Wester Ross Salmon Stream Nutrient Restoration

Pilot Project 2024-2025

Final report, January 2026

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Wester Ross Salmon Stream Nutrient Restoration Project – final project report

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Please note that all photos of fish in this report are of lightly sedated fish which were returned to the water following recovery.

Summary

Numbers of wild salmon and sea trout returning to rivers in Wester Ross have fallen in recent years (especially pre-1980). A decline in the number of adult salmon and sea trout returning to freshwater to spawn leads to a reduction in the amount of available food for juvenile salmon, further depressing wild salmon populations. This is primarily because of a reduction in the amount of decomposing adult salmon carcasses which provide marine-derived nutrients [MDN] supporting the production of aquatic insects upon which juvenile salmon feed.

To address this issue, this pilot project aimed to explore the practicalities of using salmon carcass analogue pellets (organic high fishmeal content farm salmon feed) to nourish salmon nursery streams within Wester Ross, using methods developed over 15+ years of research in nearby streams within the River Conon system.

Objectives were as follows:

1. to investigate the use of an alternative source of marine nutrients as an 'analogue' for the missing salmon carcasses and salmon eggs,
2. to explore methods of application,
3. to record outcomes for aquatic invertebrates and juvenile fish.

Salmon carcass analogue pellets (organic high fishmeal content farm salmon feed) [SCAP] were kindly provided by Hendrix-Genetics Inverkerry Hatchery. These were applied to two treatment sites in each of: the Torridon River, the Coulin River (River Ewe headwaters) and Docherty Burn in December 2024 and February 2025, following baseline surveys of invertebrates and juvenile fish.

Subsequent monitoring indicated that the nutrients from the decomposing SCAP dispersed in different ways. At some sites, large spate events swept much of the material away; at other sites spates buried it more deeply under newly deposited sediment.

Responses to nutrient application from biota were recorded at treatment sites in the Docherty Burn, including increased production of green periphyton on the streambed and higher numbers of mayfly larvae post-treatment. At one site in each of the Docherty Burn and Coulin River, there was some indication that salmon fry and parr had grown more quickly post-treatment, consistent with expectations based on previous work elsewhere.

However, 'Storm Floris' (in early August 2025) and 'Storm Amy' (October 2025) both prior to follow-up juvenile fish monitoring surveys caused much movement of streambed sediment and made it impossible to fully understand outcomes for fish.

Future work should focus on developing methods of salmon carcass analogue application which are less vulnerable to being swept away in big spates. Several options to help renourish stream ecosystems and thereby support juvenile salmon production are proposed, including more focus on nourishing riparian habitats and streamside ecosystems rather than applying salmon carcass analogues directly into the water.

This project was supported by the Highlands and Islands Environment Foundation and Wester Ross Area Salmon Fisheries Board. Thankyou to all the estates that provided permissions for this project, Nature Scot, and several volunteers.

1. Introduction

1.1 Background

A decline in the number of adult salmon and sea trout returning to freshwater to spawn can lead to a reduction in the amount of available food for juvenile salmon. This is because of a reduction in the amount of decomposing adult salmon carcasses: marine-derived nutrients [MDN] to support production of aquatic insects upon which juvenile salmon feed (McLennan et al, 2019; Bernthal, 2022) and because of reductions in the amounts of 'surplus' fish eggs: food for pre-smolt salmon parr (Cunningham, 2024a; Cunningham, 2024b).

Some of these issues were recognised in the late 20th century as scientists began to understand more about the importance of annual contributions of marine-derived nutrients from runs of returning Pacific salmon spp. for maintaining the fertility and productivity of coastal ecosystems in northwest America. Stockner et al (2000) discussed the issue in '[Cultural oligotrophication: causes and consequences for fisheries'](#).

From Stockner et al (2000):

'To many persons, oligotrophication is synonymous with "clean" water and aesthetic improvements, but to others, it often implies an unproductive and declining fisheries resource. In this article we use a phosphorus (P) mass-balance approach to provide a historic perspective for the ongoing oligotrophication of highland terrestrial and aquatic ecosystems and the concurrent eutrophication of lowland, coastal ecosystems. Because mined sources of P for fertilizer production are declining and costs are likely to increase substantially within the next century, we opine that it is time to reconsider the ways we manage our nutrient resources. We should recommence all means of recycling P and consider ways to reintroduce recycled nutrients in a balanced N:P ratio to some aquatic ecosystems, in a carefully controlled and ecologically sensitive way to restore sufficient fisheries production levels. If we continue to mismanage P sources and ignore the importance of nutrient balances for the maintenance of productive fisheries, then choices soon will have to be made between having aesthetically clear freshwaters but unproductive fisheries, or productive fisheries in "greener" lakes and streams.' (Stockner, et al 2000).

Many of the points made in this article apply equally to northwest Scotland where the management of ecologically damaged and nutritionally degraded river catchments also affects outcomes for wild salmon populations. However, twenty-five years later, there is still inadequate understanding of the oligotrophication issue in Scotland and how best to address it. SEPA, Nature Scot and Marine Scotland are yet to actively encourage and promote proven methods for supporting the recovery of stream ecosystem fertility where there has been a decline in productivity due to loss of adult salmon.

This is partly because of precaution based on experiences with dealing with over-enrichment of water and land with excess phosphorus fertiliser (eutrophication) and domestic and industrial effluents at the opposite end of the fertility spectrum which have damaged populations of freshwater pearl mussels and other freshwater biota. However, at the other end of the nutrient spectrum, oligotrophication associated with declines in salmon and sea trout numbers can also be harmful to wild salmon populations and has probably also harmed important freshwater pearl mussel populations through malnourishment.

In areas such as Wester Ross, lower river nutrient levels, combined with rising water temperatures, cause malnutrition of juvenile salmon and thinning of salmon smolts. This may be contributing to reduced survival of salmon post-smolts at sea and so a vicious circle of further reductions in the number of returning adult salmon to nourish stream ecosystems (Cunningham 2024b).

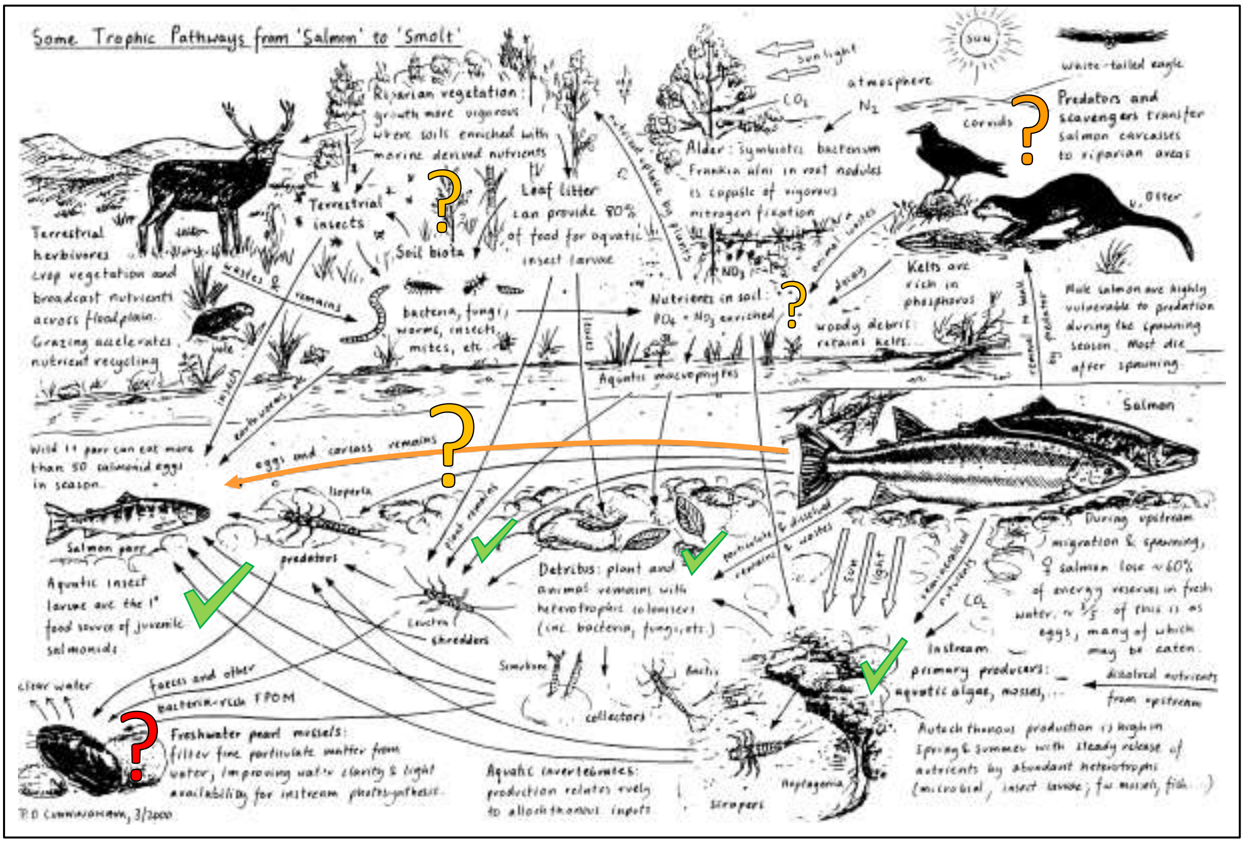
Other factors have also contributed to declining wild salmon populations. In Wester Ross these include sea lice infestation and genetic introgression associated with salmon farming; warming water temperatures at sea, more extremes of flood, erosion and drought associated with climate change; and changes in marine ecosystems, perhaps including increasing populations of mammalian predators in coastal waters (seals and dolphins). Most of these factors are likely to be more harmful to salmon populations where salmon smolts upon arrival in the sea are already malnourished, so less able to cope with other challenges.

The pilot project reported here follows many years of research elsewhere to address the issue of declining adult salmon numbers, including much experimental work in the neighbouring River Conon catchment (Bernthal et al 2022). Our project aimed to learn more about the practicalities for fisheries management purposes of reversing the downward spiral of nutrient depletion and declining salmon numbers, through placement of 'salmon carcass analogue pellets' into riverbeds to support juvenile salmon growth.

This report presents a summary of some of our findings with a focus on further recommendations to address the nutrient deficit in salmon spawning streams in Wester Ross and thereby help to provide vital support for wild salmon populations and associated biota.

Figure 1.1 shows some of the trophic pathways via which adult salmon can provide nourishment for juvenile salmon. Our project focussed on learning about how to provide support for in-stream 'autochthonous' biological production (green ticks).

Figure 1.1. 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). Our initial pilot project reported here focusses on these pathways. 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).



1.2 Aims and objectives

The main aim of the project was to test methods developed elsewhere for addressing the salmon stream nutrient deficiency (oligotrophication) issue within some of the salmon streams of Wester Ross.

Objectives for this project were as follows:

1. to investigate the use of an alternative source of marine nutrients as an 'analogue' for the missing salmon carcasses and salmon eggs,
2. to explore methods of application,
3. to record outcomes for aquatic invertebrates and juvenile fish.

The application methods piloted were based on those described by McLennan et al (2022), Bernthal et al (2022) and Bernthal (2024) who conducted their experimental research in streams within the River Conon system in Easter Ross. Amongst their many findings were that juvenile salmon (both fry and parr) grew faster in streams where salmon carcass analogues were applied associated with an increase in the biomass of invertebrate animals. Juvenile salmon were significantly larger at the end of their first summer and after two years in treatment streams than in untreated control streams.

Figure 1.2 shows the concept for the project. Formerly there were many decomposing salmon carcasses and surplus fish eggs (salmon and trout) in spawning streams from late autumn, associated with larger runs of salmon and sea trout (and for sea trout, larger fish) than in more recent years (especially since around 1990). There are still stories within living memory of spawning streams being 'full of adult fish' in October and November, e.g. River Ewe headwaters and River Gruinard headwaters in the late 1960s and early 1970s [e.g. Eric Ross, pers. comm.; Eoghain McLean, pers. comm.].

A reduction in available marine-derived nutrients and food to support juvenile salmon production means that some streams can be populated by high numbers of very small slow-growing juvenile salmon. In extreme cases (e.g. in parts of the big Gruinard River and Little Gruinard River), it is possible that much of the energy and nutrition available may simply be required to enable juvenile salmon to maintain themselves without growing (Cunningham, 2024b) resulting in rates of survival of salmon fry to become smolts, and lower survival of smolts because they are too small and poorly nourished when they go to sea (c. Armstrong et al, 2018).

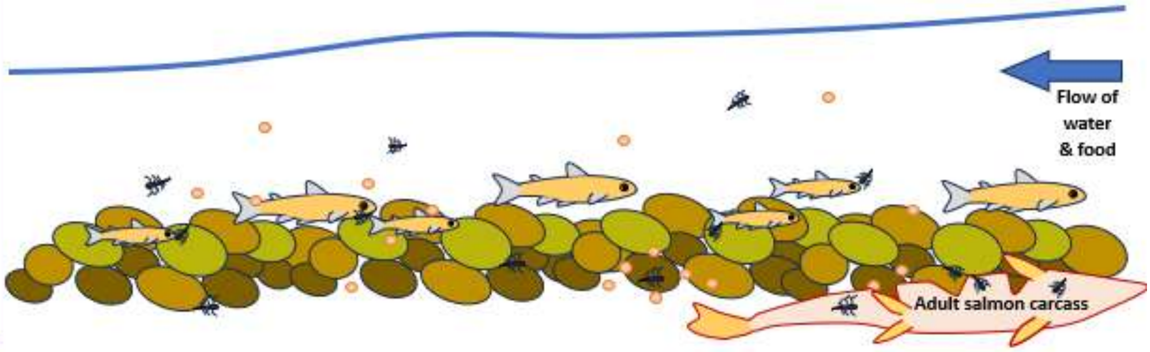
All the study streams in this Wester Ross project supported natural populations of wild spawned salmon and trout (in contrast to Bernthal, 2024 where study streams were stocked). Locations of study streams and project sites are shown in Figure 3a-d.

The project adopted a before - after, control - treatment approach. In order to compare and contrast findings, two treatment sites were chosen where treatment was applied, with one or more 'control' sites in the same stream nearby.

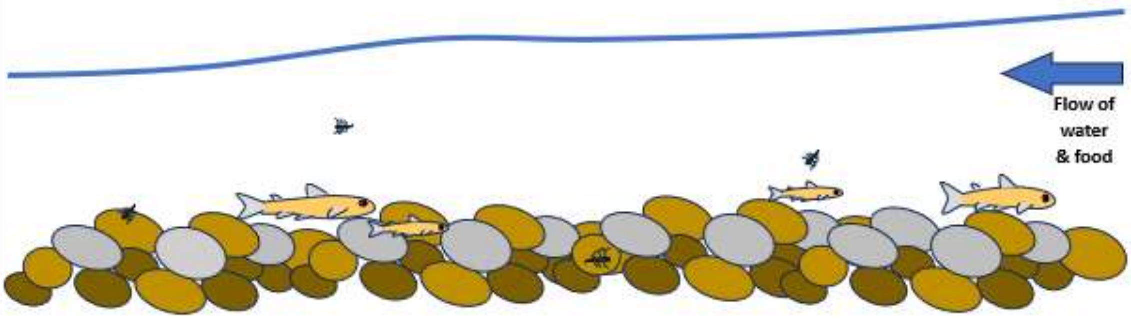
Figure 1.2. Initial project concept

Diagram to illustrate project concept

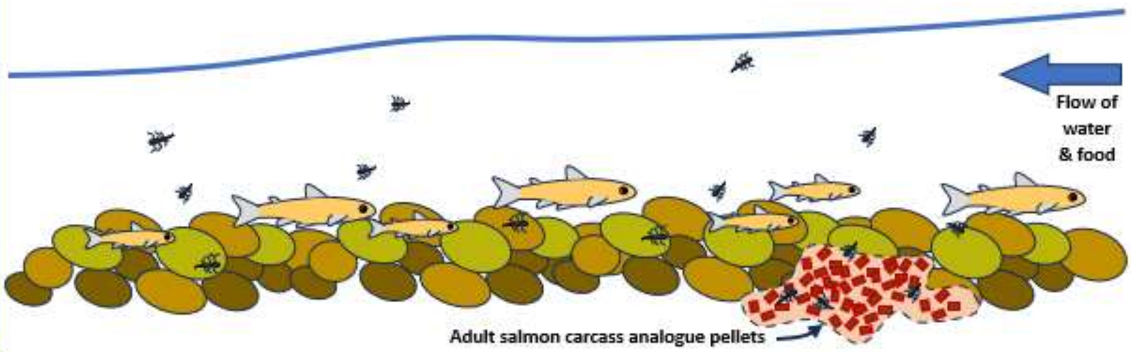
Past: stream ecosystem nourished each autumn and winter with marine derived nutrients from decomposing adult salmon carcasses and surplus salmon eggs which provide direct and indirect sources of food (including insect larvae) for juvenile salmon. Juvenile salmon grow longer and fatter (higher condition factor); smolts are large and well nourished.



Present: nutrition for juvenile salmon greatly reduced due to big reductions in decomposing adult salmon carcasses and surplus salmon eggs available. So juvenile salmon have less food, and there are times in the year when there is inadequate food to sustain growth; there are many malnourished, thin salmon fry and thin parr; fewer well-fed smolts to migrate to sea.



Proposed: salmon carcass analogue pellets [SCAP] are applied to provide supplementary nutrition for the stream ecosystem, resulting in more food for juvenile salmon; restoring production and quality (body condition) of salmon smolts, so more adult salmon return to the river in subsequent years.



2. Locations and methods

2.1 Locations

Three project streams were chosen: the Coulin River, the Docherty Burn (both in the headwaters of the River Ewe), and the Torridon River. Figure 2.1a-d shows the locations of treatment and control sites.

Figure 2.1a. Location of the three project study streams. Thank you to OpenStreetMap for base maps.

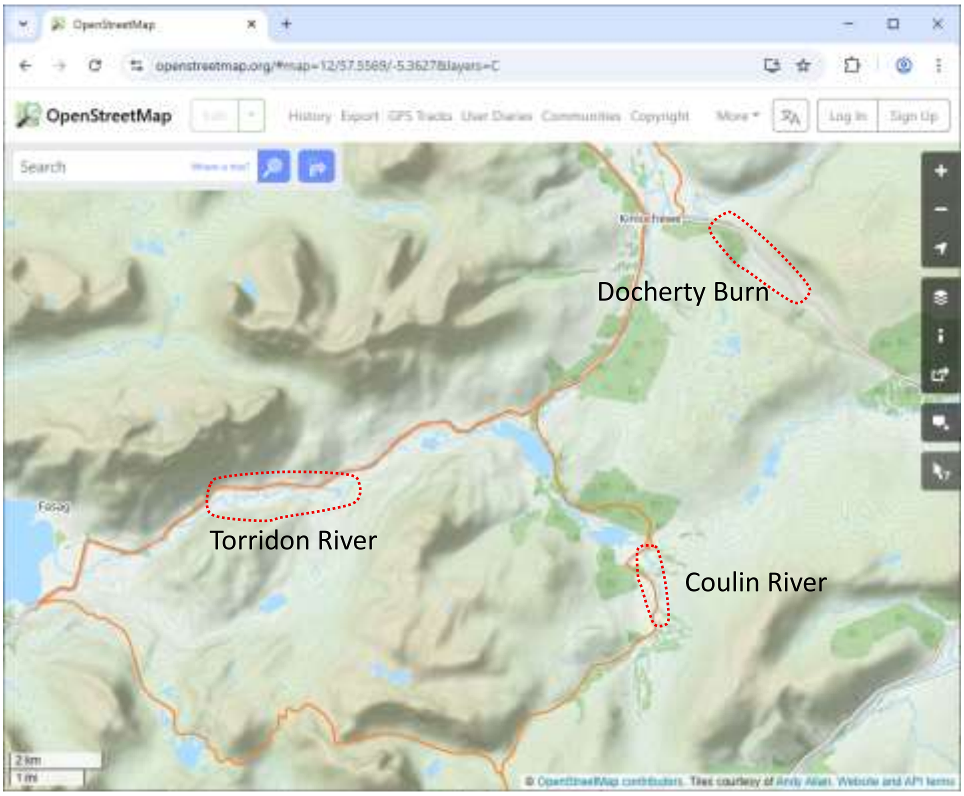


Figure 2.1b. Location of treatment sites (red) and a control site (yellow) in the Torridon River.

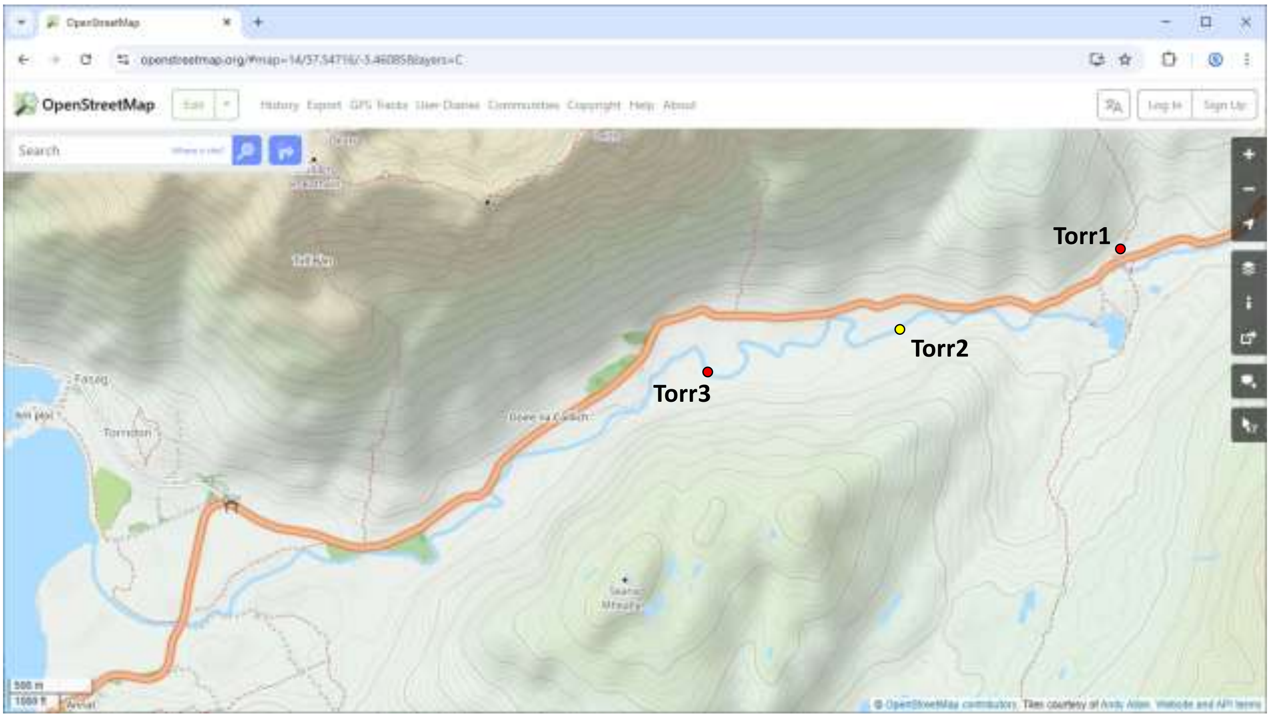


Figure 2.1c. Location of treatment sites (red) and a control site (yellow) in the Coulin River. Thank you to OpenStreetMap for base map.

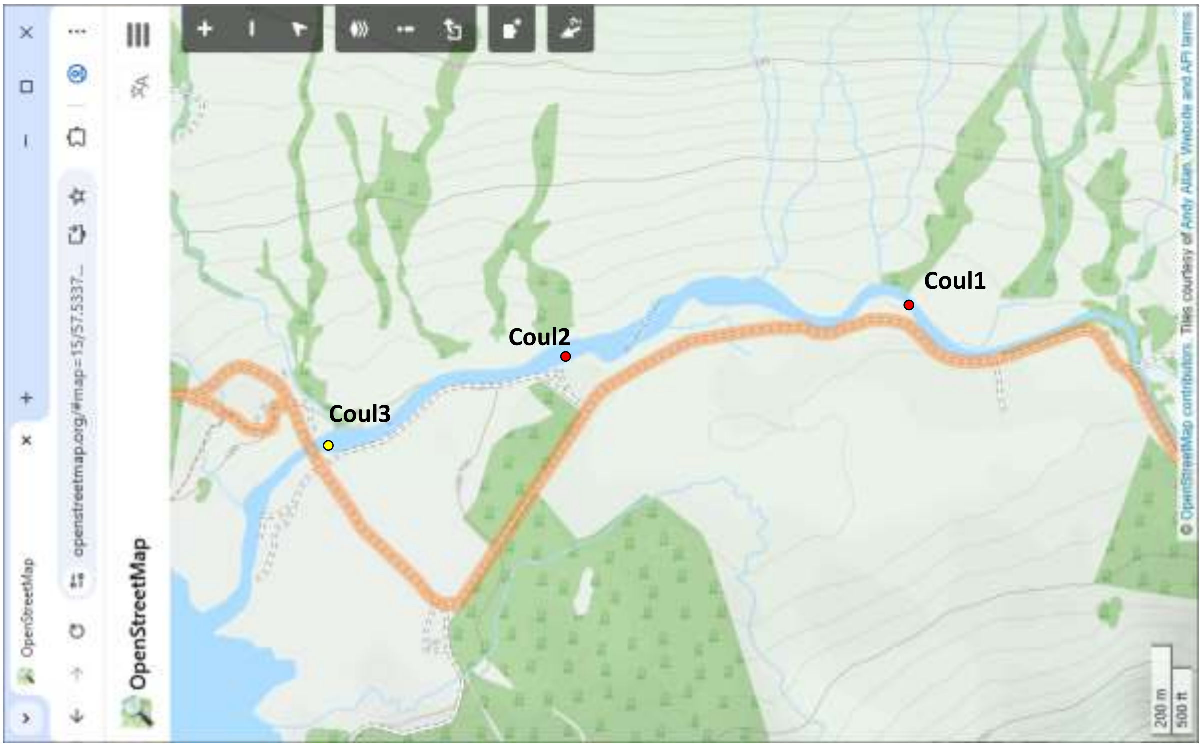
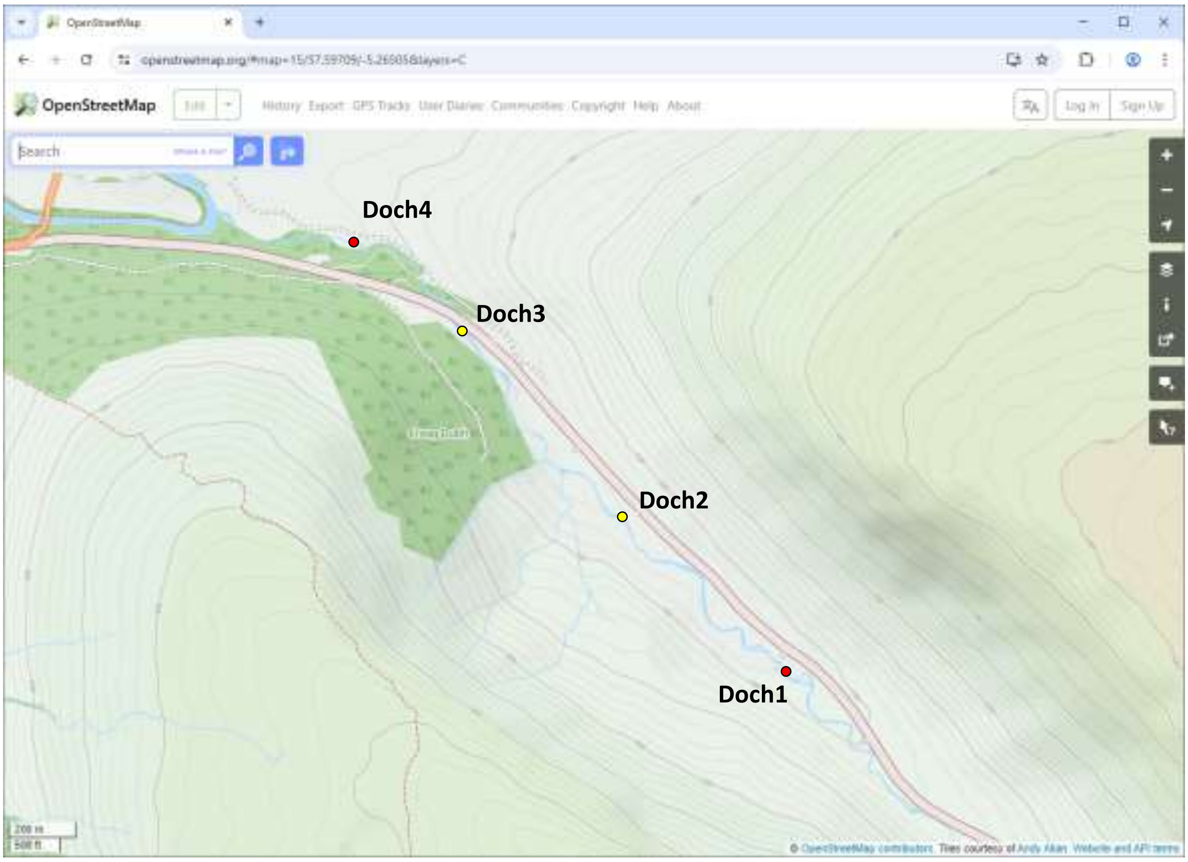


Figure 2.1d. Location of treatment sites (red) and a control sites (yellow) in the Docherty Burn. Thank you to OpenStreetMap for base map.



2.2 Brief description of study streams and why they were chosen

2.2.1 Torridon River

The headwaters of the Torridon river drain the northeastern slopes of Liathach and the southeastern slopes of Beinn Eighe, two spectacular, rocky mountains carved out of hard Torridonian sandstone and Cambrian quartzite, both rocks with insoluble minerals which yield very little nutrient (e.g. phosphorus). A second major tributary drains the western slopes of Sgurr Dubh and Sgur an Lochan Uaine composed of similar unyielding underlying geology. These two streams flow into Lochan Iasgair ('the fishing loch') at the top of the mainstem Torridon River which flows through a classic 'U' shaped valley carved from ancient rocks to enter Loch Torridon about 8km further downstream. The valley floor has thick peat deposits; the valley sides would once have been wooded with mostly birch and Scots pine but have been managed for many years as grazing for livestock and red deer, with periodic burning. Organic soils have become increasingly worn away and infertile. Conductivity of water in the Torridon River has typically been measured at between 20µS and 40µS.

The juvenile salmon population in the Torridon River has been closely monitored by Wester Ross Fisheries Trust [WRFT]. In recent years, juvenile salmon distribution has been variable, with still good numbers of mostly very small salmon fry and slow growing parr found in the 'flats' above Glen Cottage; but very low densities of juvenile salmon in some of the downstream sections. The absence or very low numbers of juvenile salmon in some of the lower sections of river may relate to low numbers of adult salmon returning to the river from the sea associated with low rates of marine survival of salmon smolts.

A lack of nutrition may be contributing to the low densities of salmon parr in the lower river; malnourished salmon fry and parr are more likely to be swept away in big winter spates than well fed ones. The upper and middle parts of the river especially are thought likely benefit from restoration of nutrition and woodlands within the catchment area.

Several near-river woodland enclosures have been set up; the wee trees are doing quite well! A much larger-scale catchment woodland restoration project, the Glen Torridon Partnership initiative, which would do much to help wild salmon well as other wildlife in the Torridon River catchment area, may be possible within the next few years.

Volunteer tree planters by the Torridon River on 16th October 2023

2.2.2 Coulin River

This is an important spawning stream for spring spawning salmon within the River Ewe – Loch Maree system. Sea trout and brown trout from nearby lochs including Loch Maree also spawn in the Coulin River and tributary streams. There are more trees in the catchment area of the Coulin River than in the catchment area of the Torridon River, including some old Caledonian pines.

However, much of the Coulin River lacks riparian tree cover and drains a catchment area which overlies hard ancient sedimentary and metamorphic rocks, so is oligotrophic and nutrient poor with conductivity typically between 30µS and 40µS. Riverbanks are grazed by cattle and deer. Because the river runs in a south-north direction and is wide and shallow in many places, water temperatures in early July can sometimes exceed 20C; too warm for juvenile salmon.

WRFT has monitored the river over 30 years and consistently recorded reasonable numbers of juvenile salmon. However, juvenile salmon grow very slowly especially near the bottom of the river; and production of smolts is thought to be low for the size of the wetted area. There is potential to elevate juvenile salmon production by restoring in-stream nutrition in combination with riparian habitat regeneration; hence reasons for the inclusion of this stream within this project.

Lower Coulin River, 25 August 2021

Coulin River 22 October 2024

2.2.3 Docherty Burn

The Docherty burn, which flows into the Kinlochewe River (River Ewe system) is smaller than the Torridon River and Coulin River. It is also less oligotrophic, with higher conductivity [typically between 50µS and 100µS perhaps associated with road salt run off as well as more basic underlying geology?] and with more vegetation including trees along riverbanks. For around 12 years, much of the burn was enclosed within a deer fence put up to keep the deer off the new road (A832) which was constructed in around 2005-06. The stream supports variable, but sometime higher densities of salmon fry and parr and juvenile trout than the Coulin River and the Torridon River. WRFT has electro-fished sites in this stream every two or three years since the 1990s.

Lower Docherty Burn, Site Doch4, 14 Nov. 2024

Docherty Burn, Site Doch1 April 2025

Docherty Burn, 23 Aug 2005

Docherty Burn, August 2007

The upstream catchment areas above the treatment sites in each stream are approximately as follows:

Torridon River 10km^2 (top site); 23km^2 (bottom site)

Coulin River 17km^2

Docherty Burn 4km^2

Further information about juvenile salmon in each of the project streams can be found in:

Status of Juvenile Salmon in Wester Ross, Juvenile fish Survey report for 2023

https://www.wrft.org.uk/files/Status%20of%20Wild%20Salmon%20in%20Wester%20Ross%20Report%20for%202021v1Feb22.pdf

About sustaining wild salmon populations in Wester Ross: are smolt production and quality declining due to lack of food (see page 30 for bit about the Coulin River)?

https://www.wrft.org.uk/files/About%20juvenile%20wild%20salmon%20nutrition%20and%20production%20in%20Wester%20Ross%20Feb24v2.pdf

2.3 Data collection

2.3.1 Aquatic invertebrates

Baseline surveys of aquatic invertebrates were carried out in 2024 on 28th November (Torridon river sites), 4th December (Coulin river sites) and on 6th December (Docherty Burn sites).

Two 3-minute kick samples (=6 minutes of kick sampling) were taken at all 10 sites for the baseline survey. Post-treatment, in April 2025, two 3-minute kick samples were taken at each of the four sites in the Docherty Burn.

The methodology for sorting taxa was similar to that of the basic Riverfly Partnership Monitoring Initiative scheme, considered to be adequate to be able to detect any major differences and changes in invertebrate populations, and one familiar to some of the participants via the Buglife Guardians of Our Rivers scheme.

Sorting kick-samples from the Docherty Burn by Beinn Eighe NNR visitor centre on 9th April 2025

Samples were sorted at the Nature Scot Beinn Eighe National Nature Reserve field station at Anancaun in November and December 2024 and by the Beinn Eighe NNR visitor centre in April 2025 to provide members of the public with an opportunity to learn more about the project.

Subsequent kick-sampling visits were made to sites in each of the burns in May 2025, with sample sorts and counts carried out on the riverbank.

At each site and on each occasion, one of the kisk-samples was taken by Peter Cunningham, the other by Nic Butler. The samples were sorted separately to be able to learn about variation in sample composition at the same site that might have been associated with sampler bias and small-scale variation (i.e. within 10m) in the densities and distribution of invertebrates at each of the survey sites.

Animals of different sizes were recorded together; for example, very small early-stage Heptageniid (flat-headed) mayfly nymphs (of around 5mm in length) were counted together with larger nymphs of 10mm or more, following the Riverfly protocol. To be able to review differences in the sizes of the animals in each taxa after sorting, photos were taken of the trays of sorted animals from each sample; information that has not been analysed so far though might be of interest in the future.

Sorting kick-samples from the Docherty Burn by Beinn Eighe NNR visitor centre on 9th April 2025

2.3.2 Juvenile fish survey

Baseline surveys of juvenile fish were carried out at all sites in October and November 2024. Subsequently all sites were surveyed in August and September 2025; with addition surveys of the two treatment sites in the Docherty Burn in November 2025.

At each site and on each occasion, a Smith-Root backpack discharging 350-400 volts was used. Surveys were led by WRFT Biologist Peter Cunningham with Nic Butler, both of whom have SFCC electrofishing training qualifications, assisted by Nicky Middleton-Jones.

The survey team of two or three fished for a minimum of eight minutes in a standardised way (typically 10 minutes or more), usually covering a wetted area of $80m^2$ or more. A one-run, semi-quantitative methodology, following Scottish Fisheries Coordination Centre [SFCC] protocol and NEPS Single Run protocol.

After capture, all fish were lightly sedated (in eugenol, c. clove oil) and measured to the nearest mm (fork length) and returned to the water following recovery.

Data collected was used to produce Catch Per Unit Effort [CPUE] data and minimum density estimates for juvenile salmon and trout, in addition to size at age comparisons (see part 3). Data also contributed to the survey of juvenile salmon for 2025 to inform the Wester Ross Area Salmon Fisheries Board (WRASFB).

Nicky Middleton-Jones and Nic Butler, surveying juvenile fish at Torr2 on 2nd August 2025

2.3 Treatment application

The salmon carcass analogue (to mimic decomposing salmon carcasses) was a high-fishmeal content organic farm salmon starter feed, kindly provided by Inverkerry Hatchery (Hendrix-Genetics).

The quantities of the 'analogue' used were based on those used by McLennan et al, 2019 and Bernthal, 2024 (amounts of treatment per unit area of stream bed); and also some consideration of former potential densities of dead salmon that would have been present along spawning streams historically; and of the need to adopt a precautionary approach.

Following baseline surveys of juvenile fish and invertebrates at project streams in late October and early November 2024, measured quantities of high-fishmeal content organic farm salmon feed pellets were put into hessian bags and buried within two treatment sites in each of the three project streams: the Torridon River, the Coulin River and the Docherty Burn in early December 2024.

At each site, approximately 10kg of feed pellets (nutritionally equivalent to about 30kg of marine fish, or about 10 salmon carcasses) was divided into five hessian bags (approx. 2kg of feed pellets per bag) and the bags were buried in the streambed within a 20m to 30m section of stream (Figure 2.2). Great care was taken to avoid areas where the substrate was smaller than cobble-sized substrate, i.e. sites where salmon and trout eggs may have been buried (redds).

Figure 2.2. The EWOS Organic farm salmon feed was poured into buckets then divided into hessian bags and buried in the stream bed. Docherty Burn site Doch1, December 2024

Box 2.1. How much nutrient was added to each of the study streams?

In total, each stream received two 20kg bags of farm salmon feed with a P content of 1.8%, split between two treatment sites, with first application in December 2024 then a second application in February 2025.

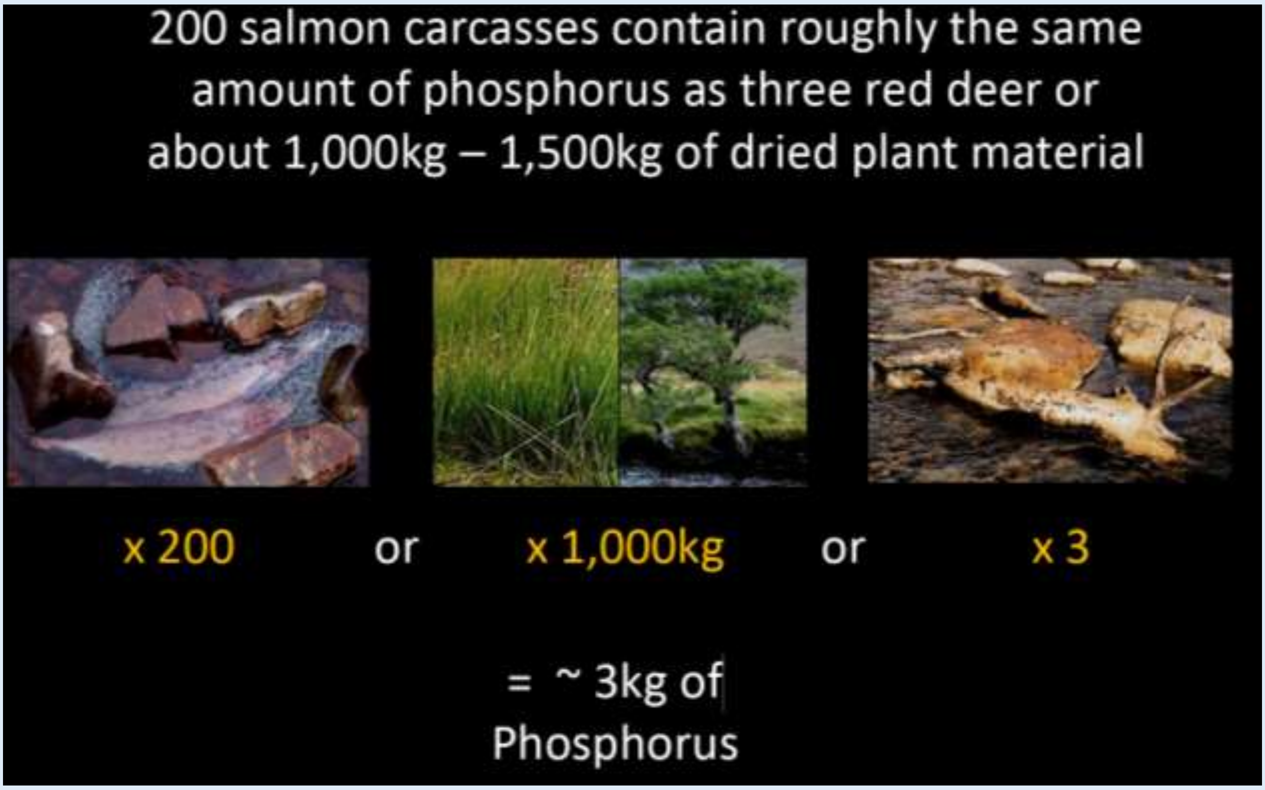
A 20kg bag of salmon feed pellets contains about 360g of phosphorus [P].

To put the amounts of nutrients added to each treatment site into context:

One salmon carcass, depending upon size, contains about 15g to 20g of Phosphorus [P]. Phosphorus is the usually the primary limiting nutrient for instream productivity.

A 20kg bag of farm salmon feed pellets (360g of P] is therefore roughly equivalent to about 20 salmon carcasses in terms of its P content. In comparison, a dead red deer is roughly equivalent to 60 salmon carcasses or 60kg of farm salmon feed pellets. Note that much of the phosphorus in a dead deer is within its bones and antlers which take a long time to break down and dissolve to release P and Ca into the water, unless ground (or chewed) to bone meal.

See also Cunningham 2017, 'Feed the Land'; slide 142 from this presentation is reproduced below. (Note that the dead red deer in this picture, photographed as found in the water, was found in the Docherty Burn in around 2002!)



By the end January 2025, following a very large spate flow in mid-December 2024, many of the hessian bags could not be found. After much searching, it was concluded that most of them had been washed away.

Subsequently a second treatment of farm salmon feed pellets was applied to each of the treatment sites in February 2025, this time burying salmon feed pellets directly within the sediment bars by the sides of the stream, with the intention of allowing the nutrients to leach out into the water within respective stream sections more slowly.

At each site, five holes were excavated in a sediment side bar exposed above the water level at the time of survey, and approximately 2kg of farm salmon feed poured into each hole, before the holes were back-filled with the same sediment that had come out of them and so 10kg of farm salmon feed per site.

In summary, at each site, a total of 20kg of farm salmon feed pellets was applied, half in December (in hessian bags) and the other half in February (buried directly into streamside sediment), equivalent to about 20 wild salmon carcasses.

Burying farm salmon feed directly within the gravel bars at the side of the stream channel 27 Feb 2025

2.4 Data compilation and analyses

2.4.1 Kick sample analyses

Counts of invertebrate taxa from kick sampling were recorded on an MS Excel spreadsheet. Comparisons were made between sites, focussing on differences in the total numbers of animals recorded per minute of kick sampling, and differences in numbers of individuals of particular taxa (e.g. mayfly nymphs).

This data can be used to obtain a score for each sample using the Riverfly methodology.

For further discussion, please see under results in Section 3.

2.4.1 Juvenile fish survey analyses

Our main aims were to find out, where possible

(1) whether juvenile salmon grew faster in response to treatment application

Juvenile fish, measured to the nearest mm in the field, were recorded and then grouped into 5mm length categories on a MS Excel spreadsheet. Counts of the number of fish in each 5mm length size-category per minute fishing were made, and results presented graphically to see whether there were differences worthy of more detailed statistical analyses (see part 3).

(2) whether the overall estimated biomass of juvenile salmon at each site increased in response to treatment application

Estimates of individual fish mass were made as follows for both juvenile salmon and trout, using the formula

where estimated fish mass (g) = $\text{length}^3 / 100$

Note that this formula does not account for variation in the condition of juvenile fish (whether they are thin or fat); however, it was beyond the scope of this pilot project to weigh individual fish in the field.

For further discussion, please see under results in Section 3.

3. Results and related discussion

3.1 Were the nutrient (salmon carcass analogue) application methods suitable for Wester Ross rivers?

A. Burying hessian bags containing farm salmon feed pellets within the streambed

Only one month after initial treatment application, none of the bags could be found at any of the sites in the Coulin River and Torridon River when searched for in January 2025. However, in the Docherty Burn, two bags were located, one at Doch4 in February 2025 and one at Doch1 in April 2025. These bags were buried more deeply under newly deposited sediment (hence our difficulty in locating them in February), and some of the feed was still within the bags having not broken down to release nutrients as intended.

These observations can be partly attributed to an unusually large spate which caused much movement of streambed stones ('bedload transportation') in December 2024 following heavy rainfall, less than two weeks after application.

Our conclusion was that the method of nutrient application by burying hessian bags with feed pellets in the streambed, as used by McLennan et al 2019 and Bernthal 2024 is not appropriate for sites where the streambed is unstable and where there can be much movement of streambed sediment during big spate flows (now more frequent than in previous years) resulting in significant washout.

Previous work by Wester Ross Fisheries Trust highlighted the problem of 'redd washout' - frequent movement of stones along the streambed in many of the larger unstable streams of Wester Ross disturbing salmon eggs.

Nic Butler with remains of a hessian bag found at Doch1 on 9th April 2025 (left) and one found at Doch4 on 27th Feb 2025 (middle and right) still containing decomposing farm salmon feed pellets.

B. Burying feed pellets directly into sediment bars at sides of river

Our follow-up treatment method (i.e. burying the feed directly within the streamside sediment below the water table), in February 2025, was partly more successful. In May 2025, areas of green algae - seen for a few metres downstream from where some of the feed was buried at Docherty Burn top site (Doch1) - demonstrated slow release of nutrients into the stream nearby. However, at Coul2 much of the SCAP had still not been fully incorporated into the stream ecosystem by May 2025 by which time the water level had dropped leaving the decomposing buried SCAP [feed pellets] stranded several metres away from the edge of the stream. So, for this site the release of nutrients may have been too slow to contribute greatly to instream productivity. The rotting farm salmon feed has a strong smell (as do rotting salmon carcasses . . .)!

We found that it was not possible to easily control the release of nutrients from an application of slow-sinking farm salmon feed buried in the streambed or streamside gravel bars, perhaps especially if the applications are made in the winter when very high spate flows are likely.

Furthermore, application methods which require burial of bags containing feed pellets disturb the imbricated streambed or stream-side gravel bars, destabilising the habitat. High spate flows are likely to wash out hessian bags buried in the streambed. If the farm salmon feed is instead buried in the sediment bars beside the main flow, some of it may remain locked within the sediment especially when the river level and water table drop during the spring; this is not ideal either.

Coul2 19th May 2025. The area where farm salmon feed had been buried in river gravels next to the stream in February 2025 was now several metres from the edge of the stream. Much decomposing farm salmon feed was still within the streamside sediment here.

In conclusion, neither method of putting nutrient SCAP into the river during the winter (to mimic natural salmon carcass decomposition) worked well enough to be recommended as a management action to enable controlled addition of nutrient into a salmon nursery stream in Wester Ross.

At most sites, much of the farm salmon feed was either washed out and washed away without trace during the winter (prior to being able to contribute much additional nutrient to nearby biota) or the feed bags or farm salmon feed were trapped for too long within the sediment, minimising the release of additional nourishment to boost production of aquatic biota.

3.2 Growth of algae on the streambed around where nutrient was added

At site Doch1, (the site with the smallest upstream catchment area), green filamentous algae (periphyton) could be seen in April and May growing in the side of the main channel just downstream from where the SCAP [fish farm feed pellets] had been buried, apparently demonstrating an effect of the added nutrient upon instream biota.

The area with the greener streambed (more periphyton on the stones) extended downstream for over five metres from where the SCAP had been buried. For this site, we remained optimistic that a response from animals and fish would be detected.

No apparent differences were noted in the amount of green periphyton on streambed stones downstream from the other treatment sites.

Green periphyton and filamentous algae immediately downstream from where salmon carcass analogue pellets had been buried by the side of the Docherty Burn at site Doch1.

Doch1 9th April 2025 (the foot in picture on the left is close to where people are standing in the picture on the right!)

Doch1 19th May2025

3.3 Invertebrates

Follow-up kick samples were taken at sites in the Docherty Burn on 9th April 2025 where other observations (described above) indicated that a response from aquatic animals might be most likely.

Table 3.1 presents a summary of the results of kick sampling for sites in the Docherty Burn for before (in November 2024) and after (in April 2025) treatment application. Note that in the Docherty Burn, SCAP treatments (farm salmon pellets) were applied only to sites Doch1 and Doch4 (shown with yellow shading in the table); no treatment was applied at sites Doch2 and Doch3.

Table 3.1. Summary of the results of kick sampling for sites in the Docherty Burn for before and after SCAP treatment application. The treated sites are highlighted in yellow shading. Note that treatments were only applied to sites Doch1 and Doch4.

	Before treatment (November & December 2024)					After treatment (April 2025)			
	Doch1_Bef	Doch2_Bef	Doch3_Bef	Doch4_Bef		Doch1_Aft	Doch2_Aft	Doch3_Aft	Doch4_Aft
Cased caddis	0	4	5	13		2	2	2	11
Caseless caddis	33	35	18	29		14	13	7	9
Baetid mayflies	54	32	46	24		85	19	17	17
Seratella	0	0	0	0		0	0	0	0
Heptagenids	57	52	104	63		69	28	32	79
Other mayflies	0	0	0	0		0	0	0	0
Leuctra stoneflies	9	13	5	18		12	12	8	6
Other stoneflies	24	27	22	27		19	24	10	22
Mites	0	0	0	0		3	2	0	1
Worms	5	7	7	6		1	5	1	0
Beetle larvae	1	0	1	2		11	15	1	7
Blackfly larvae	12	5	0	1		18	1	4	3
Beetle adults	0	0	0	0		2	5	0	2
Tipulid larvae	1	2	0	4		1	1	2	3
Dragonfly larvae	0	0	0	0		0	2	0	0
Snail	0	0	0	0		0	1	0	0
Leach	0	0	0	0		0	0	0	1
Salmon fry	0	0	0	0		0	0	0	1
Salmon egg	1	0	0	0		0	0	0	0
Chironomid	3	12	0	0		0	0	0	0
Totals	**200**	**189**	**208**	**187**		**237**	**130**	**84**	**162**

Before the treatment, between 187 and 200 animals were recorded at all four sites, a fairly uniform distribution. Caseless caddis fly larval, Baetid mayfly nymphs and Heptageniid (flat-headed) mayfly nymphs were the most numerous taxa at all sites, followed by 'other stoneflies'.

Following treatment, on 9th April 2025, the highest numbers of animals were recorded at Doch1 followed by Doch4, both treatment sites. Heptageniid mayflies (flat-headed mayflies) and Baetid mayfly larvae increased the most compared to the control sites where no treatment had been applied. The number of baetid mayfly nymphs was approximately 4x higher at site Doch1 than at the other three sites in the Docherty Burn.

These results are consistent with the hypothesis that added nutrients provide more food for the aquatic invertebrates which juvenile salmon feed upon, particularly mayfly nymphs. This was despite our limited success in controlling the release of nutrients at treatment sites and limited follow up kick-sampling.

McLennan et al (2019) found that macroinvertebrate biomass and abundance were five times higher in the high parental nutrient streams, even 1 year after the carcass analogue addition, and led to faster growth of juvenile salmon over the next 2 years (but with no change in population density).

3.4 Juvenile fish surveys

Juvenile salmon were recorded at all sites before and after treatment. However, there were also juvenile trout at some (but not all) sites, making interpretation of outcomes more complex. And in contrast to studies by McLennan et al (2019) and Bernthal (2024), the numbers of juvenile fish at each site at the beginning of the project were variable rather than precisely stocked into each section as eyed eggs (as in previous experimental studies).

Our assessment of outcomes focussed on comparison of (1) size at age of juvenile salmon and trout; (2) estimates of biomass of fish per minute.

Docherty Burn

Figure 3.1 and Figure 3.2 show the sizes at age for juvenile salmon and trout at the two Docherty Burn treatment sites (Doch1 and Doch4) in 2024 (pre-treatment) and 2025 (post treatment). The graphs have been grouped together for ease of comparison.

Figure 3.1a. Size at age of juvenile salmon at Doch1 in 2024 and 2025, expressed as numbers of fish recorded per minute of electrofishing. Columns in red are for salmon fry (young of the year, age 0+); columns in green for age 1+ year old fish; and in blue for age 2+ year old fish. Note that the river was high on 5th Aug 2025 following Storm Floris . . .

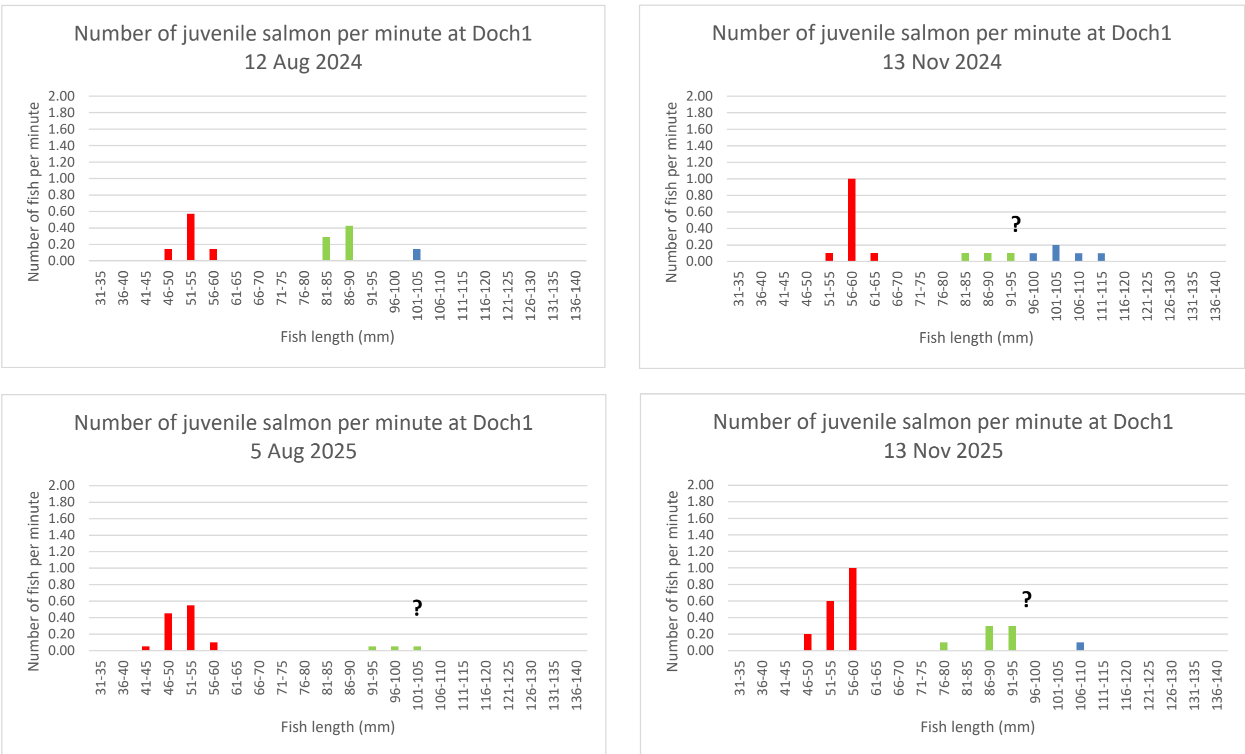


Figure 3.1b. Size at age of juvenile trout at Doch1 in 2024 and 2025, expressed as numbers of fish recorded per minute of electrofishing. Note that the river was high on 5th Aug 2025 following Storm Floris . . .

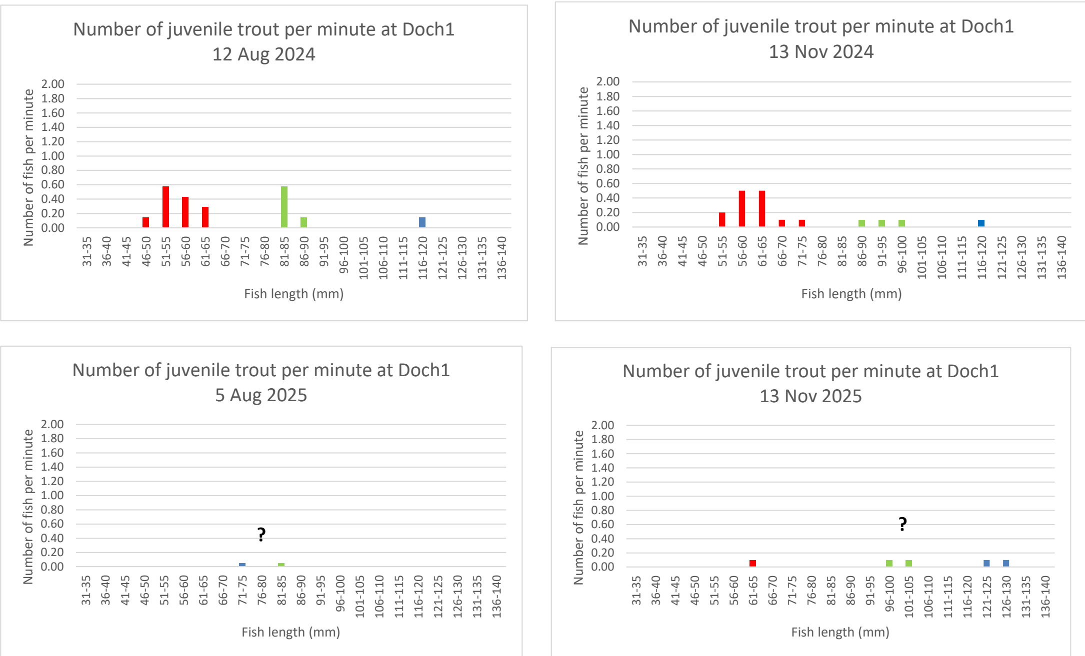
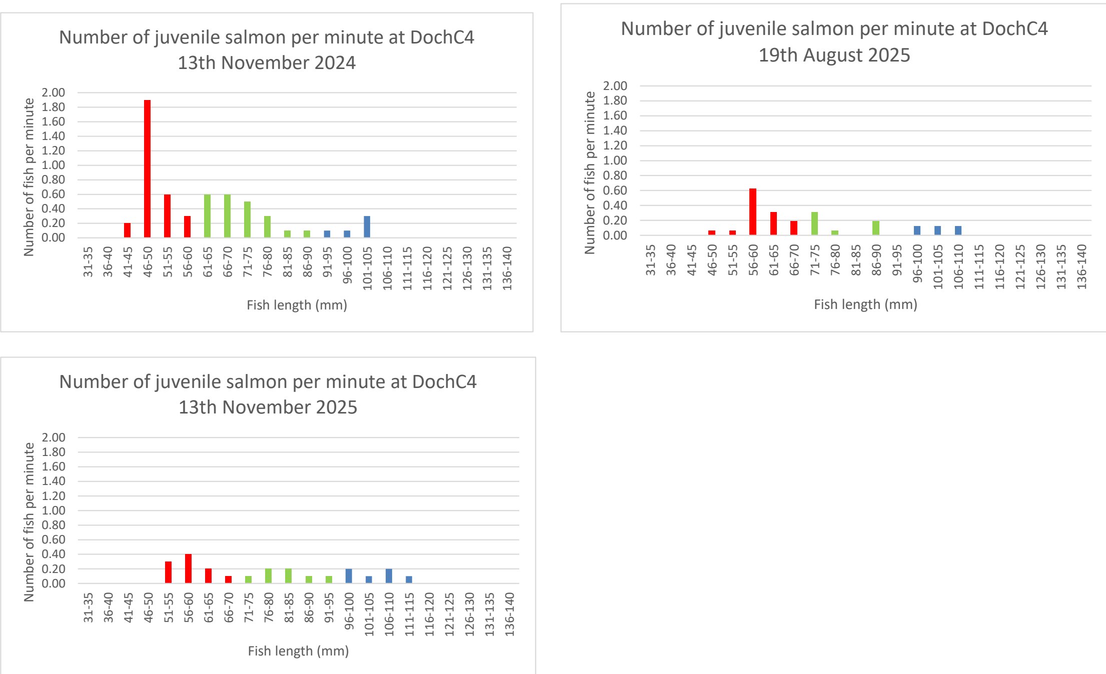


Figure 3.2 Size at age of juvenile trout at Doch4 in 2024 and 2025, expressed as numbers of fish recorded per minute of electrofishing. Note that the river was high on 5th Aug 2025 following Storm Floris . . .



The most obvious difference between the two years is that at Doch1 fewer trout were recorded in 2025 post treatment than in 2024, a finding that is thought to be unrelated to our trial!

There was no obvious difference in the average size of the salmon fry between the two years at Doch1. However, at Doch4, the median size for salmon fry (age 0+) and salmon parr (age 1+) was around 10mm longer in November 2025 than in November 2024.

The survey on 5th August 2025 was two days after an unseasonal and unexpected summer spate (Storm Floris) which may have washed some of the fish away or moved fish into the area from further upstream. There was an even bigger spate flow on 3rd – 4th October 2025 (Storm Amy) further obscuring outcomes associated with added nutrition.

However, at Doch4, we found that juvenile salmon were larger for their age on 13th November 2025 (following treatment) than on 13th November 2024 - but there were fewer of them; so perhaps the smaller ones had simply been washed away by Storm Amy when the river channel here shifted with much bedload sediment movement and realignment of the channel? Or perhaps they had grown faster because there were fewer of them in 2025 than in 2024 following the big spates in December of that year?

Estimates of biomass of fish per minute

Table 3.2 contrasts the biomass of fish recorded at the two treatment sites before (2024) and after (2025) treatment at the two treatment sites in the Docherty burn.

Table 3.2 biomass of fish recorded at the two treatment sites before (2024) and after (2025) treatment at the two treatment sites in the Docherty burn. (left) Doch1, top site; (right) Doch4, bottom site.

Doch1. Top site

Mass of fish per minute where mass (g) = length^3 / 100					
		12-Aug-24	13-Nov-24	05-Aug-25	13-Nov-25
Sal mass		7.97	10.97	3.25	10.01
Trt mass		9.86	7.87	0.52	6.58
Total mass		**17.83**	**18.83**	**3.76**	**16.59**

Doch4. Bottom site

Mass of fish per minute where mass (g) = length^3 / 100				
		13-Nov-24	19-Aug-25	13-Nov-25
Sal mass		18.23	10.40	13.86
Trt mass		0.00	0.00	14.05
Total mass		**18.23**	**10.40**	**27.90**

At both treatment sites in the Docherty Burn, there was no increase in the biomass of juvenile salmon per minute recorded in November 2024 and November 2025; indeed, at the lower site (Doch4) the overall salmon biomass was higher in 2024 than in 2025 following treatment. That the overall estimated biomass of fish at Doch4 was higher on 13th November 2025 than on 13th November 2024 was due to one large trout of 152mm (estimated mass of 15.05g) that was captured on the latter date; it weighed as much as all the juvenile salmon in the bucket combined!

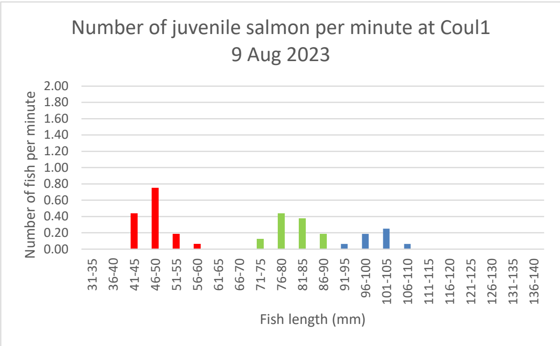
The lack of evidence of any increases in juvenile salmon biomass at the treatment sites in the year following treatment application may have been partly due to fish movement (removal) caused by streambed instability during high spate flows associated with Storm Floris and Storm Amy in August and October 2025 respectively.

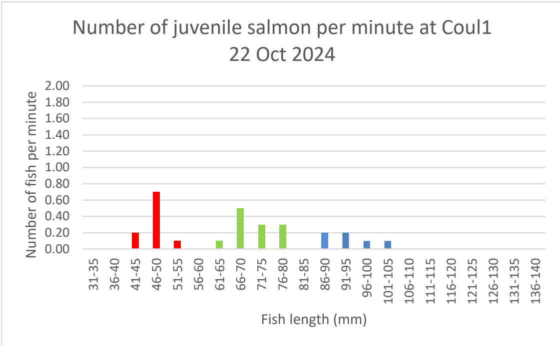
Coulin River

Figure 3.3 shows the sizes at age for juvenile salmon and trout at the three Coulin River sites

Figure 3.3a. Size at age of juvenile salmon at Coul1 in 2023, 2024 and 2025 (following nutrient treatment), expressed as numbers of fish recorded per minute of electrofishing. Note that the river was high on 5th Aug 2025 following Storm Floris.

Pre-treatment





Post-treatment

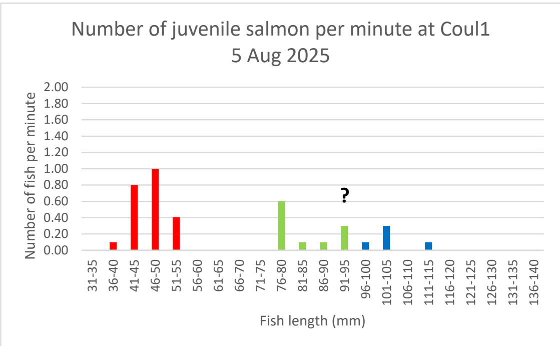
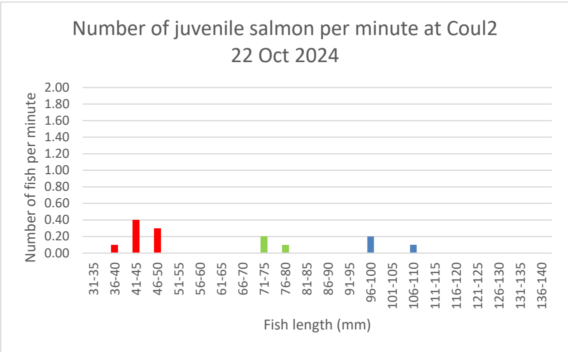
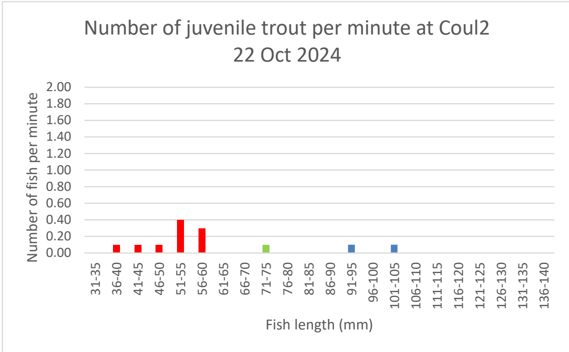


Figure 3.3b Size at age of juvenile salmon and trout at Coul2 in 2024 and 2025 (following nutrient treatment), expressed as numbers of fish recorded per minute of electrofishing. Graphs have been arranged for ease of comparison. Also note that the river was higher than normal on both 22nd October 2024 after recent rainfall and on 5th August 2025 following Storm Floris . . .

Pre-treatment

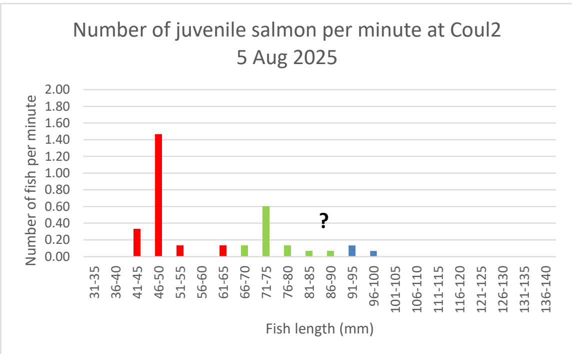


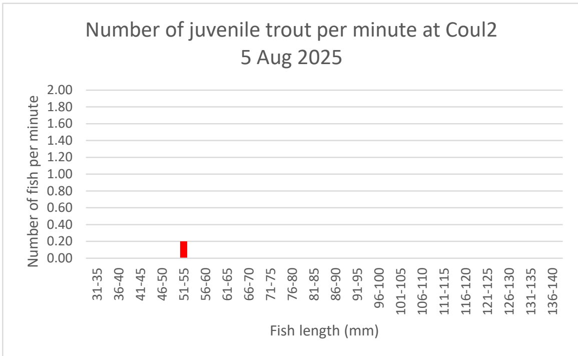


Juvenile salmon, Coul2, 22nd October 2024. Small salmon fry and parr



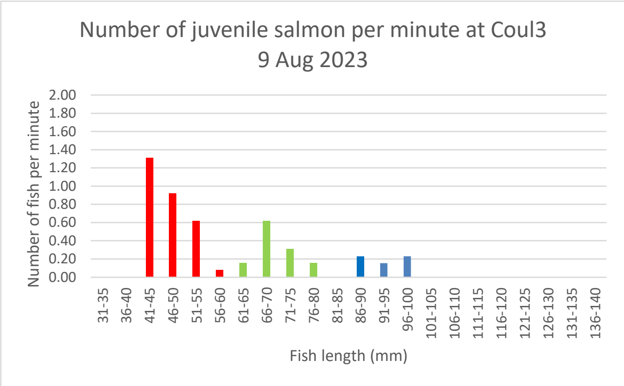
Post-treatment

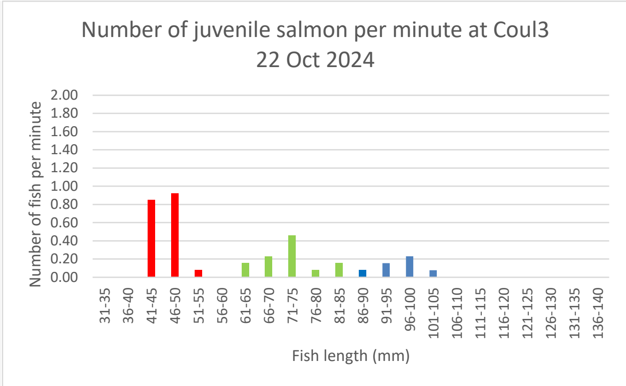


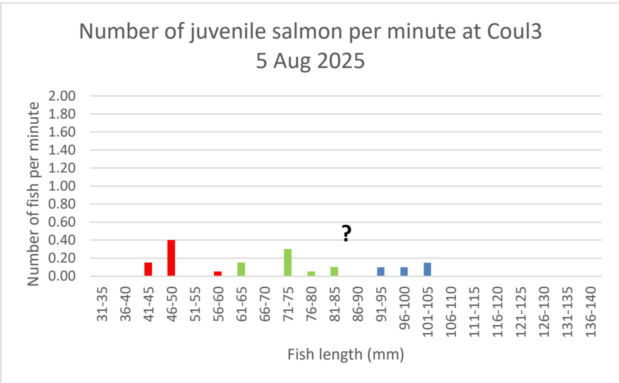


Juvenile salmon, Coul 2, 6th August 2025. The salmon fry and parr were mostly slightly bigger for their age than on 22nd October 2024.


Figure 3.3c Size at age of juvenile salmon and trout at Coul3 in 2023, 2024 and 2025 (following nutrient treatment at two upstream sites), expressed as numbers of fish recorded per minute of electrofishing. Note that the river was high on both 22nd October 2024 after recent rainfall and on 5th August 2025 following Storm Floris . . .







Biomass

Table 3.3 contrasts the biomass of fish recorded at the two treatment sites in the Coulin River before (in 2024) and after (in 2025) treatment.

Table 3.3 biomass of fish recorded at the two treatment sites in the Coulin River before (in 2024) and after (in 2025) treatment. (left) Coul1 and (right) Coul2 and at the control site Coul3, 500m downstream from Coul2 (below)

Coul1

Mass of fish per minute				
where mass (g) = length^3 / 100				
		09-Aug-23	22-Oct-24	05-Aug-25
Sal mass		14.36	11.35	15.69
Trt mass		0.32	2.18	0.00
Total mass		**14.67**	**13.53**	**15.69**

Coul2

Mass of fish per minute				
where mass (g) = length^3 / 100				
			22-Oct-24	05-Aug-25
Sal mass			5.49	9.10
Trt mass			4.03	0.33
Total mass			**9.52**	**9.43**

Coul3

Mass of fish per minute				
where mass (g) = length^3 / 100				
		09-Aug-23	22-Oct-24	05-Aug-25
Sal mass		13.46	11.63	6.89
Trt mass		1.33	0.86	0.00
Total mass		**14.79**	**12.49**	**6.89**

At both treatment sites in the Coulin River, there was no increase in the biomass of juvenile salmon per minute recorded in October 2024 and August 2025.

The lack of evidence of any increases in juvenile salmon biomass at the treatment sites in the year following treatment application may have been partly due to fish movement (removal) caused by streambed instability during high spate flows associated with Storm Doris and Storm Amy in August and October 2025 respectively.

Torridon River

Data from the Torridon river sites has not yet been analysed as for the Coulin River and the Docherty Burn sites. This is because of the larger size of the Torridon River compared to other rivers and that, given the evidence that much of the nutrient had dispersed away from Torridon River sites discussed earlier, any response from invertebrates and fish would likely have been smaller than for other rivers.

Nic Butler with yellow buckets, processing fish by Doch1 on 6th August 2025. The midges were out. . .

4. Discussion

4.1 Nutrient application

The nutrient application method initially followed that of McLennan et al 2019 and Bernthal 2024, with farm salmon feed [SCAP] placed in hessian bags and buried in the streambed under large stones. However, within the first month of our study, it appears that a large spate washed many of the bags away despite large boulders being placed on top of many of them to weight them down with the result that nutrients would have been distributed over a much larger area and at much lower concentration than intended.

Our washout problem was partly associated with the natural imbrication of stones on the undisturbed streambed. Even boulders settle on the streambed only where they are naturally aligned to remain stable in a high flow. So, when a hole is excavated in a stony streambed and then stones are replaced on top of the buried hessian bags they would not have been in the same imbricated positions as before, therefore vulnerable to being moved at very high spate flows. The large spate flows in mid-December 2024 came at just the wrong time, especially for our treatment sites in the Coulin and Torridon Rivers. But perhaps this is a useful lesson for the long term.

Only at sites Doch1 and Doch4 in the Docherty Burn (the smallest of the study streams) were hessian bags found following the big spate in December 2024. However, at one of the sites, in contrast to what appears to have happened in the Coulin and Torridon Rivers, sediment had been buried on top of where the bags were buried (Doch1).

Overall, even the Docherty Burn results are rather inconclusive so far as to whether the nutrient application contributed to increased production of juvenile salmon. Possibly, any increase in production of periphyton associated with increased nutrient availability was offset by washout of nutrients, stones with periphyton and both invertebrate larvae and juvenile fish associated with Storm Floris and Storm Amy. That said, our findings do not contradict those of McLennan et al (2019) nor Bernthal (2024).

In conclusion, the experimental approach of burying farm salmon feed [SCAP] (as an analogue to decomposing salmon carcasses) in the streambed in early winter (to mimic the natural timing of when most salmon carcasses would be present) is probably not a practical method for replacing missing nutrients for fish conservation and fisheries management purposes. Burying farm salmon feed in the streambed is also time consuming, and the release of nutrients uncontrollable and may contribute to destabilisation of an imbricated streambed in some situations.

The alternative of burying farm salmon feed pellets [SCAP] in streamside gravel bars is also difficult to control, and likely to be too laborious relative to the potential benefits to juvenile salmon.

4.2 Response of periphyton and small animals (excluding fish) to stream nutrient addition

The green algae growth around the side of the Docherty Burn at site Doch1 was a visible response to nutrient enrichment.

For other biota, and at other sites, our data and observation are largely inadequate to demonstrate outcomes. Our data hints to an increase in the number of mayfly nymphs (larvae) at the treatment sites compared to the control sites following treatment for sites in the Docherty Burn, as anticipated.

Some of the heptageniid mayfly larvae were very large in April, close to hatch; there were also many very small ones . . . much harder to spot and count. Focusing on numbers of heptageniid larvae above a minimum size may in future help to clarify outcomes. Where the streambed is stony, this species group (flat-headed mayflies) did appear to be a dominant aquatic invertebrate in terms of overall invertebrate biomass. Mayfly nymphs were also captured during e-fishing for juvenile fish and counts were made. This data has not been analysed.

4.3 Juvenile fish response

No clear responses in the growth or overall biomass of juvenile salmon that might be associated with application of nutrients was detected at any of the treatment sites, except perhaps at Coul2. This may have been due to problems associated with application and release of nutrients from the farm salmon feed pellets into the target areas, and also subsequent movements of juvenile salmon; both factors associated with large spate flows including those associated with Storm Floris in early August 2025, and Storm Amy in October 2025 (see Figure 4.1).

Note also that the timings and river conditions at times of juvenile fish surveys on 5th August 2025 and 13th November 2025 were such that our data set was probably inadequate to be able to compare like with like.

Figure 4.1 BBC weather forecast for Monday 4th August 2025 (Storm Floris) and Friday 3rd October 2025 (Storm Amy). Rainfall associated with both storms affected our ability to understand project outcomes.

Sources: https://ichef.bbci.co.uk/images/ic/1024x576/p0ltwxjx.jpg; https://www.bbc.com/weather/articles/cy042drenj8o

Stream bed and stream channel changes in Docherty Burn: Site Doch1

27th February 2025 – before

13 November 2026 – after. Freshly deposited sediment at Doch1 following Storm Amy outlined in yellow.

Changes at Doch4 following Storm Amy 13 November 2025. In addition to much new sediment deposited on top of the gravel bar, a new main channel has formed in the right side of the bottom picture.

Before – February 2025

After – November 2025

McLennan et al (2019) noted that 'macroinvertebrate biomass and abundance were five times higher in the high parental nutrient streams, even 1 year after the carcass [analogue] addition, and led to faster growth of juvenile salmon over the next 2 years (but with no change in population density). This faster growth led to more fish exceeding the size threshold that would trigger emigration to sea at 2 rather than 3 years of age. There was also higher genetic diversity among surviving salmon in high parental nutrient streams; genotyping showed that these effects were not due to immigration but to differential survival.'

Bernthal (2024) put some of the nutrient into the research project streams in early summer, where the possibility of washout associated with a big spate is less. This may be more practical and provide better value in terms of providing nutrition to biota at the right time of year. However, this does not mimic the more natural timing of when most salmon carcasses would be present in spawning streams in late autumn and early winter.

Cunningham et al (2002) explored what happens to spawned salmon in spawning streams during and following spawning. A high proportion of them were pulled out of the water by otters onto the river banks and eaten by otter, fox, pine marten and possibly other animals on the riverbank rather than remaining within the water to decompose. Therefore, in a natural situation (even without bears and wolves), a high proportion of the marine nutrients associated with salmon carcasses would have been initially incorporated into riparian and terrestrial food webs (rather than within freshwater) and slowly released during periods of rainfall into the river through leaching and run-off of animal droppings (e.g. otter spraints).

These and other observations provide reason for changing the method of nutrient application to develop a more practical and effective way of mitigating for declines in the transfer of marine-derived nutrients associated with spawning salmon and sea trout into juvenile salmon nursery streams.

Options for future pilot projects (for discussion):

1. Secure hessian bags containing farm salmon feed pellets more firmly to the streambed. One option being considered is to attach the hessian bags to large 20kg stud chain links and letting them sit on the streambed. However, they would be more exposed to larger animals, e.g. otter, fox, herring gull which may break them open. This might be overcome by using chicken wire mesh or similar to protect them (c. Williams et al 2009)?

2. Use faster sinking pellets specifically to be able to deploy them so that they settle onto the streambed between the stones. This may be an option – perhaps by developing a better salmon carcass analogue pellet incorporating high % of sterile organic fishmeal (as used in farm salmon feed) mixed with a higher-density slow-release binder?

3. Apply salmon carcass analogue (salmon feed pellets or other P-rich equivalent fertilizer) into riparian areas which slope into the streams rather than directly into the streams? That would be just as near to mimicking nature as discussed above. A high proportion of spawned salmon can be removed from the water onto the riverbanks by otters and eaten by otter, fox, badger . . . pine marten . . . rather than remaining to decompose in the river (Cunningham et al 2002). If salmon carcass analogue pellets [SCAP] were thinly distributed in suitable stream-side vegetation (e.g. amongst shrubs and grasses), they could leach more slowly into the stream and / or help to nourish streamside vegetation, supporting growth of trees and shrubs, which in turn would feed nutritious vegetation and woody debris into the water; different trophic pathways (Figure 1.1). Such a study could work in parallel with continuing development of riparian streamside enclosures, such as those recently set up along the Torridon River.

4. Scale up the amount of nutrient applied and spread it over larger section of stream, for example 60kg of farm salmon feed pellets (equivalent to about 60 salmon carcasses) per site over a ~500m length of stream.

Note that SEPA expressed concern about the potential for unregulated application of nutrients into rivers prior to the project being undertaken. After providing SEPA with information about the proposed project and the quantities of SCAP to be used at treatment sites, there was no objection. However, the need for licensing of nutrient application into rivers for the purposes of enhancing productivity of juvenile salmon, especially if scaled up, should be subject to further discussion to ensure all are confident that there will be no adverse impacts upon associated biota of conservation concern.

5. Conclusions

This pilot project set out to learn more about practical application methods for treating sections of salmon nursery stream with farm salmon feed pellets as an analogue to former marine-derived nutrients provided by adult salmon and sea trout, to support and increase production of juvenile salmon from spawning streams in Wester Ross.

Instead, we have learned more about how very big spates can affect juvenile salmon and trout populations and our ability to investigate the practicalities of applying salmon carcass analogues to salmon nursery streams in Wester Ross.

Although there was some evidence that the added nutrient helped to nourish biota in the Docherty Burn, big spates in December 2024, August 2025 (Storm Floris) and October 2025 (Storm Amy) obscured outcomes at sites in the Coulin River and Torridon River.

Future pilot studies could consider spreading salmon carcass analogue pellets over a larger area including riparian areas where there are shrubs and trees (using farm salmon fish feed pellets or other slow-release nutritional equivalents) and increasing the size of treatment areas and amounts of treatment applied by two or three times.

Indirect benefits of the project include raising awareness of the importance of wild salmon among those with a general interest in wildlife ecology and biodiversity conservation and the challenge of how to support ecosystem processes that formerly contributed to higher numbers of wild salmon and sea trout returning from the sea to the rivers of Wester Ross.

The project has also provided opportunities for participants including volunteers to learn much about aquatic invertebrate diversity in some of the salmon nursery streams in the WRFT area. This may help to encourage follow-up studies.

Acknowledgements

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Appendix 1. Results of kick sampling

A1.1 Baseline surveys

A1.1.1 Torridon River (numbers of individuals in a 3-minute kick sample, and 40-minute sort at Beinn Eighe NNR Field Station)

28th November 24	Kick	Kick	Kick	Kick	Kick	Kick		Totals	Totals	Totals
Torridon River top down	Torridon River	Torridon River	Torridon River	Torridon River	Torridon River	Torridon River		Torridon River	Torridon River	Torridon River
Site	1a	1b	2a	2b	3a	3b		1	2	3
sampler	Peter	Nic	Peter	Nic	Peter	Nic				
40 minute sort										
Taxa										
Cased caddis	0		6	1	0	0		0	7	0
Caseless caddis	33	10	3	10	9	3		43	13	12
Baetid mayflies	51	43	3	6	6	10		94	9	16
Seratella								0	0	0
Heptagenids	8	9	29	40	37	59		17	69	96
Other mayflies								0	0	0
Leuctra stoneflies	15	2	8	3	2	2		17	11	4
Other stoneflies	3	6	7	14	6	9		9	21	15
Mites			1					0	1	0
Worms			8	2				0	10	0
Beetle larvae								0	0	0
Blackfly larvae				2	2			0	2	2
Beetle adults								0	0	0
Tipulid larvae				2		1		0	2	1
Dragonfly larvae								0	0	0
Snail								0	0	0
Leach								0	0	0
Salmon fry								0	0	0
Salmon egg								0	0	0
Chironomid								0	0	0

A1.1.2 Coulin River (numbers of individuals in a 3-minute kick sample, and 40-minute sort at Beinn Eighe NNR Field Station)

4th December 2024	Kick	Kick	Kick	Kick	Kick	Kick		Totals	Totals	Totals	
Coulin River top down	Coulin River	Coulin River	Coulin River	Coulin River	Coulin River	Coulin River		Coulin River	Coulin River	Coulin River	
Site	1a	1b	2a	2b	3a	3b		1	2	3	
Sampler	Nic	Peter	Nic	Peter	Nic	Peter					
Notes				streambed green	left side of channel	midstream					
40 minute sort											
Taxa (number present)											
Cased caddis	0	3	1	2	3	4		3	3	7	
Caseless caddis	2	10	6	12	5	24		12	18	29	
Baetid mayflies	1	10	8	5	9	4		11	13	13	
Seratella								0	0	0	
Heptagenids	13	45	33	35	22	27		58	68	49	
Other mayflies	1			2		4		1	2	4	Leptophlebid
Leuctra stoneflies	5	6	7	4	13	7		11	11	20	
Other stoneflies	3	3	10	9	12	8		6	19	20	
Mites								0	0	0	
Worms			1					0	1	0	
Beetle larvae								0	0	0	
Blackfly larvae					2			0	0	2	
Beetle adults			1					0	1	0	
Tipulid larvae				1	4			0	1	4	
Dragonfly larvae								0	0	0	
Snail								0	0	0	
Leach								0	0	0	
Salmon fry								0	0	0	
Salmon egg				1				0	1	0	
Chironomid								0	0	0	

A1.1.3 Docherty Burn (numbers of individuals in a 3-minute kick sample, and 40-minute sort at Beinn Eighe NNR Field Station)

5th December 2024	Kick	Kick	Kick	Kick	Kick	Kick	Kick	Kick		Totals	Totals	Totals	Totals
Docherty burn top down	Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn		Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn
Site	1a	1b	2a	2b	3a	3b	4a	4b		1	2	3	4
Sampler	Nic	Peter	Nic	Peter	Nic	Peter	Nic	Peter					
Taxa													
Cased caddis	0	0	4		5	0	7	6		0	4	5	13
Caseless caddis	14	19	28	7	4	14	11	18		33	35	18	29
Baetid mayflies	12	42	16	16	34	12	13	11		54	32	46	24
Seratella										0	0	0	0
Heptagenids	25	32	24	28	37	67	30	33		57	52	104	63
Other mayflies										0	0	0	0
Leuctra stoneflies	3	6	6	7	3	2	7	11		9	13	5	18
Other stoneflies	13	11	12	15	5	17	17	10		24	27	22	27
Mites										0	0	0	0
Worms	2	3	7		3	4	4	2		5	7	7	6
Beetle larvae	1				1			2		1	0	1	2
Blackfly larvae	8	4	5				1			12	5	0	1
Beetle adults										0	0	0	0
Tipulid larvae	1		2				4			1	2	0	4
Dragonfly larvae										0	0	0	0
Snail										0	0	0	0
Leach										0	0	0	0
Salmon fry										0	0	0	0
Salmon egg	1									1	0	0	0
Chironomid	3			12						3	12	0	0
Notes	stonefly taxa id'd												

A1.2 Follow up kick-sampling, April 2025

A1.2.1 Docherty Burn (3-minute kick; ~30-minute sort at Beinn Eighe NNR visitor centre)

9th April 2025	Kick	Kick	Kick	Kick	Kick	Kick	Kick	Kick		Totals	Totals	Totals	Totals
Docherty burn top down	Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn		Docherty Burn	Docherty Burn	Docherty Burn	Docherty Burn
Site	1a	1b	2a	2b	3a	3b	4a	4b		1	2	3	4
sampler	Nic	Peter	Peter	Nic	Peter	Nic	Nic	Peter					
Taxa													
Cased caddis		2	1	1	2		7	4		2	2	2	11
Caseless caddis		14	10	3	7		4	5		14	13	7	9
Baetid mayflies	4	81	11	8	16	1	8	9		85	19	17	17
Seratella										0	0	0	0
Heptagenids	13	56	11	17	22	10	56	23		69	28	32	79
Other mayflies										0	0	0	0
Leuctra stoneflies	7	5	3	9		8	5	1		12	12	8	6
Other stoneflies		19	17	7	10		14	8		19	24	10	22
Mites	3			2			1			3	2	0	1
Worms	1		3	2	1					1	5	1	0
Beetle larvae	4	7		15	1		7			11	15	1	7
Blackfly larvae		18	1		4		1	2		18	1	4	3
Beetle adults		2	1	4			1	1		2	5	0	2
Tipulid larvae		1		1	2		3			1	1	2	3
Dragonfly larvae				2						0	2	0	0
Snail			1							0	1	0	0
Leach								1		0	0	0	1
Salmon fry							1			0	0	0	1

A1.2.2 Four streams 19th May 2025 (3-minute kick sample; 20-minute sort on riverbank)

Torridon River above and below Torr4; Coulin River, above and below Coul3; above and below Doch1; and (for comparison) a 2-minute kick sample above and below outflow for Kinlochewe septic tank (which discharges far more nutrient into the river than we did at any of our treatment sites!).

19-May-25	Kick	Kick	
Torridon site 4. 2min kick. River low. No signs of applied feed	Torridon 4 below	Torridon 4 above	
NG 934 563	4b	4a	
Taxa			
Cased caddis	19	11	inlcude Grannom
Caseless caddis	2	4	
Baetid mayflies	3	7	
Seratella			
Heptagenids	3	14	
Caenis	16	9	
Leuctra stoneflies	1		
Other stoneflies	4	3	
Mites			
Worms			
Beetle larvae			
Blackfly larvae			
Beetle adults	4		
Tipulid larvae			
Chironomid	1	3	
Dragonfly larvae			
Snail			
Leach			
Salmon fry			
Sampler	Nic	Peter	
Amount of veg in tray	1	3	
Pics on drone			
15.1C at 11:00hrs			

19-May-25	Kick	Kick
Coulin River site 3. 2 min kick. Very low	Coulin 3 below	Coulin 3 above
NH 024 543	3b	3a
Taxa		
Cased caddis	3	1
Caseless caddis	1	4
Baetid mayflies	1	3
Seratella		
Heptagenids	3	7
Caenis	1	
Leuctra stoneflies	1	4
Other stoneflies	1	1
Mites		
Worms	1	1
Beetle larvae	1	6
Blackfly larvae		2
Beetle adults		1
Tipulid larvae		
Chironomid		
Dragonfly larvae		
Snail		
Leach		
Salmon fry		
Sampler	Nic	Peter
Amount of veg in tray	3	1
Pics on drone		
salmon feed still visible and rotting in holes in gravel on side of river, now about 5m from water's edge.		
19.0C at 13:00hrs		

19-May-25	Kick	Kick
Docherty Burn site1. 2 min kick. Very low	Doch B 1 above	Doch B 1 below
NH 055 605	1a	1b
Taxa		
Cased caddis	1	7
Caseless caddis	0	4
Baetid mayflies	2	4
Seratella		
Heptagenids	14	7
Caenis		
Leuctra stoneflies	2	
Other stoneflies		2
Mites		
Worms		
Beetle larvae	1	1
Blackfly larvae		5
Beetle adults		1
Tipulid larvae		
Chironomid		20
Dragonfly larvae		
Snail		
Leach		
Salmon fry		
Sampler	Nic	Peter
Amount of veg in tray		
Pics on drone		
salmon feed still visible and rotting in holes in gravel on side of river, large green algae area by side of stream		
18.7C at 14:20		

19-May-25	Kick	Kick	
Kinlochewe River above and below septic tank outflow at confluence 2 min kick. Very low	A'Gharbhie above outflow	Kinlochewe River below outflow	
NH 030 624			
Taxa			Comments
Cased caddis	5	0	
Caseless caddis	2	3	
Baetid mayflies	10	32	mostly large nymphs
Seratella			
Heptagenids	5	11	
Caenis	2	1	
Leuctra stoneflies	3		
Other stoneflies		2	
Mites			
Worms		1	
Beetle larvae	2		
Blackfly larvae	1	6	
Beetle adults			
Tipulid larvae			
Chironomid		8	
Dragonfly larvae			
Spider mite	10		
Leach		2	
Salmon fry			
Sampler	Nic	Peter	
Amount of veg in tray	little brown algae	lot of green algae	
Pics on drone			
stedy flow of brown water coming out of outflow, ~50+ minnows feeding nearby nipping in and out of enriched flow			
19.9C at 15:10			

Appendix 2. Summary of Catch Per Unit Effort data for juvenile salmon surveys. Sites shaded in pink are post-treatment surveys. Other shading is for CPUE (and fish density values) from red 'very low' to green 'high'; for further explanation, please see Cunningham, 2022.

Date	Site Code	River system	Site	easting	northing	conduct. µS	temp °C	time (mins)	wet area (approx) m2	sal fry number	sal par number	trt fry number	older trout number	sal fry per minute	sal par per minute	trt fry pre minute	older trout per minute	sal fry per m2	sal par per m2	trt fry per m2	older trout per m2	eels	minnow	comments
02/09/2021	Torr1d	Torridon	Allt Coire an Anmoich from roadbridge	195873	856845	34	17	10	125	16	16	1	3	1.60	1.60	0.10	0.30	0.13	0.13	0.01	0.02	2		previous data
02/09/2024	Torr1d	Torridon	just above roadbridge	195874	856848	26	12.4	10		5	21	1	4	0.50	2.10	0.10	0.40					seen		previous data
07/11/2024	Torr1a	Torridon	Allt Coire a Ammoich big channel by island	195948	856931			5		1	17	4	4	0.20	3.40	0.80	0.80							
07/11/2024	Torr1b	Torridon	Allt Coire a Ammoich small channel by island	195971	856904	32	11.4	5		1	9	2	7	0.20	1.80	0.40	1.40						1	
07/11/2024	Torr1c	Torridon	Allt Coire a Ammoich below island	194931	856560			5		4	11	1	0	0.80	2.20	0.20	0.00							
07/11/2024	**Torr1**	**Torridon**	**Allt Coire a Ammoich (totals)**	**195948**	**856931**	**32**	**11.4**	**15**		**6**	**37**	**7**	**11**	**0.40**	**2.47**	**0.47**	**0.73**						**1**	sal fry 45mm-61mm; sal par 69mm-110mm
20/08/2025	Torr1ab	Torridon	Allt Coire a Ammoich (nutrient proj top site) A	195935	856903	14	12.2	12	120	6	13	3	1	0.50	1.08	0.25	0.08	0.05	0.11	0.03	0.01			NB fishing. Below island
20/08/2025	Torr1c	Torridon	Allt Coire a Ammoich (nutrient proj top site) B	195935	856912	14	12.2	5	40	1	1	4	2	0.20	0.20	0.80	0.40	0.03	0.03	0.10	0.05	seen		NB fishing. Right chanel at bottom of island
20/08/2025	Torr1	**Torridon**	**Allt Coire a Ammoich (totals)**	**195948**	**856931**			17	160	7	14	7	3	**0.41**	**0.82**	**0.41**	**0.18**	0.04	0.09	0.04	0.02			
02/09/2021	Torr2	Torridon	main river ~100m above burn mouth	194621	856542	40	18.6	11	120	12	22	2	0	1.09	2.00	0.18	0.00	0.10	0.18	0.02	0.00	2		previous data
02/09/2024	Torr2	Torridon	100m upstream from burn mouth	194652	856565			12		29	1	0	2	2.42	0.08	0.00	0.17							previous data
07/11/2024	Torr2	Torridon	main river above burn mouth	194646	856560	17	11.5	10		10	9	0	0	1.00	0.90	0.00	0.00						1	sal fry 45mm-61mm; sal par 82mm-100mm
20/08/2025	Torr2	Torridon	main river us of conf of Allt a Gharaidh Dhuibh	194646	856560	18	15.2	10	200	15	9	0	0	1.50	0.90	0.00	0.00	0.08	0.05	0.00	0.00	2		NB fishing. About 10 fry missed
02/09/2021	Torr3	Torridon	main river above Glen Cottage	193417	856428	42	16.5	9	100	25	7	5	0	2.78	0.78	0.56	0.00	0.25	0.07	0.05	0.00			previous data
02/09/2024	Torr3	Torridon	above Glen Cottage	193413	856433	27	12.8	11.5		29	4	1	1	2.52	0.35	0.09	0.09					1		previous data
07/11/2024	Torr3	Torridon	main river above Glen Cottage. By treatment site	193423	856335	25	11.4	10		13	9	0	1	1.30	0.90	0.00	0.10							sal fry 46mm-56mm; sal par 86mm-117mm
20/08/2025	Torr3	Torridon	main river above Glen Cottage. Usual site	193416	856428	23	16.6	10	125	12	5	1	0	1.20	0.50	0.10	0.00	0.10	0.04	0.01	0.00			
20/08/2025	Torr3	Torridon	main river above Glen Cottage. By treatment site	193423	856335	23	16.6	10	160	13	3	1	1	1.30	0.30	0.10	0.10	0.08	0.02	0.01	0.01			
25/08/2021	Coul1	Ewe	Coulin, main river at pine trees	202550	853657	30	16.5	15	130	24	23	7	0	1.60	1.53	0.47	0.00	0.18	0.18	0.05	0.00		6	2 double crossings, 50 fish missed
22/10/2024	Coul1	Ewe	Coulin River by pines	202550	853635	44	7.3	10		10	18	4	2	1.00	1.80	0.40	0.20							high water. Sal fry 42mm-51mm; sal par 64mm-101mm
05/08/2025	Coul1	Ewe	Coulin River by pines	202550	853635	27	12.8	20	150	23	16	0	0	1.15	0.80	0.00	0.00	0.15	0.11	0.00	0.00		7	NB efishing
22/10/2024	Coul2	Ewe	Coulin River by logs stacks wood	202426	854423	nr	nr	15		8	8	10	3	0.53	0.53	0.67	0.20						2	sal fry 40mm-49mm; sal par 74mm-107mm
05/08/2025	Coul2	Ewe	Coulin River by logs stacks wood	202426	854423	28	13.2	16	150	32	20	2	0	2.00	1.25	0.13	0.00	0.21	0.13	0.01	0.00			NB fishing . Fast and quite deep
25/08/2021	Coul3	Ewe	Coulin, main river above new metal bridge	202262	854904	30	19.9	9	110	17	10	1	0	1.89	1.11	0.11	0.00	0.15	0.09	0.01	0.00	2	2	1 in 3 escaped esp in deeper water
22/10/2024	Coul3	Ewe	Coulin River just above Bailey bridge	202262	854905	nr	nr	13		24	21	0	1	1.85	1.62	0.00	0.08						1	sal fry 41mm-52mm; sal par 64mm-102mm
05/08/2025	Coul3	Ewe	Coulin River just above Bailey bridge	202262	854905	26	13.5	15	170	13	19	0	0	0.87	1.27	0.00	0.00	0.08	0.11	0.00	0.00	1	3	NB fishing. Bit too deep - many fish missed
12/08/2024	Doch1	Ewe	Docherty Burn from watergate upstream	205504	860506			7		6	8	10	6	0.86	1.14	1.43	0.86	0.09	0.11	0.14	0.09			
13/11/2024	Doch1	Ewe	Docherty Burn at watergate	205504	860506	104	9.3	10		13	8	14	5	1.30	0.80	1.40	0.50	0.09	0.06	0.10	0.04			low clear, sal fry 55mm-65mm, sal par 85mm-111mm
05/08/2025	Doch1	Ewe	Docherty Burn from watergate upstream	205499	860510	74	13.5	20	120	23	3	2	0	1.15	0.15	0.10	0.00	0.58	0.08	0.05	0.00			NB fishing. Bit too deep - many fish missed
13/11/2025	Doch1	Ewe	Docherty Burn, above watergate (Roger's seat)	205505	860507	nr	nr	10	150	18	8	1	5	1.80	0.80	0.10	0.50	1.80	0.80	0.10	0.50			sal fry 46-60mm, sal par 80-108mm
13/11/2024	Doch2	Ewe	Docherty Burn below gate	205048	860963	94	9.6	10		6	27	1	2	0.60	2.70	0.10	0.20					seen	1	sal fry 47mm-?65mm; sal par 71mm-118mm; hybrids
13/11/2024	Doch3	Ewe	Docherty burn at road bridge	204592	861557	80	9.2	10		0	19	0	5	0.00	1.90	0.00	0.50							sal parr 75mm-135mm
19/08/2025	Doch3	Ewe	Docherty Burn just above road bridge	204592	861557	87	17.9	25	180	8	8	0	0	0.32	0.32	0.00	0.00	0.04	0.04	0.00	0.00			NB&PC on anode. 70% of fish seen missed. Frustrating
13/11/2024	Doch4	Ewe	Docherty Burn 400m ds of road bridge	204246	861822	100	9.9	10		30	27	0	0	3.00	2.70	0.00	0.00							sal fry 45mm-53mm; sal parr 58mm-104mm
19/08/2025	Doch4	Ewe	Docherty Burn 300m downstream from roadbridge	204246	861822	106	17.4	15	110	17	18	0	0	1.13	1.20	0.00	0.00	0.15	0.16	0.00	0.00			NB fishing. 40% missed. fry-par split uncertain.
13/11/2025	Doch4	Ewe	Docherty Burn, lower nutrient site below road	204257	861817	72	6.4	10	180	10	13	0	1	1.00	1.30	0.00	0.10	0.06	0.07	0.00	0.01			sal fry 55-63mm, 70mm; sal par 75-112mm