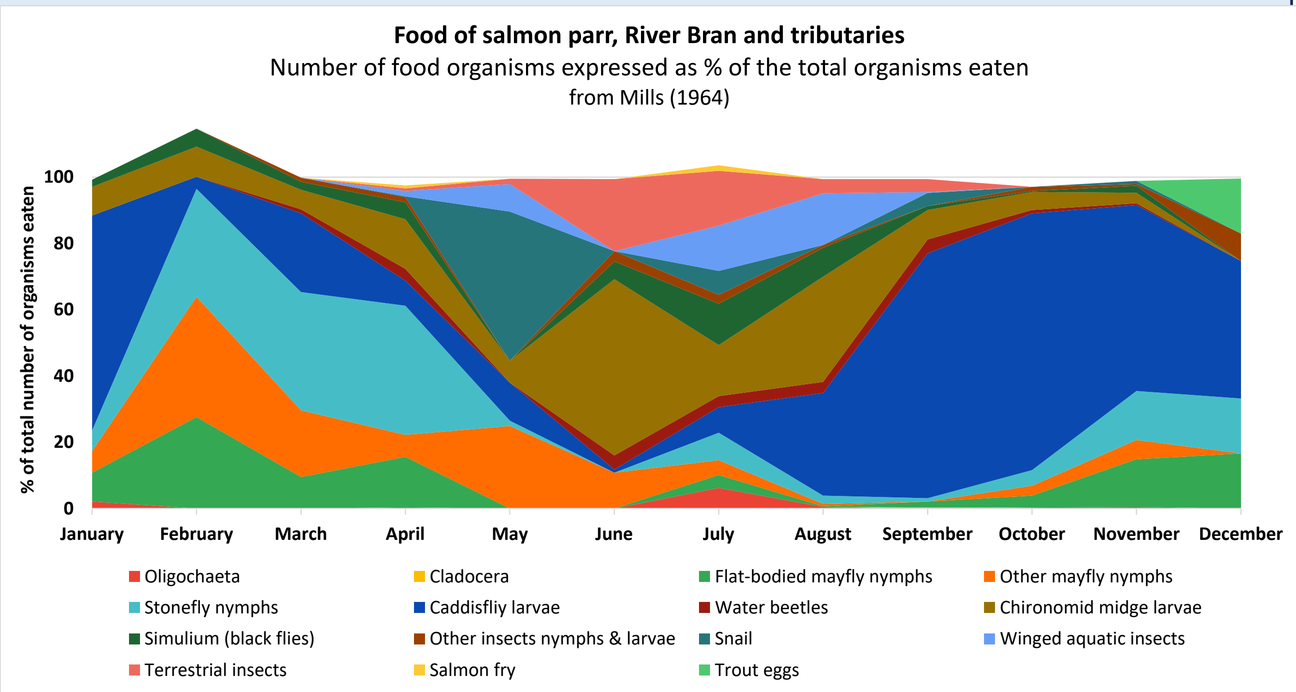
After the stonefly and mayfly hatches, mostly between March and early June, the summer can be a hungry period for juvenile salmon in some rivers (see Box 1). This is the time of year when water temperatures may be near optimum for growth of juvenile salmon. Where there is a fertile riparian corridor with riparian trees, wind-blown insects and other organic matter from riparian areas (river banks) can provide the major source of nutrition during this period. Benefits of riparian trees for fish were reviewed as part of the Riverwoods evidence review (Ogilvy et al, 2022; see also Cunningham 2021b). Trees and other riparian vegetation can be an important source of leaf litter (food for caddisfly larvae); and support both juvenile salmon production and freshwater pearl mussel production (Brauns et al, 2021). Trees can also provide shade, providing a cooling effect in the summer when water temperatures may otherwise get too high (reviewed in Ogilvy et al, 2022).

The two Gruinard rivers are unusual in so far as there are no permanent houses within either river catchment area. Both river systems drain largely de-vegetated catchment areas. Historically there were permanent dwellings within both catchment areas. The people who lived by the rivers would have contributed to the

Box 1. What do salmon parr eat? Food of salmon parr, River Bran and tributaries (River Conon system)

The only study of the diet of salmon parr throughout the year in Scotland that we know of is that of Derek Mills (1964), who carried out a study of the growth of juvenile salmon stocked into the nearby River Bran. The graph below has been produced from data from that study.

Number of food organisms per species group expressed as a percentage of the total organisms eaten. Data from Table 12, Mills, 1964.



Some notes:

1. Note the large proportion of mayfly nymphs and stonefly nymphs in food of parr from February to April. After April many mayflies and stoneflies have hatched and left the river so there are fewer nymphs available in summer months.

2. Chironomid midge larvae were major food in June and July. They mostly inhabit slower flowing water and still water, possibly a major food for salmon parr at loch outflows (e.g. top of Allt Beith river and Gruinard rivers)? In areas away from loch outflows, there would not be so many available to parr. Is this the main reason why salmon parr are usually much bigger for their age at loch outflows?

3. Caddis fly larvae were important from August to January. Many species are collectors of small bits of detritus of both aquatic and terrestrial origin. Numbers of caddis fly larvae in rivers tend to be higher where there is a wooded riparian corridor. So, rivers which have less riparian vegetation have fewer caddis fly larvae as food for juvenile salmon for this time of year.

4. Trout eggs were found in parr in December. Salmon first ascended the Bran in 1960 following fish pass development as part of the Conon hydro scheme (Mills and Graesser 1981). However, 'no salmon were allowed up again' until 1966, so salmon eggs, potentially an important food for wild parr in December and January, would not have been available. So, to the extent that salmon eggs and carcasses were not available to the River Bran ecosystem where the study took place, it is not entirely natural.

Thank you to Shraveena Venkatesh and Anthony Hall for helping with data transfer to MS Excel.

fertility of respective stream systems (though perhaps not quite so much as from the Kinlochewe village septic tank outflow into the Kinlochewe River in recent years, see WRFT Newsletter October 2023).

Loss of catchment vegetation in the Gruinard rivers catchment areas has been associated with grazing pressure that has inhibited tree growth and catchment burning. Fire has been used as a land management tool in recent years. Buring of large areas can adversely affect insect abundance (Ramchunder et al, 2013).

Problems with deer and livestock extraction and no replacement of exported nutrients into catchment

Harvesting and removal of deer (through deer stalking) and sheep (sent to market) may have led to much further loss of fertility from the catchment areas of both Gruinard rivers, further depriving biota from life-limiting nutrition, especially phosphorus. This was discussed at the WRFT Catchment Vegetation Revival meeting at Kinlochewe in April 2023.

Problems associated with a lack of returning adult salmon and sea trout

Because of low rod catches of adult salmon, the Little Gruinard River was given a Grade 3 'mandatory catch and release' conservation grading by the Scottish Government in 2023, the inference being that in recent years, there have been inadequate numbers of adult fish returning from the sea to ensure adequate egg deposition even for repopulating accessible riverine habitat within the system with juvenile salmon.

As stated earlier, the Little Gruinard River became the first river in Scotland to introduce mandatory catch and release in 1990, so in practical terms the grading makes no difference to the management of angling (further background information can be found in the Little Gruinard River Fisheries Management Plan, Cunningham, 2011)). Furthermore, like its neighbour, the 'big' Gruinard River system, it is possible that the numbers of adult salmon required to maintain healthy wild salmon populations in the Little Gruinard River system have been underestimated using the formula adopted by Marine Directorate for regulating salmon fishing in Scotland. This formula not does not attribute any requirement for the provision of surplus salmon eggs as a food for juvenile salmon. Is the Scottish Government's conservation grading methodology fit for purpose for highly oligotrophic river systems with large areas of loch habitat?

For oligotrophic rivers like the Gruinard rivers, 'surplus' salmon eggs and the carcasses of adult salmon which remain within the system can represent a vital source (i.e. one upon which lives depend) of nutrition for juvenile salmon, perhaps especially for pre-smolt salmon during the winter months before emigration from freshwater to the sea.

This is explored in Box 2 which provides contrasting estimates of the amounts of surplus salmon eggs that would be available to salmon parr during late autumn and winter during periods when marine survival of smolts is good (10% return rate) compared to when it is poor (2% return rate).

For the Gruinard River, when marine survival rates were high, there may have been as many as 70 eggs available on average for each of around 10,000 pre-smolts during the late autumn and winter prior to smoltification. However, if marine survival rates are now just 2%, the corresponding reduction in surplus salmon eggs may mean only 10 eggs per pre-smolt salmon. One salmon egg is estimated to provide about one day's energy requirements for a pre-smolt salmon at typical winter water temperatures.

This calculation does not include the indirect transfer of marine derived nutrients from salmon carcasses and eggs into periphyton, then invertebrates then for juvenile salmon; nor transfer via terrestrial pathways (shown on Figure 1). Nor is the contribution from any washed-out sea trout eggs as food for juvenile salmon taken into consideration (might have been of significance in smaller headwater streams in the past).

This reduction in marine derived nutrient and marine derived energy transfer to pre-smolt salmon parr could make a big difference at smolt emigration time. Smolts that migrate to sea with an 'empty tank' will need to find food much sooner than those that go to sea with a 'full tank', or else they are more likely to be eaten!

For the Gruinard rivers the big reduction in the amounts of marine derived nutrients transferred by adult salmon may further exacerbate problems of malnutrition (as observed in the 2023 juvenile fish survey).

Box 2. Salmon eggs as winter nutrition model for the Gruinard River (Loch na Sealga to the sea): how many surplus eggs are needed for pre-smolt salmon?

Assume river length 8,000m and wet width 12.5m, so river wetted area of 100,000m^2. At smolt production of 10 smolts per year per 100m^2 of river area, annual smolt production of 10,000 smolts.

At marine survival of 10% (of 10,000 smolts), return of 1000 adult salmon. If sex ration of adult salmon is 50%:50% males to females, then **500 adult female salmon** (assume all 500 survive and spawn).

If each female salmon is of average mass 2.5kg, then total mass of 1,250 kg of female salmon. If 1,200 eggs per kg, then total transfer of eggs to river is 1,500,000 eggs. To produce average fry density at swim up of 1 fry per m^2 of stream habitat, just 100,000 eggs are needed. So over 1,400,000 surplus eggs.

If just 50% of surplus eggs are eaten by salmon parr before they smolt in late autumn early winter, then each pre-smolt has (700,000 eggs / 10,000 pre-smolt salmon).

That is an average of 70 eggs (or alevins) per pre-smolt salmon. Potentially the most important winter food source for pre-smolt salmon parr in the Gruinard River? Salmon parr are known to be able to eat from 12 – 15 eggs in a meal (Youngson, 2014); then they take many days to digest the eggs.

However, if the marine survival is only 2% (of 10,000 smolts) then return of only 200 adult salmon; or **100 female salmon**. At 2.5kg per female salmon, 250kg of female salmon. If 1,200 eggs per kg, then total transfer of eggs to river is only 300,000 eggs. To produce average fry density of 1 fry per m^2 of stream habitat need just 100,000 eggs. So only 200,000 surplus eggs.

If 50% of surplus eggs are eaten by large salmon parr before they smolt in late autumn early winter, then each pre-smolt has (100,000 eggs / 10,000 pre-smolt salmon), **so just 10 eggs per pre-smolt salmon**.

What is the energy value of a salmon egg to a salmon parr?

A salmon egg (wet mass) weighs from 0.05g to 0.14g (variation in egg size), with an **energy content of 0.4kJ to 1.0kJ**, mostly as protein and lipid (Berg et al, 2001).

A fasting salmon needs 30 – 80 kJ of energy per kg per day (Kaushik & Medale, 1994), so 0.03kJ to 0.08kJ per g per day. Therefore, **a 10g parr (of length ~100mm) would need 0.3kJ to 0.8kJ per day**; a 20g (~120mm) parr would need 0.6kJ to 1.6 kJ per day, and so on (energy requirements also vary according to water temperature).

Therefore, one salmon egg would provide approximately the energy requirements of a salmon parr of 100mm – 120mm for a day during winter months.

<u>Conclusions from this model:</u>

So, at marine survival rate of 10% (until 1980s?) from smolt to adult salmon, surplus salmon eggs may be able to provide 10,000 pre-smolt salmon with minimum energy requirements for about 70 days . . .

However, at a marine survival rate of just 2% (closer to recent years?) surplus eggs may be able to provide food requirements for an average pre-smolt salmon of only 10 days.

4. Recommendations; how to address the malnutrition problem?

Salmon populations in both of the Gruinard rivers may have been hit with a 5x whammy, contributing to malnutrition of juvenile fish as a result of:

- Removal of top salmon predators from catchment areas (bears, wolves, then people) so less retention of marine nutrients via salmon carcass transfer to add fertility to river banks;
- Removal of vegetation from the catchment areas of both river systems over a long period of time due to grazing pressure, trampling, soil erosion and burning of vegetation;
- Export of nutrients in deer, sheep and cattle carcasses from both catchment areas;
- Reduction in the numbers of returning adult salmon and sea trout (for several reasons) and the amount of marine derived nutrition available for juvenile salmon, particularly since the 1980s;
- Rising water temperatures (so higher energy requirements for a juvenile salmon).

Malnourishment is likely to also affect populations of the critically endangered Freshwater pearl mussel in both river systems, through reduced recruitment (c. Brauns et al, 2021). What is known by Nature Scot?

With fewer returning adult salmon and a degraded ecosystem with many missing trophic links, there are certain times of year when juvenile salmon may be particularly hungry, including mid to late summer and through winter months. Bigger, fatter smolts have been shown to have higher rates of marine survival than smaller thinner ones (Armstrong et al, 2018).

There is a need to produce more smolts and larger smolts in the wild (Gregory et al, 2019).

Especially for the Gruinard rivers, does this mean providing more food for juvenile salmon?

Studies elsewhere in Scotland have demonstrated that growth and biomass per unit area of juvenile salmon can be raised by adding nutrients analogous (according to experimental design) to those that would have been provided by the carcasses of many adult salmon that historically entered rivers from the sea. Initial studies utilised whole salmon carcasses which were wired into research project salmon nursery streams (Williams et al, 2009), and more recently salmon carcass analogue pellets (farm salmon feed) in hessian bags retained within the streambed to mimic salmon carcass decomposition (e.g. McLennan et al, 2019; Bernthal, et al, 2022) to learn about instream trophic pathways and how juvenile salmon and other instream biota responded.

However, even after more than 20 years of research (including several PhD studentships), much of it carried out within the neighbouring River Conon catchment area, there are still several trophic pathways from adult salmon to smolt which remain inadequately researched and understood; some of these may be of vital importance for sustaining production and condition of salmon smolts from some rivers in Wester Ross.

As indicated in Part 1.2, there is still a need to learn much more about:

(1) the importance (potentially vital in some rivers) of surplus washed-out salmon eggs and alevins as a food for overwintering pre-smolt salmon as well as the invertebrate communities which support salmon fry and parr.

(2) the importance of lochs (still water habitat) as a source of food for juvenile salmon (including parr inhabiting rivers downstream from loch habitat), including nutrition derived from salmon carcasses.

(3) the importance of transfer of marine nutrient derived from salmon carcasses to riparian habitats and terrestrial ecosystems which provide vital nutrition for juvenile salmon during summer months (much of it in form of winged insects).

However, the need for further research can no longer be used as justification for not taking actions to address the problem of malnutrition for Atlantic salmon and Freshwater pearl mussels.

The Atlantic salmon has recently been added to IUCN red list of 'endangered species' in Great Britain. The Scottish Government needs to do more to protect wild salmon which have always been an important part of the economic and cultural fabric of Scotland.

To safeguard salmon populations in both of the Gruinard rivers, we need to apply the best available knowledge. Action is required as soon as possible or else populations are likely to decline much further.

Wild salmon have a complex life-cycle and face a multitude of pressures, including damage to freshwater habitats, competition and predation as a result of spread of invasive non-native species, climate change, breeding with escaped farm salmon, capture in marine fisheries; and especially around the west of Scotland, infestation by parasitic sea lice associated with inadequately regulated open-cage production of farmed salmon. In April and May 2023, sea lice levels recorded on sea trout sampled in Wester Ross were once again much too high; post-smolt salmon migrating through the Inner Sound are likely to have experienced elevated mortality https://www.wrft.org.uk/files/WRFT%20Newsletter%20October%202023.pdf.

In May 2023, sea lice infested sea trout were reported by anglers in the Loch Broom – Little Loch Broom area, correlating with high lice counts on farmed fish at the nearby WRF (MOWI) Ardmair salmon farm. For the first time for many years, high lice counts were reported on farmed fish at this farm in 2023, linked to production cost-cutting by the new owners MOWI? Lice levels on this farm were far too high early in 2024 (Scotland Aquaculture, 2024). Sea lice infestation presents a resurgent threat to emigrating salmon smolts and salmon populations in all the important salmon rivers which flow into the Wester Ross MPA.

For the Gruinard River the following recommendation need to be discussed with a view to taking action to address the issue of malnutrition:

1. Catchment-scale restoration of ecosystem fertility; to replace the life-limiting nutrients that have been exported in deer and sheep carcasses. This could be achieved through feeding bone meal or other slow-release organic phosphorus and calcium rich fertiliser to areas where vegetation could take up the additional nutrient. Discussions took place with representatives of Nature Scot and SEPA in June 2023; further response awaited.

2. Revegetation of catchment areas. This does not need to be just trees. Indeed, trees will not grow in some areas where soils and organic growing mediums have been eroded away and fertility has been lost without the restoration of a suitably nutritious growing medium.

3. Balancing the export of nutrients in deer and livestock carcasses that are removed from catchment areas with return of nutrients that are imported. Approximately 1kg of phosphorus is removed with every deer that is taken off the hill (most of it in bone; see Cunningham, 2017). The amount of phosphorus that needs to be returned each year should be at least as much as the amount removed by the deer cull. Then multiply by 100+ years for past exports of phosphorus that have not been made good. SEPA and Nature Scot have been asked for advice on using incinerated farm salmon carcasses as a P and Ca rich by-product like bone meal, other ideas are to reclaim bones from game dealers. 'Red tape' (EU classification of incinerated salmon farm mort and red deer bones as processed animal waste) appears to be the main issue obstructing progress?

4. Restoring as much lush leafy woody vegetation as close to riverbanks as possible, as sources of nutrition for the river. This will require fenced enclosures, until deer numbers within catchment areas are in balance with an adequate all year-round deer food supply (so they have more than enough food at all times of year).

5. In stream nutrient enhancement. Methods that were reviewed by Bernthal et al (2022) need to be applied to the Gruinard Rivers. This could also greatly benefit freshwater pearl mussels.

6. Direct supplementary feeding of the fish (Box 3). This could be done in summer and autumn months using slow-sink organic salmon feed pellets, carefully monitored to ensure that feed pellets are consumed and incorporated into the instream food-web within short periods of time. Quite small amounts of feed could make quite a big difference to salmon parr growth, smolt numbers, smolt size and smolt condition?

Box 3. How to feed wild juvenile salmon?

Over the past 40 years there has been a big increase in the numbers of people who feed garden birds. Some wild bird populations which exploit food provided by people have benefited greatly.

Bird feeding is based on providing small amounts of food regularly, and ensuring that it is all eaten. However, what is particularly unnatural is that birds learn to return to the same location to feed every day.

To feed juvenile salmon, small amounts of food at regular intervals could work well if the juvenile salmon learn to eat the food provided. However, the aim would be to provide food at low concentrations distributed over a large area, initially starting by providing food to smaller areas and monitoring carefully; to mimic a natural food source (e.g. drifting Chironomid larvae or black flies). Underwater cameras could be used to monitor fish behaviour (c. Orlov et al, 2006).

Slow sink (?2cm / second) commercial pellets could be used on trial basis to learn about how wild salmon parr respond to provision of supplementary food. Here's an example of a slow sink salmon fry pellet: Nutri Sprint, https://www.skretting.com/en/feed-for-aquaculture/nutra-sprint-for-atlantic-salmon-29/ . Looks like about sink rate of 2cm per second in video?

How much food would be needed?

The model in Box 1 is based on a conservative estimate of potential smolt production from the wetted area of the mainstem Gruinard River (excluding tributaries and headwaters) of 10,000 smolts per year. Actual smolt production may have been less than this in recent years; potential smolt production may be 20,000 smolts per year based on estimated for other rivers (i.e. 20 smolts per $100m^2$ wetted habitat area).

Juvenile salmon of average mass 10g need around 0.5kJ per fish per day to maintain their condition (see Box 1). So, to provide for 50% of food requirements for 10,000 pre-smolt salmon parr of average mass 10g, the equivalent of 2,500kJ per day would be required.

Farm fish food contains about 21kJ per gram of feed (FAO,?). Therefore, to provide 50% to juvenile salmon energy requirement for 10,000 salmon parr, the amount of salmon food required would be only (2,500/21) g = 119g of salmon feed per day, or 850g per week. How much difference would that make to parr growth and body condition if fed over the May – September period (20 weeks)?

Could this be packaged small amount of food into 100g bags, and to distribute one to each of three beats per fishing day (assume 5 days per week) during the fishing season?

We feed wild birds where natural food sources are no longer adequate to support populations. Why are we not providing supplementary food for starving salmon?

7. Until salmon farmers can demonstrate reliable and consistent control of on-farm sea lice; open cage salmon farms need to be located away from the Wester Ross Marine Protected Area into which all of the main rivers described within this report discharge. To protect important wild salmon populations, nearby farms must control sea lice on farmed fish or else they need to be shut down.

Acknowledgements

Juvenile fish surveys in 2023 were led by Peter Cunningham assisted by Dr Shraveena Venkatesh (Nature Scot graduate placement), Nic Butler, Dr Sue Ward, and many volunteers including Rob Cooper, Gerry Lucas, Alasdair Macdonald, Chloe Hall, Anthony Hall, Rachel Hedley, Steve Merrill, John Ogle and family, Donald Macleod, Franki Kalinowski, Mark Williams and family, Dr James Close, Dr Steve Kett and others; and in earlier years assisted by Colin Simpson and many others. Surveys were funded by Scottish Government's National Electro-fishing Survey of Scotland (led by the Marine Directorate with support from Fisheries Management Scotland), Wester Ross Area Salmon Fishery Board and Canaird River Company Ltd (DRG Hydro); with in-kind support (permissions and access) from Keanchulish estate, Langwell estate, East Rhidorroch estate, Dundonnell estate, Gruinard estate, Eilean Darach estate, Tournaig estate, Inverasdale estate, Gairloch estate, Kinlochewe estate, Coulin estate and the Applecross Trust. Thank you to Anthony Hall and Peter Jarosz for help with data compilation. Thank you to Michael Aitchison, Peter Jarosz, Alasdair Macdonald and Sue Ward for comments and corrections.

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Appendix 1. Methodology

The purpose of this document was to review the main findings of juvenile fish surveys in 2023 with a view to informing wild salmon conservation and management in the Wester Ross area, focussing on how best to respond to safeguard wild fish populations in a timely manner.

Producing estimates of biomass for juvenile salmon from recorded length measurements

The relationship between the length of a juvenile almon and its weight varies according to its body condition (how fat or how thin it is). For the purposes of this document, the following equation was used to calculate the mass of juvenile salmon of different lengths, grouped into 5mm length size classes.

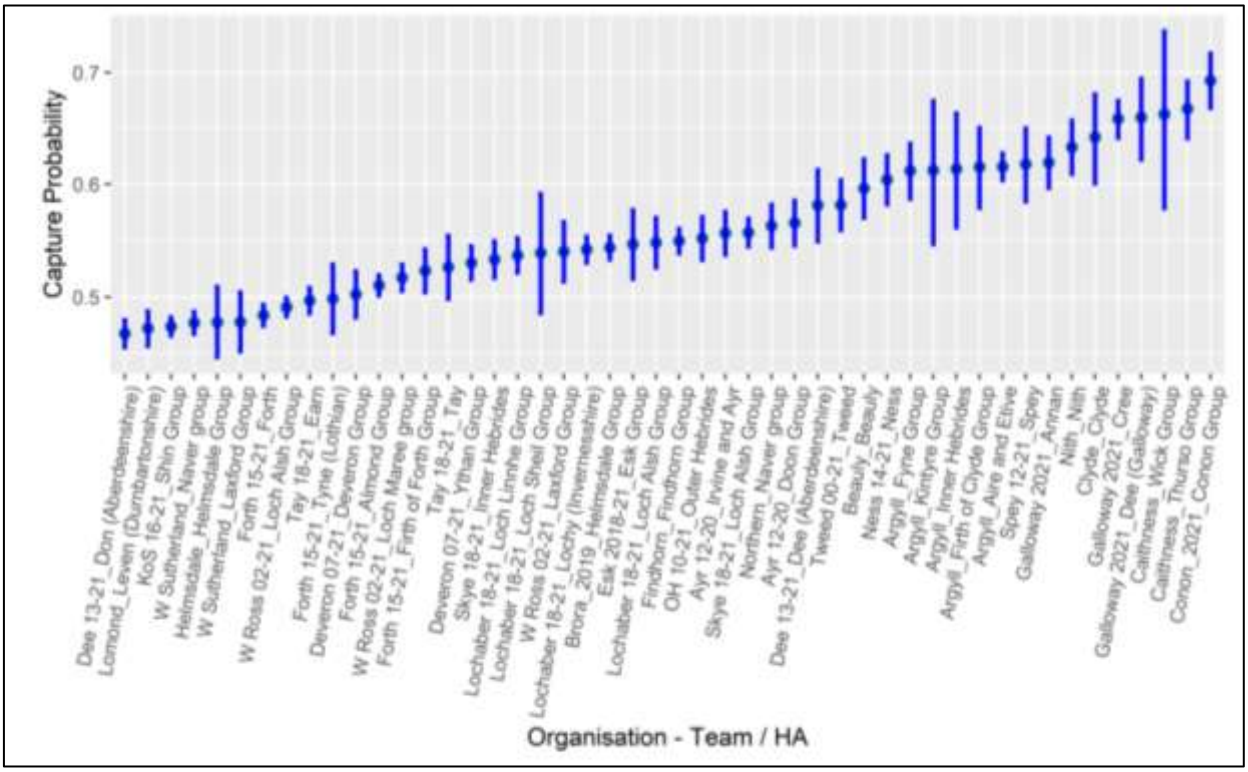
Juvenile salmon mass = (measured fish length in cm)^3/100) x 1.1.

The values obtained overlap actual length – weight data for juvenile salmon recorded in Wester Ross and nearby areas, so were regarded as being adequate for the purpose of producing biomass estimates for different sites which could be contrasted for different sites and rivers.

Producing estimates of numbers of fish per unit area and biomass of juvenile salmon per unit area

The capture probability for the WRFT e-fishing team per site, led by Peter Cunningham, has been estimated at around 53% per run, from data analysed as part of the NEPS survey in earlier years (2018 – 2021, see Malcolm et al, 2023), as shown in Figure 16 below.

Figure 16 (copied from Malcolm et al, 2023) Combined partial effect of Organisation - Team and of Region 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. Only Organisation - Teams contributing to NEPS in 2021 are shown. Note WRFT capture probabilities.



For one-run sites, the equation used to estimate actual number of fish at a site assumes that we caught 53% of those present at the site. As explained in the text, for some main river sites one-run sites in the Gruinard

River and Little Gruinard (top site), our catch may have been less than 53% of fish present, because of deep water and high water temperature. However, the main observation of interest was of differences in the sizes of juvenile salmon at different sites; so, the main conclusions were judged to be well founded.

At electro-fishing sites where three runs were carried out, minimum density estimates used are simply: all the fish that were caught over the three runs added together divided by the area of river fished. So even after three runs, some fish are left; perhaps about 10%.

(remaining fish = 100% - [53% + (0.53 x 47% = 25%) + (0.53 x 22% = 11.6%) = 11% of fish remaining after 3 runs). So, the actual number of juvenile salmon present at each site may have been around 5%-15% higher than figures used in this report, but not a lot more than that (except for eels, which were not efficiently caught). Zippin estimates are often used for greater precision and accuracy; for the purposes this document it was felt this would be add unnecessary complexity which would add little for the purpose of the analyses.

The methodology provides estimates of fish numbers and biomass from which it is possible to safely conclude for conservation and fishery management purposes, that:

(1) there were large differences between sites in juvenile salmon densities expressed as numbers of fish per $100m^2$ and biomass of fish per $100m^2$.

(2) the total estimated biomass of juvenile salmon and the proportion of biomass represented by larger parr which were big enough to become smolts the following year varied considerably between sites.

(3) juvenile salmon sizes and numbers of larger salmon parr at main river Gruinard River and Little Gruinard sites (all fished as one run sites) were much smaller and lower than elsewhere.

The latter conclusion is the one where a practical response could bring about the biggest benefits for wild salmon in Wester Ross.