Minimising adverse effects of conservation: Ecological effects of restoration of salmon carcasses to upland streams (Ref IAP2-18-31)

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In partnership with Centre for Ecology & Hydrology (Edinburgh) and CASE partners Marine Scotland and Cromarty Firth Fishery Trust

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Key Words
- Salmon, eutrophication, freshwater ecosystems, community ecology, conservation

Overview

Salmon populations are declining and in need of active conservation measures, but how is their freshwater habitat best managed to maximise their survival? The juveniles live in upland streams that would previously have contained many adult salmon that would have died after spawning, so releasing nutrients into an otherwise nutrient-poor environment. So is it possible to boost salmon productivity by adding fertilisers to replace the nutrients previously supplied by the adult carcasses? And if so, does this cause problems of eutrophication further downstream, where nutrient levels are naturally (and unnaturally) higher? This multidisciplinary PhD project will focus on these unresolved questions of the impact of nutrients on upland stream communities, in the context of a current conservation debate. In so doing it will provide the scientific data essential for conservation policy makers who must manage an ecosystem so as to conserve a threatened species without causing unintended ecological problems elsewhere. It will combine fieldwork in the beautiful highlands of Scotland with laboratory analyses, ecological theory with large scale field experiments, and practical conservation management with development of policy.

Populations of migratory fish – especially those that die after spawning - leave behind adult carcasses and waste products on the spawning grounds. This results in a significant net import of nutrients to the breeding areas, a phenomenon long known in the case of Pacific species of salmon, but now also apparent in Atlantic salmon despite their lower population densities. These nutrients fertilise the streams in which the fish lay their eggs, resulting in increases in algae and macro-invertebrates – so providing more food to the young fish: the last act of the dying parent salmon is therefore to indirectly feed its offspring. However, this nutrient input has greatly reduced due to major declines in salmon populations and barriers to upstream migration. As a result, the upland streams in which salmon spawn (which naturally have few other nutrient sources) have become increasingly nutrient-poor. We have recently shown experimentally that loss of these carcasses causes significant and sustained reductions in the populations of stream macroinvertebrates\(^1\): streams lacking carcasses had only one fifth the biomass of macroinvertebrates compared to streams in which a few carcasses were placed, and this effect persisted for at least a year after the carcasses were added. This lack of macroinvertebrates leads to slower growth of the young salmon which would normally feed on them. Worryingly, stronger genetic selection for particular phenotypes in these streams without carcasses leads to a reduction in the genetic diversity of the surviving young salmon\(^1\). Fishery managers in
both North America and Europe have therefore suggested that conservation measures for salmon populations should include the restoration of nutrient levels in spawning areas, through the addition of salmon carcasses (or more usually ‘fake’ carcasses, composed of dried pellets made from fish tissue, which decompose in the same way as real carcasses and have similar ecological effects but are easier to keep and transport). This addition of fake carcasses could help salmon populations by restoring the nutrient levels (and hence food supply) in the streams in which the young salmon live for several years prior to migration to sea, so potentially boosting their growth and survival.

This innovative project will be the first to provide these key data, using field experiments run in a river system in the Scottish Highlands that allows full manipulation of both salmon populations and fake carcasses in natural streams. It will examine all levels of the food web from algae to predatory fish and will be interdisciplinary, linking hydrology, nutrient pathways, primary production, food web structure, population dynamics, behavioural ecology, conservation, fisheries policy and catchment management. It will have important consequences for conservation, fisheries management and ecosystem management, not only in the context of salmon since the approach will be relevant for the management of other migratory populations and all freshwater ecosystems limited by nutrients.

Specific aims: Using an experimental approach in natural streams, the project will:

1. Quantify the relationship between carcass numbers and impacts on algal growth rate, macroinvertebrate density, biomass and diversity, and juvenile salmon growth and survival rate.
2. Quantify the time scale over which decaying carcasses have a measurable impact on downstream macroinvertebrate communities, separating effects into those due to direct consumption of carcasses and those due to boosting of primary production.
3. Quantify relationship between carcass input, stream discharge and distance downstream that effects are measurable.
4. Derive maximum safe levels of carcass input for given river lengths and discharge and catchment land use, so as to achieve boosts to salmon productivity while avoiding downstream eutrophication.

Methodology

This project will involve experiments in the River Conon catchment in the Highlands of Scotland. It will be run in collaboration with CASE partners Marine Scotland (Director of Freshwater laboratory: Dr John Armstrong) and the Cromarty Firth Fishery Trust (Director and fisheries manager: Simon McKelvey), as in previous work by the primary supervisor. This study system and supervisory team offers the unparalleled opportunity to conduct controlled experiments on the impact of nutrients derived from wild salmon carcasses in natural streams: hydropower dams on the main river prevent the upstream (but not downstream) migration of salmon, and so the salmon population has been maintained since the 1960’s by the fishery managers collecting and fertilising eggs using wild adult salmon trapped as they return from...
the ocean to spawn, then placing these eggs at realistic densities in suitable spawning habitat in the many headwater streams of the catchment that are above the dams. The only human intervention is thus the collection and transport of eggs from below to above the dams – but this provides the opportunity to manipulate and control nutrient levels and fish populations in each stream: the student can choose the number of (fake) adult salmon carcasses that are placed in each section of each stream, and can likewise allocate salmon eggs. Moreover, the same number of salmon eggs from known families can be used in all experimental streams so that each stream starts with exactly the same salmon population density and genetic material (juvenile salmon being the only fish present except for very small numbers of trout). This allows the project to measure stream productivity including the growth and survival rates of the young salmon in natural yet controlled conditions.

In each winter of the project salmon eggs will be collected from wild adult females trapped as they return to the river, fertilised with sperm from wild males and then distributed equally across 10 streams (100 per family per stream). At the same time fake adult salmon carcasses (composed of bagged dried fish pellets) will be added; in the first experiment these will be added at 5 different densities (2 replicate streams per density) in order to address Objectives 1 and 2, while in the experiment to address Objective 3 the chosen streams will receive the same number of fake carcasses but will vary in discharge and size. Macronutrient nutrient export of N, P and K will be measured monthly, and primary production recorded both by measuring daily and monthly growth rates of biofilm (e.g. algae, bacteria, fungi) using an innovative new sensor patented by CEH and standard algal scrape techniques. Instream macroinvertebrates will be sampled by ‘electrobugging’ as in our previous work\(^1\), then identified down to appropriate taxa and weighed to determine taxonomic diversity and biomass. Sampling will be done 4 times per year to address Objective 2, with sampled macroinvertebrates being assigned to functional feeding groups (e.g. collectors, grazers, scrapers, shredders and predators). Fish will be captured by electrofishing, weighed and measured to determine biomass and density\(^4\). Discharge and river length data will be provided from existing databases, combined with land use information and data from the field experiments and analysed using GIS in order to address Objectives 3 and 4.

**Spring, Summer:** 3 weeks fieldwork to sample streams. Analysis of samples, statistical analysis.

**Year 2:** Similar format to Year 1 but running new experiment, to address Objective 3. Start of GIS training. Total of 4 weeks fieldwork, spread over the year. Writing up and publication of results from 1\(^{st}\) expt. (2 papers)

**Year 3:** GIS analysis to address Objective 4, plus final experiments to be decided by student on basis of earlier results. Writing up and publication of results from 2\(^{nd}\) expt. (2 papers).

**Final 6 months:** Analysis and writing up of final experiments and thesis, and final 2 papers.

**Training & Skills**

The student would normally be based in the Fish Biology Group, a vibrant group of around 25 fish ecologists at the University of Glasgow (see [https://twitter.com/GlasgowUnifish](https://twitter.com/GlasgowUnifish) for details of what the group does). There will be 3 periods of fieldwork per year (total duration c.4 weeks), working alongside the fisheries biologists of the Cromarty Firth Fishery Trust. The project supervisors and their teams, coupled with CASE collaborators at Marine Scotland and at the Cromarty Firth Fishery Trust, have a wide range of expertise which will result in the student receiving a broad interdisciplinary training in both concepts (community ecology, entomology, fisheries biology and management, hydrology, nutrient cycling, conservation) and practical skills (electrofishing and bugging, field surveying, invertebrate identification, GIS, statistics, policy development, catchment management, practical conservation). This will make the student eminently employable across a broad range of fields ranging from academia to environmental policy and practical conservation.

**References & Further Reading**


**Timeline**

**Year 1 Winter:** Literature review, planning, salmon spawnings, spreading of eggs and carcasses across experimental streams to address Objectives 1 and 2.

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