	Council <i>Update on the Review of the Effect of Salmon Aquaculture on Wild Atlantic Salmon Populations</i>	CNL(23)13 Agenda item: 5g)
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Update on the Review of the Effect of Salmon Aquaculture on Wild Atlantic Salmon Populations

Purpose

The purpose of this paper is to provide Council with an update on the efforts to provide the latest scientific knowledge on the impacts of sea lice and escaped farmed salmon on wild salmon.

Decisions

- no decision is required.

Background

At its 2021 Annual Meeting, [CNL\(21\)62](#), NASCO agreed to fund a study to provide the latest scientific knowledge on the impacts of sea lice and escaped farmed salmon on wild salmon. A detailed proposal to enable this work to be conducted was provided to Council in 2022, [CNL\(22\)07](#).

The proposal laid out the approach to be taken to provide a State of Knowledge paper where the goal is to conduct a systematic review and potential meta-analysis of the effect of (1) salmon lice and (2) escaped farmed salmon on wild Atlantic salmon. The estimated costings for the work were €83,000. The work of the Expert Group would be co-ordinated by Paddy Gargan with the following members:

Ian Bradbury (escaped farmed fish); Damien Brady, (coastal ecology); Simon Jones (salmon lice); Sten Karlsson (escaped farmed fish); Eva Thorstad (salmon lice); and Knut Wiik Vollset (salmon lice).

The Group agreed that it was necessary to structure this process in a transparent and rigorous way to ensure that the findings are robust and control for bias. To structure the process and achieve this end, the Group contacted Steven Cooke, Director of the Canadian Centre for Evidence-Based Conservation, in May 2022 and invited him to join the Group. Professor Cooke with his team will guide the process of critical appraisal. Professor Cooke has led over 30 evidence syntheses over the last five years and is familiar with relevant methods.

At the 2022 NASCO Annual Meeting, [CNL\(22\)53rev](#), Council asked the Secretary to liaise with the co-ordinator of the Expert Group to request:

- a) the feasibility of including the impact of disease pathogens from farmed fish in their analysis;
- b) the provision of any resulting additional costs;
- c) the provision of a timetable to illustrate how the funding from NASCO could be provided over two financial years; and
- d) that a representative of the Group present an update to Council at the 2023 Annual Meeting; and
- e) to consider the responses from the Expert Group to the requests inter-sessionally.

In response to items a) and b), after discussion with the Group, the co-ordinator contacted Åse Helen Garseth from the Norwegian Veterinary Institute and she agreed to join the Group and

lead the disease pathogen work, if Council agreed to the addition of that work. Dr Garseth provided an estimated cost of €45,000 to include the additional cost on disease pathogens.

In late January 2023, the Council discussed, inter-sessionally, the possibility of including the disease pathogen work into the State of Knowledge paper. The Parties decided that, as NASCO has not adopted a policy on disease pathogens, together with the additional costs involved, not to include the disease pathogen aspect in the State of Knowledge paper. With regard to item c), a timetable is provided below to illustrate how funding will be provided over two financial years. This report update addresses item d) above. Additionally, the co-ordinator will be available for questions during the agenda item in Council, as requested.

The Agreed Approach

After considerable discussion during the early part of 2022, the Expert Group agreed that the approach that should be taken for the genetic introgression work and the sea lice work was quite different. Two sub-groups have, therefore, been formed. For the genetic introgression aspect, this subject was reviewed in 2017 and the relevant experts in the Group felt they have all the relevant literature and therefore a systematic review and critical appraisal was not necessary. There is also a lot more definitive information on the impacts of escaped farmed salmon on wild salmon and little or no conflict in the literature on the impact of escapes.

For the sea lice work, the Group felt that a systematic review and critical appraisal of the literature will be required and the approach and methodology that will be taken will be different to the escapes work. It was, therefore, agreed that one paper on the genetic introgression work and a separate paper on the impacts of sea lice would be produced. The possibility of combining the findings of both papers into a third policy paper with management implications has also been raised.

Proposed Working Methods for the Genetic Introgression Work Programme

The escape of farmed salmon has been documented everywhere salmon farming occurs and escapees have repeatedly been shown to interbreed with wild salmon, resulting in genetic changes to wild populations (Karlsson *et al.* 2016, Glover *et al.* 2017). The resulting offspring of escaped farmed salmon display reduced survival in comparison to wild salmon (Fleming *et al.* 1996, Fleming *et al.* 2000, McGinnity *et al.* 2003, Sylvester *et al.* 2019, Wacker *et al.* 2021) and resulting population decline has been demonstrated both experimentally and through simulation studies (Bradbury *et al.* 2020, Castellani *et al.* 2015, 2018; Fleming *et al.* 2000, McGinnity *et al.* 2003, Skaala *et al.* 2019). In contrast to the effect of salmon lice, the effect of genetic introgression is a much broader research question as the impacts may affect various life history stages differently (Bolstad *et al.* 2017, 2021). Consequently, although there are numerous studies on the effect of genetic introgression on wild fish, it may be a more difficult topic on which to conduct a meta-analysis. Given this, the introgression paper will review the large body of work evaluating the impact of escaped farmed salmon on wild salmon populations, focusing on the presence of escapees in the wild, evidence for hybridisation and introgression and the consequences for wild populations and, where possible, focusing on the mechanisms and magnitude of effect.

The working methods will review the effects of genetic introgression from the information below:

- data on number or presence of escapees in wild rivers;
- genetic estimates of introgression in the wild;
- modelling the population impacts of escapees and introgression;

- estimates of hybrid survival and reproductive success;
- experimental and modelling evidence of population response to hybridisation;
- changes in life history traits of wild salmon populations exposed to escapees;
- changes in other traits including immune response, lipid storage, gene expression, or behaviour (including increased predation risk) due to hybridisation;
- the combined effect of introgression and supplementary stocking; and
- the geographic extent of impact in terms of how far escaped farmed salmon spread.

Proposed Working Methods for the Sea Lice Work Programme

The literature search for sea lice will be conducted in collaboration with the Norwegian Institute for Nature Research (NINA), the University of Bergen and the Institute of Marine Research in Norway. During this process, exclusion criteria will be defined through discussion with the defined experts for the different topics. The process of the literature search will involve reading a subset of the papers found in initial searches and defining exclusion terms that can identify non-relevant literature. The literature search began in January 2023 and continued until March 2023. Consistency checks were undertaken in April. After full-text screening and feedback from the sea lice sub-group, data extraction and critical appraisal will be conducted in September / October 2023.

Once the literature search is completed, a standardised critical appraisal of all the literature will be conducted. Critical appraisal is an important step for identifying and evaluating sources of bias. Some studies report conclusions that are poorly supported by their data. Critical appraisal involves developing a method of scoring individual studies where those studies with rigorous experimental design (e.g. representative sampling, large sample size, replication in space and time, relevant comparators etc.) would score well and ones with weak experimental design would be scored poorly. After scoring it is possible to conduct analyses that only use high-quality studies, to conduct analyses on high-, medium- and low-quality studies and compare findings (i.e. by means of sensitivity analyses with meta-analysis) or downweight the influence of low-quality studies in formal analysis. All decisions regarding critical appraisal are recorded so that readers can understand the basis for rankings. For these reasons, it is important that the critical appraisal tool be developed with care. Using a workshop that involves both subject matter experts and evidence synthesis experts is critical for generating a tool that reflects research standards across disciplines. The critical appraisal was finalised at a three-day meeting in Edinburgh in February 2023.

Based on the critical appraisal, an evaluation will be made as to whether there is sufficient empirical data and relationships developed to undertake a meta-analysis e.g. randomised control studies. If so, resources will be allocated for data extraction for search and analysis.

State of Knowledge Workshop held at NASCO Headquarters, Edinburgh Scotland, February 7 - 9, 2023

A hybrid workshop took place at the NASCO headquarters to progress work on the State of Knowledge paper with regard to impacts of sea lice and genetic introgression. The overall goals of the workshop were:

1. To provide background on evidence synthesis and systematic reviews.
2. Refine questions with regard to the impact of sea lice on wild salmon.
3. Work collaboratively to develop the critical appraisal tool.
4. Develop an overall work plan including duties and timeline.

5. Identify other relevant scientists to invite to the team.

The in-person participants focused almost entirely on the sea lice synthesis whereas the remote participants met separately to advance the synthesis dealing with introgression.

Genetic Introgression

As it had already been agreed to progress the work on escaped farmed salmon in a different manner, this sub-group provided an update on genetic introgression of farmed salmon on wild Atlantic salmon. It also outlined its working methods which included holding a meeting to draft an outline of the proposed paper and identify tasks to be undertaken. The introgression sub-group concluded that the most important task is to collect existing data for the different geographic regions in the distribution range of salmon aquaculture and provide estimates of genetic introgression of wild Atlantic salmon. The goal is to create a map of salmon aquaculture and level of genetic introgression in the whole distribution range of Atlantic salmon. The sub-group agreed to progress this work and report back to the overall Group on its progress.

Impacts of Sea Lice

Day 1:

Introduction to systematic reviews, presentations on impact of sea lice and introgression. Introduction to critical appraisal and discussion on State of Knowledge Paper format.

Day 2:

The sea lice sub-group revisited review questions and came to the overarching question: *What are the impacts of sea lice from aquaculture on wild Atlantic salmon?*

Sub-questions:

- a) *to what extent does sea lice from aquaculture contribute to the burden of sea lice on migrating salmon post smolts?*
- b) *how does the (various) level of sea lice infestation impact the performance of wild salmon post smolts?*
- c) *is there a population reduction in wild adult salmon from salmon lice? If so, how much?*

To help with the development of the critical appraisal tool, for each question the sea lice sub-group outlined study eligibility and discussed the different ways primary studies investigate these questions. The sub-group then outlined for question c), what were the ideal study designs to investigate this question with respect to reducing their potential biases in the methodological conduct. These ideal designs will be used as comparisons or benchmarks in which to assess how the primary studies in the current evidence base meet these standards (i.e. for critical appraisal). Using these ideal study designs, the sub-group then tested a few example primary papers, and made modifications where necessary. This work will be continued remotely over the next few months for questions a) & b), engaging with further topic / methodological experts.

Day 3:

Discussion on roles and responsibilities of the sea lice sub-group, and discussion of timelines for sea lice review. The sub-group also discussed who to invite as topic and methodological experts for the sea lice paper.

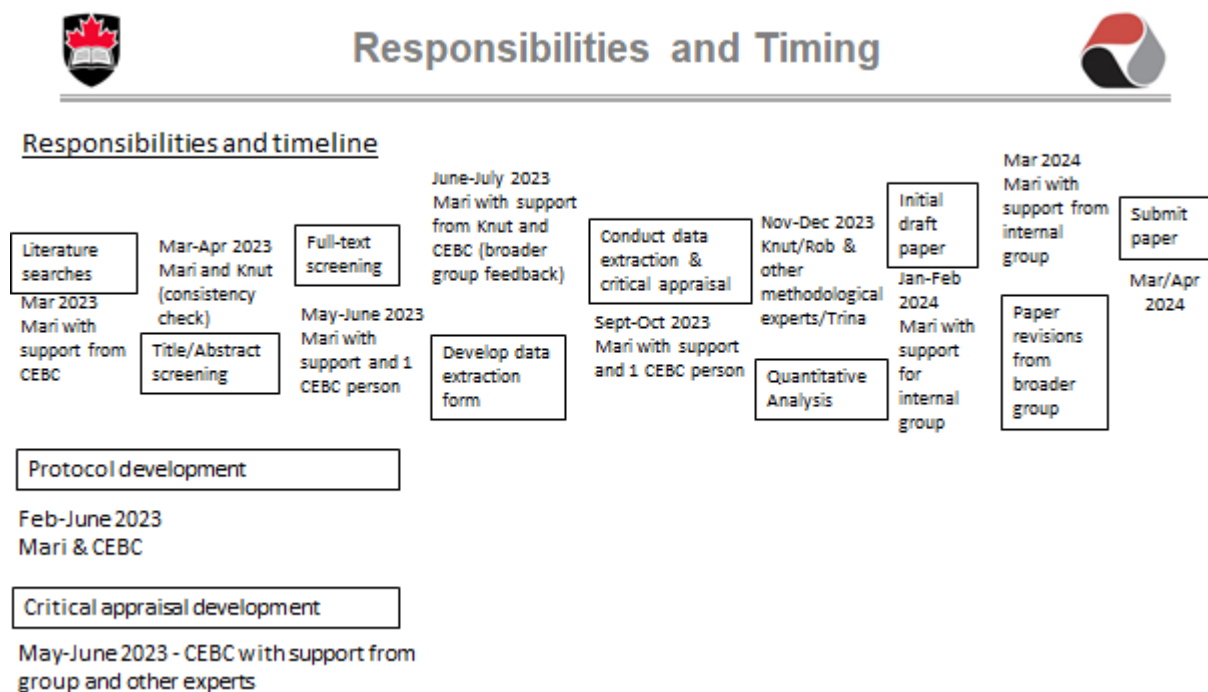
Overall Decisions:

It was agreed that the Group would produce two papers, one on the impacts of sea lice on wild salmon and one on the impacts of genetic introgression on wild salmon. Methodologies are different for both papers. The sea lice paper will be an evidence synthesis (i.e. systematic

review) with critical appraisal, while the genetic introgression paper will serve as an update to a comprehensive review published in 2017 (Glover *et al.*) and will focus on recent advances and broader geographic scope (but will not include a critical appraisal of the evidence base). The Group noted that the topics are related, but quite different so require different approaches, and cohesiveness would be lost if the two topics are combined in a single paper. The possibility of producing a third ‘summary’ paper for policy and management was also discussed. This will depend on the outcomes of the first two components of the process, but the Group acknowledges the need to develop related products (beyond the reviews) that better serve managers and policy makers.

Workshop Outcomes – Responsibilities & Timelines (Sea Lice)

A work plan with responsibilities and timelines to achieve finalisation and submission of a State of Knowledge paper on the impacts of sea lice on wild Atlantic salmon was prepared and is set out below.



Sea lice Systematic Review

Progress since the Workshop in February 2023

Following the workshop in February, search strings vetted at the workshop were rechecked with a librarian at University of Bergen as well as librarians at NINA. No changes were made. A title and abstract screening questionnaire was developed and tested (i.e. detailed inclusion / exclusion criteria in question form used when screening articles at the title and abstract stage). Searches have been performed in three bibliographic databases (i.e. Web of Science, Scopus and Proquest), resulting in 1845 unique hits after duplicate removal. Before screening began, two reviewers, using a subset of 10% of these search results, undertook a consistency check to ensure consistent and repeatable decisions were being made. The results of the consistency checks were compared between reviewers and any discrepancies were discussed. All 1845 items have been screened at title and abstract. A call for grey literature was developed and is in circulation. Detailed accounting of all reviewer activities has been kept and will be used in the development of the review protocol.

Next steps and timeline:

- conduct searches targeting grey literature and theses in ORIA and Google scholar. Then screen these items at title and abstract;
- prepare the review protocol; register with [PROCEED](#) by June;
- continue to develop critical appraisal tools (delayed in progress; see revised timeline); and
- full-text screening of all items included at the title and abstract stage (delayed in progress; see revised timeline).

The sea lice sub-group invited the following sea lice experts to participate in the sub-group: Sussie Dalvin – Institute of Marine Research, Norway; Sandy Murray – Marine Scotland Science; Frank Nilsen – University of Bergen Norway; and Sam Shephard – Inland Fisheries Ireland.

Workshop Outcomes – Responsibilities & Timelines (Genetic Introgression)

The genetic introgression sub-group held a number of meetings and has invited more scientists into the sub-group in order to have a broad geographical coverage. The sub-group now comprises the following experts;

- Scandinavia: Sten Karlsson; Eva Thorstad; Geir Bolstad;
- British Isles: John Gilby; Phil McGinnity;
- North America: Ian Bradbury; Brendan Wringe; and
- Iceland: Leó Gudmundsson.

The full sub-group has had a startup meeting, has an outline for the paper and identified tasks to be followed up. The most important task over the coming months is to collect existing data for the different regions in the distribution range on aquaculture and estimates of genetic introgression. The goal is to create a map of aquaculture and the level of genetic introgression in wild salmon stocks in the whole distribution range of Atlantic salmon by the end of the year.

Overall Costing

The original budget for the sea lice and farm escapes element of the work was estimated at €83,000. The costing will be spread over 2023 and 2024.

Description	Cost Estimates (€)	Details	Expected budget drawdown
<i>Costs for Expert Meeting</i>	19,411	Costs associated with travel & accommodation for Workshop, February 2023, Edinburgh	February 2023
<i>Search term development and literature review, Data extraction & analysis</i>	27,000	Costs of data extraction and applying critical appraisal tool, Costs for standard search term development	Jan to June 2023
<i>Writing of manuscript, sea lice</i>	15,000	Writing and project co-ordination	Sept 2023 to March 2024
<i>Writing of manuscript, genetic introgression</i>	15,000	Writing and project co-ordination	Sept 2023 to March 2024
<i>Publication fee (e.g. Nature/</i>	6,500	Costs for publication of paper in high-ranking journal	Mid to late 2024

Science/Science advances			
Total Estimated Cost	82,911		

Possible EU Grant Funding to support Project Costs

At a NASCO Heads of Delegation meeting in late January 2023, discussion took place that members of the State of Knowledge Expert Group will have considerable hidden costs in staff time spent on the project which their institutions will have difficulty in covering. Following the Heads of Delegation meeting, the Expert Group was made aware by the NASCO Secretariat that the EU, through DG MARE, may be able to make funding available to support the State of Knowledge project. The level of funding that could be provide is unclear at present and it would likely not be available until towards the end of 2023 at the earliest.

The members of the State of Knowledge Expert Group were very supportive of any such initiative as Group members will put in a considerable amount of time at the cost of their institutions and support for such work would be greatly appreciated.

Ongoing Work on the State of Knowledge Papers

Work will continue on the level of genetic introgression of farmed salmon in wild Atlantic salmon stocks throughout 2023 to produce a distribution map across the whole North Atlantic range leading to provision of a draft paper on genetic introgression. Work is continuing on the systematic review and critical appraisal of the impact of sea lice on wild Atlantic salmon with a view to having a quantitative analysis and initial draft paper by the end of the year.

Secretary and Expert Group Co-ordinator
Edinburgh
4 May 2023