NASCO	**Council** ***Final Report on the Review of the Effect of Salmon Aquaculture on Wild Atlantic Salmon Populations – May 2025***	**CNL(25)17** **Agenda item: 5.g)**

Final Report on the Review of the Effect of Salmon Aquaculture on Wild Atlantic Salmon Populations – May 2025

Purpose

The purpose of this paper is to provide Council with a final report on work done 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 was 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 original estimated costings for the work were around €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 at Carleton University in Canada, in May 2022 and invited him to join the Group. Professor Cooke with his team would 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: the feasibility of including the impact of disease pathogens from farmed fish in their analysis; the provision of any resulting additional costs; the provision of a timetable to illustrate how the funding from NASCO could be provided over two financial years; that a representative of the Group present an update to Council at the 2023 Annual Meeting; and to consider the responses from the Expert Group to the requests inter-sessionally.

In response to the first two items, 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.

A budget of €82,911 was agreed, to be paid from NASCO's Periodic Projects Special Fund.

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 were, therefore, formed. For the genetic introgression aspect, this subject was reviewed in 2017 and the relevant experts in that sub-group felt they had 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, that sub-group felt that a systematic review and critical appraisal of the literature would be required and the approach and methodology that would be taken would 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 was also 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 would 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 would 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 would 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 would be defined through discussion with the defined experts for the different topics. The process of the literature search would 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 were conducted in September / October 2023.

Once the literature search was completed, a standardised critical appraisal of all the literature was 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 down-weight 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, therefore, finalised at a three-day meeting in Edinburgh in February 2023.

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

Genetic Introgression Project – Progress Since June 2024

For the genetic introgression work, the individual member institutions have gathered data to be included in the manuscript. Specifically, the sub-group aims to create a short and concise manuscript of the status of farmed salmon and its genetic impact on wild salmon, where the main product would be a map showing the scale of farmed salmon production in the North Atlantic and, correspondingly, data on farmed to wild genetic introgression. All the available data have been pulled together to create a data table with farmed salmon production and genetic introgression data.

The proposed paper will be a straight to the point paper with a synthesis of the knowledge: the magnitude of genetic introgression and the consequences for wild salmon populations. It is intended to submit the paper to the high-impact journal NATURE Communications in summer 2025. This paper will be different to what has been already published in that the data on farmed salmon production, and genetic introgression will be presented throughout the distribution range of Atlantic salmon.

The State of Knowledge paper on genetic introgression of farmed Atlantic salmon in wild salmon populations is nearing completion. Data have been collected on farmed salmon production in the North Atlantic and data from analyses of genetic introgression. Some additional molecular genetic analysis work is being completed at time of writing. Although most of the text has been set out in a draft manuscript and many of the presentations of results are ready, there are some additional analyses to be completed.

The project team held a series of meeting in 2024 and 2025 as set out below.

Meetings in 2024

2 April: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Phil McGinnity, Eva Thorstad, Brendan Wringe, **2 May**: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Tony Kess, Phil McGinnity, Eva Thorstad, Brendan Wringe, **23 May**: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Tony Kess, Phil McGinnity, Eva Thorstad, Brendan Wringe, **13 June**: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Tony Kess, Phil McGinnity, Eva Thorstad, Brendan Wringe, **26 June**: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Tony Kess, Phil McGinnity, Eva Thorstad, Brendan Wringe, **11 September**: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Tony Kess, Phil McGinnity, Eva Thorstad, Brendan Wringe, **2 October**: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Tony Kess, Phil McGinnity, Eva Thorstad, Brendan Wringe, **16 October**: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Tony Kess, Phil McGinnity, Eva Thorstad, Brendan Wringe, **31 October**: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Tony Kess, Phil McGinnity, Eva Thorstad, Brendan Wringe, **18 November**: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Tony Kess, Phil McGinnity, Eva Thorstad, Brendan Wringe, **11 December**: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Tony Kess, Phil McGinnity, Eva Thorstad, Brendan Wringe

Meetings in 2025

26 March: Geir Bolstad, Ian Bradbury, John Gilbey, Leó Gudmundsson, Sten Karlsson, Tony Kess, Phil McGinnity, Eva Thorstad, Brendan Wringe

Work Undertaken since June 2024

The following is a description of the work undertaken since June 2024 and the main findings in the preparation of a paper on genetic introgression of farmed Atlantic salmon in wild salmon populations throughout its native range.

1. Compilation of data on number or presence of escapees in wild rivers.
2. Collection of existing data for the different geographic regions in the distribution range of salmon aquaculture and provide estimates of genetic introgression of wild Atlantic salmon.
3. Integration of genetic and genomic studies across the North Atlantic to map the current extent of genetic introgression from the farms into recipient wild populations across rivers in the species range.
4. Tested the hypothesis that interbreeding with domestic salmon is both significantly altering and erasing diversity present within wild Atlantic salmon on an unprecedented global scale.
5. A map was created of salmon aquaculture and the level of genetic introgression in the whole distribution range of Atlantic salmon.

6. Results show that the major producers of farmed salmon (Norway, Scotland, Canada, Iceland), in the North Atlantic, all have undergone farmed-to-wild gene flow.
7. Using molecular genetic markers, the study investigated genetic introgression of escaped farmed salmon in 481 salmon rivers.
8. Genetic introgression was detected in 57 % (275) of the investigated rivers, throughout the North Atlantic, and no wild salmon population is safe from genetic introgression.
9. Preparation of a draft paper entitled: '*Genetic introgression of farmed Atlantic salmon in wild salmon populations throughout its native range*'. It is anticipated that the paper will be submitted to the high-impact journal, Nature Communications, in summer 2025.

Sea Lice Systematic Review – Progress Since June 2024.

A systematic review protocol was developed entitled 'Impacts of sea lice from aquaculture on wild Atlantic salmon: – Does exposure to sea lice from aquaculture have a population-reducing effect on wild Atlantic salmon?'. The protocol achieved the following results:

Given the evidence base, the focus for the meta-analysis was on the Randomised Control Trial (RCT) studies (10 papers, 113 datasets). Using evidence from multiple North Atlantic countries, this rigorous systematic review included a quantitative synthesis using robust meta-analytical methods to provide estimates of the overall population-level effect of sea lice from aquaculture on wild Atlantic salmon. Due to differences in study design and reported measurements of sea lice impact between experimental and observational studies, separate meta-analyses was performed to obtain summary estimates of the sea lice impact. These estimates were compared narratively and discussed in the report, including limitations of each study design as related to the critical appraisal findings.

Meta-analysis was conducted on the RCT studies. The quantitative data were extracted from all the studies and unique data sets were identified. A few of the studies provided information / estimates on the sea lice infestation pressure along the out-migration route. The project team also developed a method to incorporate infestation pressure (INF P) into the analysis.

<u>The project team held a series of meeting in 2024 and 2025 as set out below.</u>

<u>*Meetings in 2024*</u>

5 July: Mari Lie Larson & Paddy Gargan, **22 August**: Mari Lie Larson & Knut Wiik Vollset, **20 November**: Mari Lie Larson, Knut Wiik Vollset, Trina Rytwinski & Damien Brady, **22 November**: Mari Lie Larson, Trina Rytwinski, Knut Wiik Vollset, Stephen Cooke, Paddy Gargan, Simon Jones, Sandy Murray, Damien Brady, Frank Nilson, Sam Shephard,**10 December**: Mari Lie Larson & Trina Rytwinski.

<u>*Meetings in 2025*</u>

8 January: Mari Lie Larson & Knut Wiik Vollset, **31 January**: Mari Lie Larson & Knut Wiik Vollset, **4 February**: Mari Lie Larson & Trina Rytwinski, **7 February**: Mari Lie Larson & Knut Wiik Vollset

<u>Work Undertaken since June 2024</u>

The list below provides a description of the work undertaken since June 2024 and the main findings on the preparation of a paper on the impact of sea lice from aquaculture on wild Atlantic salmon:

1. Following critical appraisal, meta-analysis of randomized controlled trials (RCTs) comparing anti-parasitic treated and untreated salmon was undertaken.

2. Assessment of potential biases and reasons for heterogeneity were done.
3. Evidence indicates that salmon lice from aquaculture negatively affects wild Atlantic salmon populations. Systematic review data show a reduction in survival and adult returns in salmon exposed to salmon lice.
4. Increased mortality linked to salmon lice infestations is documented in countries with significant salmon aquaculture, including Norway, Ireland, and Scotland, suggesting a widespread impact across the North Atlantic.
5. Studies show a degree of bias due to limitations in study design, including inadequate documentation of salmon lice levels during out migration and the effectiveness of anti-parasitic treatments. These biases suggest that the true impact of salmon lice on wild salmon populations may be greater than current estimates.
6. A paper has been prepared entitled '*Does exposure to sea lice from aquaculture have a population-reducing effect on wild Atlantic salmon? A systematic review'*.
7. The paper will be submitted to the high-impact journal, Fish and Fisheries, in summer 2025.

Project Costing

NASCO Funding

The original budget for the sea lice and farm escapes element of the work was estimated at €82,911. The major costings have been spread over 2023 and 2024. To date the costs for items 1-5 below have been paid. Payment for item 6 is expected to be requested from NASCO in mid-2025.

Cost Item	Description	Costs Paid (EUR)	Details	Budget drawdown
1	***Costs for Expert Meeting***	19,411	Costs associated with travel & accommodation for Workshop, February 2023, Edinburgh	February 2023
2	***Search term development and literature review, Data extraction & analysis***	27,000	Costs of data extraction and applying critical appraisal tool. Costs for standard search term development	September 2023 November 2024
3	***Writing of manuscript, sea lice***	12,700	Writing and project co-ordination	December 2024
4	***Writing of manuscript, genetic introgression***	12700	Writing and project co-ordination	December 2024
5	***Overall Project Co-ordination Costs***	5,460	Overall project co-ordination	December 2024
	Total Costs Paid to Date	**76,411**		
Costs remaining				
6	**Publication fee (e.g. Nature / Science / Science advances**	6,500	Costs for publication of paper in high ranking journal	Expected Mid 2025

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. To meet this shortfall, the European Union, through DG MARE, made funding available to support the State of Knowledge project. NASCO entering into an agreement from 1 November 2023, for 12 months, to implement a research project in relation to 'IMPAS – Contribution to the study of the genetic introgression and sea lice impact on wild Atlantic salmon'. This funding from the European Commission provided grant aid of 80% of €29,221.70 for the genetic introgression project and 80% of €33,234.20 for the sea lice project.

Workpackage	Costs Paid (EUR)	Budget drawdown
Project Co-ordination	1,618	November 2024 March 2025
Writing of manuscript, sea lice	21,400	December 2024 March 2025
Writing of manuscript, genetic introgression	24,610	November 2024 March 2025
Total Costs	**47,628**	

Secretary and Expert Group Co-ordinator
Edinburgh
9 May 2025