Managing the Atlantic Salmon in a Rapidly Changing Environment – Management Challenges and Possible Responses

NASCO

Report of the NASCO Symposium for the International Year of the Salmon

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Tromsø, Norway

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IYS Symposium Report:

Managing the Atlantic Salmon in a Rapidly Changing Environment – Management Challenges and Possible Responses

with additional support from ICES

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Contents

Preface

The North Atlantic Salmon Conservation Organization (NASCO) is an intergovernmental organization established in 1984. Its vision is to pursue the restoration of abundant Atlantic salmon stocks throughout the species' range with the aim of providing the greatest possible benefits to society and individuals.

In response to the increasing threats to wild salmon and recognising that environmental change and human impacts across the Northern Hemisphere are placing salmon at risk, NASCO and her sister organization, the North Pacific Anadromous Fish Commission, agreed to hold the International Year of the Salmon (IYS), with its focal year in 2019. The aim of the initiative was to raise awareness of the issues facing salmon stocks, to increase collaboration among those working to conserve and restore salmon and to stimulate investment in research.

For NASCO, the focal event of the IYS in the North Atlantic was its Symposium entitled 'Managing the Atlantic Salmon in a Rapidly Changing Environment – Management Challenges and Possible Responses', hosted by Norway in advance of NASCO's Thirty-Sixth Annual Meeting. The aims of the Symposium were to:

- allow for the identification of the main management challenges for the Atlantic salmon;
- assist in clarifying the role NASCO can play in addressing them in the future; and
- provide a basis for a major outreach initiative to increase public and political awareness of these challenges.

A Steering Committee was set up to develop the programme, report the proposed programme to the NASCO Council prior to its 2018 Annual Meeting and to prepare a report / publication from the Symposium. The Steering Committee agreed that a series of scientific presentations would be used to set the scene, but that the focus for the Symposium would be on management challenges. Speakers were invited to contribute to a programme developed by the Symposium Steering Committee, and a call for posters was distributed widely, requesting contributions to identify challenges specific to the North Atlantic salmon and assist in clarifying the role NASCO can play in addressing them in the future. Attendance at the Symposium was open to all.

Speakers and poster presenters were managers, scientists, and representatives of non-governmental organizations across the NASCO area, and representatives of indigenous peoples from Canada, Greenland and Norway. Presenters were asked to focus on identifying any management challenges to salmon from their perspective, what their responses to these challenges were, and what they envisaged could be done to solve these management challenges in the future.

Based on the many and varied contributions to the Symposium, the Steering Committee drew up a series of recommendations for the Council of NASCO to address the management challenges and responses presented at the Symposium. These were reported to Council as paper CNL(19)16 which is given in full below.

This report is structured as follows. The Report from the Tromsø Symposium on the Recommendations to Address Future Management Challenges sets the scene from the Symposium and includes the conclusions from the Steering Committee. The contributed papers on the Symposium themes: 'Climate Change and State of the Salmon'; 'Management Challenges and Solutions – Perspectives from Different Groups and Viewpoints'; and 'What Can Be Learned From Other Perspectives: Pacific Salmonids and Public Outreach Perspectives?' are provided, as is an introduction to the Symposium discussion. The abstracts from the submitted posters are then included.

Report from the Tromsø Symposium on the Recommendations to Address Future Management Challenges

CNL(19)16

Report from the Tromsø Symposium on the Recommendations to Address Future Management Challenges

Managing the Atlantic Salmon in a Rapidly Changing Environment – Management Challenges and Possible Responses

Symposium held in Tromsø, Norway June 3 - 4, 2019
ahead of the North Atlantic Salmon Conservation Organization's (NASCO) Annual Meeting

REPORT FROM THE SYMPOSIUM STEERING COMMITTEE

Executive Summary

This Executive Summary is a short compilation of results from the NASCO International Year of the Salmon Symposium entitled 'Managing the Atlantic Salmon in a Rapidly Changing Environment - Management Challenges and Possible Responses'. Two summaries are presented here: the advice for all agencies and organizations who are involved in the conservation and protection of Atlantic salmon; and, recommendations to NASCO.

Summary of Advice for Agencies and Organizations:

1. Managers and conservation organizations need to promote strong, healthy, and resilient populations of local wild salmonids in rivers and estuaries in order to reduce the impacts of changing ecosystems. A primary strategy to achieve this is protecting the genetic integrity of stocks, enhanced water quality and habitat protection including improving access for salmon to important habitats, and minimizing human impacts reducing growth and survival in rivers and coastal areas;

2. Salmon management traditionally has focused on managing harvest and artificially stocking rivers to offset salmon mortality or population decline. In the face of a rapidly changing environment, management approaches and decision-making should be broadened to include ecosystem protection of rivers, estuaries and marine environments including water quality, habitat quality and other valued components of the ecosystem;

3. Aquaculture managers need to have a strong focus on preventing any escape of farmed salmon from pens and / or consider using sterile salmon within their operations. They should reduce the mortality of wild fish caused by salmon lice and pathogens by implementing stricter disease and parasite control programs. This should be supported by rigorous monitoring and reporting to agencies concerning the prevalence of escapes and disease outbreaks;

4. In light of current knowledge concerning the risk and benefits of stocking, all agencies, managers and conservation organizations involved in stocking to artificially supplement populations of any life stage, should adhere to the following principles:

   a. Stocking with hatchery fish of any life stage to augment natural wild Atlantic salmon populations should be an action of last resort, after all other conservation activities have been tried (e.g. optimizing river habitat and water quality), and primarily for preserving endangered populations. If deemed necessary, after carefully evaluating the risks and benefits, stocking should be conducted in a way that minimises or eliminates potential negative effects and maintains genetic integrity and genetic variation of the wild population to the maximum extent possible;

   b. If deemed necessary, stocking should only include the use of local, wild broodfish, emphasize stocking of early life stages, always minimizing time in captivity, and, balance the number of stocked fish to the number of broodfish and the number of naturally reproducing fish; and

   c. In any stocking program, all hatchery produced fish of any life stage should be tagged in some way to be traceable and the effects of stocking should be evaluated.

5. Agencies, managers and conservation organizations considering introductions or managing invasive species should consider the following principles:

   a. Discourage any introduction, intentional or otherwise, of non-native species into salmon rivers;

   b. If established, invasive species should be eradicated where possible, and prevented from spreading when eradication is not feasible; and

   c. Work with other organizations to ensure strong and healthy populations of local Atlantic salmon to mitigate the potential impacts of invasive species.

6. To optimize species productivity under future conditions fisheries managers and conservation organizations should ensure the highest number of wild smolts in the best condition leave from rivers and near-coastal areas to the ocean;

7. Fisheries managers and scientists should continue studies to understand the magnitude and causes of mortality for Atlantic salmon during the marine phase of their life cycle to identify the importance of reduced sea survival due to ocean ecosystem effects versus human impacts in rivers and near-coastal areas and to predict spawner numbers for management. Such research must also include studies in the beginning of the sea migration (i.e. in estuaries and coastal areas);

8. Fisheries managers and scientists should continue to meet and to augment the exchange of information and ideas on how salmon management related to biological reference points is done in different regions as a way to encourage greater consistency among the countries in the use of biological reference points, cataloguing habit types and amounts of different habitat. NASCO could facilitate such knowledge exchanges; and

9. Managers, scientists, conservation organizations and governments should recognise that people are a critical element of the conservation process. Addressing human dimensions requires incorporation of traditional and local knowledge and indigenous perspectives in activities related to salmon science, conservation and management.

Recommendations for NASCO

The IYS Symposium Committee has identified a number of areas where NASCO could either start new initiatives, update and modernize existing guidelines, work with the Parties, or facilitate the development and dissemination of information to promote the future conservation of Atlantic salmon:

10. To remain relevant in a period of rapid environmental and social change NASCO needs a renewed strategy to respond to the challenges facing wild Atlantic salmon. To begin this process NASCO should specifically identify strategic activities to deal with climate change and its cascading effects on salmon and salmon habitat, possibly by updating its 2005 'Strategic Approach for NASCO's 'Next Steps';

11. Given the advances that have been made in the last 15 years in understanding genetic effects of artificial population supplementation, i.e. stocking, and given the conclusions of the 2017 NASCO 'special session on Understanding the Risks and Benefits of Hatchery and Stocking Activities to Wild Atlantic Salmon Populations', NASCO should immediately update its 2004 'Guidelines on the Use of Stock Rebuilding Programmes in the Context of the Precautionary Management of Salmon Stocks' with reference to the summary of advice given above (No. 4);

12. Given the importance of habitat and water quality conservation as a key strategy to conserve salmon into the future, NASCO should update its 2010 'Guidelines for the Protection, Restoration and Enhancement of Atlantic Salmon Habitat'. Updated guidelines should not only consider the physical environment and include estuaries but should also seek to optimize water quality by considering the chemical and biological quality (e.g. toxic substances, diffuse agricultural pollution, persistent organic pollutants) as well as availability and distribution of prey in the future;

13. Given the advances in the understanding of human dimensions and the importance of incorporating indigenous and local knowledge into salmon conservation, NASCO should update and modernize its 2004 'Guidelines for Incorporating Social and Economic Factors in Decisions under the Precautionary Approach'. This update should include recent advances in human dimensions and the incorporation of traditional and local knowledge and indigenous perspectives;

14. Recognizing the importance of salmon to indigenous peoples and the role that indigenous peoples play in salmon conservation, NASCO should improve the participation of indigenous people in NASCO;

15. NASCO should continue efforts, begun under the International Year of the Salmon, to raise global awareness about the status of wild Atlantic salmon, the threats they face, potential solutions, and actions that can be taken;

16. NASCO should facilitate co-operation between Parties when there is a need for international collaboration to prevent or reduce the threat to salmon stocks from invasive species;

17. Given the continued impacts of domestic salmon farming on wild salmon, NASCO should strengthen compliance to the agreed international goals of '100% farmed fish to be retained in all production facilities and, 100% of farms to have effective sea lice management such that there is no increase in sea lice loads or lice-induced mortality of wild salmonids attributable to the farms'. This is as stated in the 2009 'Guidance on Best Management Practices to Address Impacts of Sea Lice and Escaped Farmed Salmon';

18. NASCO should establish a new goal to prevent the spread of disease pathogens from fish farms to wild fish consistent with the existing goals on containment and sea lice in the 2009 'Guidance on Best Management Practices to Address Impacts of Sea Lice and Escaped Farmed Salmon', and the 2016 'Theme-based Special Session: Addressing Impacts of Salmon Farming on Wild Atlantic Salmon';

19. Given the need to identify the importance of reduced sea survival due to ocean ecosystem effects versus human impacts in rivers and near-coastal areas and to predict spawner numbers for management, NASCO should support and continue to encourage research on mortality for Atlantic salmon at the beginning and the end of the marine phase of their life cycle in estuaries and near-coastal areas as well as on the high seas; and

20. Given the success of this Symposium and the positive feedback the Committee has received from participants, NASCO should consider hosting similar events in the future.

Introduction

To mark the International Year of the Salmon, a two-day symposium titled *Managing the Atlantic Salmon in a Rapidly Changing Environment – Management Challenges and Possible Responses* was held ahead of the 36th Annual Meeting of the North Atlantic Salmon Conservation Organization (NASCO). The focus was on challenges facing the Atlantic salmon and possible responses that can help conserve Atlantic salmon. Speakers were invited based on a program developed by the Symposium Steering Committee, and a broad call for posters was distributed widely. Attendance at the Symposium was open to all.

The Symposium was structured under two main themes: 1) climate change and state of the salmon, with scientific overviews being provided on these subjects, and 2) management challenges and solutions.

Speakers and poster presenters were managers, scientists, representatives of non-governmental organizations, and representatives of indigenous peoples from Norway and Canada. Presenters were provided with a topic and asked to provide an overview from their perspective, their views on the management challenges, and potential responses.

This report presents the conclusions and advice of the Symposium Steering Committee based on the oral and poster presentations of the Symposium, and on the discussion with the audience at the end of the Symposium. The report includes the Committee's recommendations to NASCO and advice to not only agencies responsible for managing Atlantic salmon, but also to other environmental agencies or organizations whose decisions or activities influence or impact salmon and their ecosystems. A more extensive Symposium proceedings containing all manuscripts provided by the speakers and copies of the poster presentations will be published at a later date.

In this report, the issues outlined in the presentations are structured according to the themes of the Symposium: 1) impacts of climate change; 2) impacts of salmon farming; 3) limitations of stocking; 4), impacts of invasive alien species;5) the importance of freshwater habitat and water quality; 6) the relatively unknown marine phase of the Atlantic salmon life cycle; 7) the use of biological reference points in management; and 8) and human dimensions. We provide a summary of conclusions and advice for each theme. We conclude with some recommendations on NASCO's role and the changes managers need to consider for effective salmon conservation in a changing world. (Note: throughout this report we refer to fisheries managers or managers. This term is broadly defined for the purposes of this report and includes not only agencies who are directly responsible for managing fish or fish harvest, but also includes other environmental agencies or organizations whose decisions or activities influence or impact salmon and their ecosystems.)

Atlantic salmon in a changing climate

Climate alteration is changing salmon ecosystems

Climate change is having a major impact on Atlantic salmon in freshwater and at sea, directly through changes in temperature, water flow and other abiotic factors, and indirectly through ecosystem changes such as food availability. Alterations to the climate in the northern hemisphere are expected to affect freshwater systems more strongly than the marine environment because temperature increases over land are expected to exceed those over ocean surfaces, and because the hydrology of rivers (flows and temperatures) is changing concurrently. Additionally, ocean temperatures are rising, and the impacts on marine ecosystems inhabited by Atlantic salmon are also of great concern.

Higher temperatures and increased hydrological variability are predicted to affect all components of freshwater systems. Precipitation is expected to increase, with 'wet' areas typically becoming wetter, but with increased variability such that the risk of both floods and droughts will increase. In northern Europe and North America, climate change is projected to result in warmer, drier summers and milder, wetter winters with more precipitation falling as rain and less as snow, a decrease in ice covered periods, and more frequent periods with extreme weather events. We may expect to see many rivers experience extreme low flows (low water levels) during summer with higher water temperatures, which is a potentially lethal combination for salmon.

The increase of atmospheric greenhouse gases through human activities leaves more carbon dioxide in the ocean and more energy in the climate system; 25-30% of the anthropogenic carbon dioxide emissions are stored in the ocean, and about 93% of the excess heat is taken up by the ocean. This leads to oceanic changes that have the potential to influence and threaten marine ecosystems. Upper ocean warming increases the vertical stratification of the water column and could lead to reduced nutrient supply into the sunlit zone. Warming also contributes to the observed decrease of global marine oxygen concentrations and is expected to lead to a decrease in the North Atlantic water circulation between 30% and 50% prior to 2100. The increasing concentration of dissolved carbon dioxide in the ocean leads to acidification, which in the long-term has the potential to affect the entire food chain. Oceanic changes are not uniform around the globe. Depending on the strength of the continued emissions of greenhouse gases, climate alterations of ecosystems will evolve, enlarging the oceanic trends already observed, although regional ecosystems may show more or less impacts than in the ocean itself.

Impacts on Atlantic salmon

Scientists are projecting that conditions for Atlantic salmon may deteriorate, both in fresh water and at sea due to climate change. The vulnerability of salmonids in a rapidly warming environment is a known concern but with some uncertainty as to how well salmonids will be able to adapt. Although salmonids have some capacity to respond and potentially adapt to variations in the environmental conditions, there are limits to these capacities, especially over short time periods.

The predicted changes to river hydrology will likely influence the population dynamics of Atlantic salmon. The average annual water flow in many regions is expected to increase, which will increase river wetted area and thereby increase the habitat available for juveniles. However, the in-year flow pattern will be variable, with high flows in autumn and winter, and periods of very low flows in summer. Future periods of low river flow during summers are, therefore, a potential bottleneck for Atlantic salmon production.

Salmon are ectotherms, and as such, the water temperature directly controls their physiology and metabolism. During spawning, eggs are laid in the gravel and the timing of hatching and how fast the fry consumes the nutrients from the yolk sack before it emerges from the gravel is controlled by water temperature. With increased water temperatures, this process will be more rapid, and the fry will emerge from the gravel earlier, which may lead to a disconnect between the timing of fry emergence and food availability. When temperatures increase, the growth of juvenile salmon in the river will generally speed up, and they may reach smolt size earlier. Studies have shown that smolt age has decreased in the past decades, as water temperatures have increased.

The warmer temperatures earlier in spring appears to have influenced migration timing, with smolts migrating to the ocean earlier in the year. There is concern that the changed ocean environmental conditions are creating a mismatch between timing of smolt sea entry and favourable conditions at sea. Migratory fishes are particularly vulnerable to warming environments as the transitions between habitats are finely tuned to specific environmental cues. The success of these transition periods has consequences for subsequent life stage survival.

Climate alteration has already imposed changes for Atlantic salmon. Water temperatures in many rivers are expected to exceed the upper thermal tolerance limit for salmonids, and during the summer, many populations are already encountering water temperatures near or exceeding experimental lethal limits. In most areas where salmon reside in water with warmer water temperatures (southern Europe), suitable cold-water refuges have been found. It is expected that cold water refuges will become increasingly more important as more rivers experience extreme temperature events.

Energy depletion at high temperatures before spawning has been shown to be greater in small salmon compared to large salmon, suggesting that smaller individuals may be more impacted by high temperatures. If so, one may expect long-term phenotypic change in salmon populations experiencing high temperatures.

Historically, research on climate effects in freshwater has focused directly on factors such as changes in water temperature and flow, while research in the marine phase has been focused on indices and correlations of growth with water temperatures. Marine ecosystems have changed in response to climate change over the past hundred years, which may have influenced the food supply for Atlantic salmon in the marine phase. The spatial distribution of food and high-productive areas may also change, which may impact the ocean migration routes and distribution of Atlantic salmon.

Changing climate effects amplifies other stressors

As the ecosystems and habitats of Atlantic salmon change due to the effects of the changing climate, there are cascading effects and negative feedback loops that are only now being identified. Some human activities will amplify the stress caused by climate change and impact the resilience of salmon and the ability to adapt to changing environments. This additional stress may in turn reduce the ability of salmon to respond to the cumulative impact of other stressors.

Other known stressors of high concern have been identified in relation to climate alteration and include:

- genetic introgression of farmed salmon and uncontrolled stocking impose an extra load on the process of adaptation and may reduce the ability of Atlantic salmon to adapt to rapid environmental changes;
- Atlantic salmon will experience temperatures that are outside the optimal range, which in turn may affect immunological and physiological functions necessary to combat diseases. This applies to both wild and farmed Atlantic salmon. Wild Atlantic salmon may be negatively impacted both in their natural habitats as well as by pathogen transmission from fish farms; and
- with an increase in water temperatures, new species may invade Atlantic salmon rivers, and other native species or introduced species may increase in abundance. This may lead to additional competition for resources, increased predation, or other ecological effects. With new fish species, risks of new viruses, bacteria, protozoans and multicellular parasites increase. Additionally, a warming ocean and other climate change impacts may influence the likelihood of pink salmon being established in Northern Europe.

Conclusions – changing climate

- most future challenges for the Atlantic salmon under current climate change scenarios cannot be predicted. NASCO can best prepare for the future by ensuring that Parties preserve healthy and resilient Atlantic salmon populations with the genetic diversity that exists today;
- climate change has already changed ecosystems and habitats and consequently have put wild salmonids under pressure, which render them more vulnerable to other stressors;
- climate change will likely have a greater impact on Atlantic salmon in the southern distribution range due to increased river water temperatures and reduced flows. Water temperatures in summer periods are already close to the lethal limit in many southern regions. Currently, the northern populations have more scope for acclimation because current river temperatures are lower and well below the lethal limits;
- global responses, beyond fisheries management, are needed to reduce climate heating and its impacts by reducing carbon dioxide emissions. Nevertheless, fish managers should consider the need to incorporate more flexibility and more perspectives into decision making around harvests;
- to maximize resilience in salmonid populations in the face of rapid environmental change, it is vital to maintain the genetic diversity and complex life histories (e.g. proportion of small and large salmon, multiple sea-age) of wild populations by ensuring natural reproduction and avoiding selective fishing;
- genetic introgression from escaped farmed salmon from aquaculture farms can reduce the ability of Atlantic salmon to adapt to climate change. Measures to prevent further escape or using sterile salmon in aquaculture will help Atlantic salmon populations to maintain resilience to rapid environmental changes;
- the artificial stocking of natural populations to augment abundance does not have the support of many in the scientific community as it is increasingly being shown that stocking negatively impacts the genetic variation and ability of Atlantic salmon to adapt to environmental change. If stocking is deemed necessary to preserve endangered populations, it should be conducted in a way that maintains genetic integrity and genetic variation;

- maintaining or increasing cold water refuges as well as access to those habitats is an important strategy and was raised in several symposium presentations;
- managing Atlantic salmon to meet the challenges posed by a warming ocean is a difficult task. Approaches that promote diverse populations to produce the maximum number of high quality wild smolts migrating to the ocean should be supported; and
- impacts of a changing climate have both local and global impacts, and populations in different regions will respond differently. Consequently, there is need for data from long-term monitoring programs to continually evaluate productivity estimates for both fresh and marine waters.

Advice – changing climate

- managers and conservation organizations need to promote strong, healthy, and resilient populations of local wild salmonids in rivers and estuaries in order to reduce the impacts of changing ecosystems. A primary strategy to achieve this is protecting the genetic integrity of stocks, enhanced water quality and habitat protection including improving access for salmon to important habitats, and minimizing human impacts reducing growth and survival in rivers and coastal areas; and
- salmon management traditionally has focused on managing harvest and artificially stocking rivers to offset salmon mortality or population decline. In the face of a rapidly changing environment, management approaches and decision-making should be broadened to include ecosystem protection of rivers, estuaries and marine environments including water quality, habitat quality and other valued components of the ecosystem.

Impacts of salmon farming

Domestic Atlantic salmon are farmed in pens in coastal areas in many jurisdictions of NASCO. The distribution and production of salmon farming in the marine environment is projected to continue to increase. The numbers and tonnage of farmed salmon in aquaculture facilities in the North Atlantic are now far larger, by orders of magnitude, than wild salmon. Just one aquaculture sea site may for instance contain more farmed salmon than the annual pre-fishery abundance of wild Atlantic salmon returning to all of Norway.

Fish farming has had some of the greatest impacts on wild Atlantic salmon populations in several areas of their distribution. These impacts include mixing of escaped farmed and wild salmon during spawning, salmon lice infestations, and pathogen transmission and infectious diseases. The impacts of salmon farming, escaped domestic salmon, and lice and other pathogens were extensively covered at the 2016 Theme-based Special Session of the NASCO Council.

Impacts of escaped farmed salmon

Wild Atlantic salmon are genetically adapted to their local environment, the prerequisites for which are genetic variation and restricted gene flow of mal-adapted genotypes that break down the genetic integrity of natural populations. Due to intentional and unintentional domestication selection, farmed salmon is genetically different from its wild origin, and less adapted to the natural environment, particularly a rapidly changing natural environment. Genetic introgression of escaped domestic farmed salmon, therefore, represents a real threat to the viability of many wild salmon populations, as it breaks down local genetic adaptation by introgression of mal-adapted genotypes and changes important life history traits in impacted wild salmon populations.

Although only a small fraction of farmed salmon escape from their net pens, they can make up a large proportion of the salmon at the spawning grounds in rivers. For instance, in Norway, among 225 populations analysed so far, about two-thirds have been changed genetically due to genetic introgression from domestic farmed salmon.

The breakdown of genetic integrity and loss of genetic variation due to genetic introgression of escaped domestic farmed salmon adds to the effects of ecosystem alteration due to a changing climate - and is posing additional challenges to the viability of wild Atlantic salmon populations now and into the future.

Pathogen transmission and infectious diseases

Large-scale intensive farming of domestic Atlantic salmon in open net cages in concentrated areas suffers similar challenges to intensive animal farming on land such as higher incidence of disease caused by parasites and pathogens. Within the fish farming industry, this has resulted in the emergence of several infectious diseases and widespread sea lice outbreaks. Pathogen and parasite exchange between wild and domestic farmed Atlantic salmon is a threat to wild Atlantic salmon populations in areas with open net pen farming.

Conclusions – Impacts of Salmon Farming

- impacts of fish farming have become the greatest threats to wild Atlantic salmon in several areas of their distribution due to impacts of escaped farmed salmon, salmon lice and pathogens causing diseases; and
- infectious disease and pathogen incidence and parasite exchange between wild and domestic farmed Atlantic salmon are real threats to wild salmon in regions where salmon fish farming is conducted. However, our understanding of the impacts from pathogens and diseases is incomplete, and there is a risk that the impacts are underestimated.

Advice – Impacts of Salmon Farming

- aquaculture managers need to have a strong focus on preventing any escape of farmed salmon from pens and / or consider using sterile salmon within their operations. They should reduce the mortality of wild fish caused by salmon lice and pathogens by implementing stricter disease and parasite control programs. This should be supported by rigorous monitoring and reporting to agencies concerning the prevalence of escapes and disease outbreaks.

Stocking

The deliberate release of hatchery produced salmon as a means to enhance salmon stocks has a long history and is practiced worldwide. Due to evidence of potential negative genetic consequences of stocking, the motivation for stocking Atlantic salmon has gradually shifted from enhancing population size for recreational fishing towards preservation of endangered populations. Hatchery and stocking activities have been covered in an earlier Theme-based Special Session of the NASCO Council in 2017.

Potential genetic consequences of stocking include:

- reduction of effective population size and loss of genetic variation due to a disproportionally large contribution of stocked individuals from a limited number of broodfish;
- breakdown of local genetic adaptation from the use of non-local broodfish;
- unintentional domestication selection of hatchery produced fish; and
- epigenetic effects from the rearing of fish under artificial hatchery conditions.

Advice – Stocking

- in light of current knowledge concerning the risk and benefits of stocking, all agencies, managers and conservation organizations involved in stocking to artificially supplement populations of any life stage, should adhere to the following principles:
    - stocking with hatchery fish of any life stage to augment natural wild Atlantic salmon populations should be an action of last resort, after all other conservation activities have been tried (e.g. optimizing river habitat and water quality), and primarily for preserving endangered populations. If deemed necessary, after carefully evaluating the risks and benefits, stocking should be conducted in a way that minimises or eliminates potential negative effects and maintains genetic integrity and genetic variation of the wild population to the maximum extent possible;
    - if deemed necessary, stocking should only include the use of local, wild broodfish, emphasize stocking of early life stages, always minimizing time in captivity, and, balance the number of stocked fish to the number of broodfish and the number of naturally reproducing fish; and
    - in any stocking program, all hatchery produced fish of any life stage should be tagged in some way to be traceable and the effects of stocking should be evaluated.

Impacts of invasive alien species

Invasive alien species are non-native species that have become established outside their native range because they have arrived there deliberately or accidentally by human activity – and that are negatively impacting native biodiversity and ecosystem services. The International Union for the Conservation of Nature (IUCN) asserts that the spread of invasive alien species is the second most significant threat to global biodiversity, after habitat loss.

Throughout the range of Atlantic salmon, there are a number of introduced species, both fishes and other organisms, which may impact Atlantic salmon as competitors, predators, vectors of new pathogens that may cause diseases, or plants that alter aquatic habitats. Examples are Northern pike (*Esox lucius*), rainbow trout

(*Oncorhynchus mykiss*), pink salmon (*O. gorbuscha*), Eurasian minnow (*Phoxinus phoxinus*), bullhead (*Cottus gobio*), Japanese knotweed (*Fallopia japonica*) and *Gyrodactylus salaris*. The impacts of many of these alien species have not been studied and consequently are not well known. However, there is one alien invasive species, the parasite *Gyrodactylus salaris*, which has been studied due to its impact in northern European rivers.

G. salaris is a parasite that causes high mortality of juveniles in Atlantic salmon populations not adapted to the parasite. It has been one of the major threats to Atlantic salmon in Norway after it was introduced, but the parasite has been successfully eradicated from many rivers, and only seven of the fifty infected rivers are still infected. However, spreading of the parasite continues in Russia and on the Swedish west coast.

Other species in the same genus as Atlantic salmon can also be invasive alien species. Pink salmon is a salmonid native to the Pacific Ocean. Deliberate releases of pink salmon into rivers in north-west Russia have resulted in self-reproducing populations. In 2017, pink salmon were documented along coasts and in rivers in many countries in the North Atlantic. Based on present knowledge, it is difficult to predict the potential impact of invasive pink salmon on native salmonids, ecosystems and ecosystem services, but there is clearly a potential risk for negative impacts. As long as there is successful reproduction of pink salmon in rivers in northwest Russia and Northern Norway, every year there will be a pool of potential invaders in the Barents Sea and the North-East Atlantic, with a risk of spreading and establishment in new areas under favourable conditions.

Conclusions – Invasive alien species

- invasive alien species have the potential to negatively impact Atlantic salmon. Knowledge of the ecological consequences or impacts of biological invasions is often gained after the introduced alien species have become well established. Once established, the impacts of alien invasive species can be severe and often expensive to reverse. This points towards a need for greater surveillance to identify new invasions as soon as possible to allow early mitigation and reversal if possible;
- management measures available to reduce potential impacts of invasive pink salmon are to hinder pink salmon from entering the rivers, to catch as many pink salmon as possible before they can spawn or try to destroy their spawning redds before hatching. Such management measures involve a significant effort and possible negative consequences for native fauna; and
- mitigation measures to reduce the risk of establishment and negative impacts of pink salmon must be implemented through co-ordinated efforts over larger areas to achieve any long-term effect. Hence, mitigation efforts may only be efficient if regional and international collaboration and co-ordination to reduce pink salmon abundance can be achieved.

Advice – Invasive alien species

- agencies, managers and conservation organizations considering introductions or managing invasive species should consider the following principles:
    - discourage any introduction, intentional or otherwise, of non-native species into salmon rivers;
    - if established, invasive species should be eradicated where possible, and prevented from spreading when eradication is not feasible; and
    - work with other organizations to ensure strong and healthy populations of local Atlantic salmon to mitigate the potential impacts of invasive species.

Freshwater habitat and water quality

Migration barriers, loss of rearing and spawning habitat and poor water quality have contributed to population declines and extirpations in large parts of the Atlantic salmon's range. Providing free passage for juveniles from their nursery grounds to the sea and for returning adults to reach their spawning grounds is necessary to support Atlantic salmon populations. The availability of suitable habitat and good water quality control the production of wild salmon from fresh water, both in terms of abundance and quality of individual fish, which impacts their subsequent sea survival.

The removal of dams and other physical barriers to salmon movement is now a well-established conservation activity to improve and re-open habitat in salmon rivers. This activity requires much interaction and support from local communities in order to be successful. Moving forward, it is necessary to re-focus on restoration of watersheds and healthy ecosystems (rather than focusing on a single species that may be locally extirpated, like Atlantic salmon). This may resonate more strongly with local people and is key for building relationships with other stakeholders.

Conclusions – freshwater habitat and water quality

In addition to discussing physical barrier removal, and warming water temperature effects, many presenters at the Symposium referred to the importance of improving or maintaining habitat quality and water quality as a front-line defence to mitigate the compounding effects of climate alteration on ecosystems and Atlantic salmon. While many in the scientific community are focused on understanding at-sea mortality, it is also important to identify smolt and post-smolt fitness as a potential concern and potential contributor to salmon declines. The quality of habitat and water in rivers including food availability mis-match and sub-lethal chronic impacts from other river stressors are areas that should be investigated to assist fisheries managers in developing appropriate protection measures.

Some other conclusions from this Symposium include:

- there is significant potential for further mitigation measures related to hydropower production, other river regulations and habitat alterations, and poor water quality throughout the distribution area of Atlantic salmon, which can greatly increase production of Atlantic salmon, and improve quality of juveniles leaving fresh water, which in turn will help increase their sea survival; and

- restoration projects that require altering the landscape (e.g., dam removal) require addressing social concerns through a strong education, outreach, and engagement program and must be sensitive to local values and aspirations.

Advice – freshwater habitat and water quality

- to optimize species productivity under future conditions fisheries managers and conservation organizations should ensure the highest number of wild smolts in the best condition leave from rivers and near-coastal areas to the ocean.

The marine phase of the Atlantic salmon

Atlantic salmon marine survival rates are variable across time and space. Atlantic salmon populations have declined over large parts of the distribution area during the last decades, and one of the reasons is reduced survival during their marine feeding and adult maturation migration. This could be a cyclic phenomenon, and salmon productivity could increase again; however, human induced climate change has also been implicated. As temperatures continue to increase over the next century, the outlook for Atlantic salmon in the North Atlantic is expected to be challenging.

Marine mortality rates vary geographically and seasonally and are typically more variable than freshwater survival. Marine mortality rates have a large influence on the number of salmon returning for spawning. It is assumed that the majority of marine mortality occurs during the first year at sea, but for multi-sea-winter stocks mortality during the second year can also be high. Marine survival rates are impacted by climate and ecosystem changes in the sea and by human activities in coastal areas such as aquaculture and power production. Also, the condition and quality of the smolts when leaving fresh water will impact marine survival.

The ability to identify and mitigate direct human-induced threats to salmon productivity across its marine range is generally available. However, natural mortality and mortality arising from indirect human activity (i.e., climate change) remains an intractable problem due to lack of information on the marine phase of the salmon, the size of the habitat, and the complexity of the ecosystem. This lack of information is one of the biggest problems we face in predicting the fate of Atlantic salmon in the longer term.

Conclusions – marine life of Atlantic salmon

- at present, it is not possible to identify and implement management actions directly to counteract salmon declines due to climate and ecosystem changes in the ocean. The best management option in situations with reduced marine survival is to optimize species productivity under future conditions by supporting approaches that promote production of a maximum number of high quality wild smolts from the rivers and near-coastal areas to the ocean;

- reduced marine survival is, in many areas, partly due to stresses caused by human activities such as aquaculture and other activities in coastal areas, which can be mitigated by proper management measures;

- there is a need to increase knowledge on the migration routes and distribution areas in the marine phase, and on which factors that are impacting the marine growth and mortality. Such knowledge can help researchers identify the importance of reduced sea survival versus human impacts and to predict annual returns of spawners for management, which at present is not possible due to lack of knowledge on marine mortality. These are complex research questions, which require data from large geographical areas and long-term research programs. Facilitating large, collaborative research programs will help improve this knowledge base;

- when recording marine survival from salmon that are leaving their natal rivers, it is important to collect data such that mortality due to impacts of smolt quality from human activities in the near-coastal areas can be distinguished from mortality that is a result of ecosystem and climate changes in the ocean;

- with declining Atlantic salmon populations, mortality from predation seems to be increasingly in focus. It is important that managers facilitate studies where the ultimate reasons for mortality are identified. Simply showing that a smolt is eaten by a predator does not necessarily mean that predation is the ultimate mortality factor. Predation may often be the end point of post-smolts in the sea, even though the ultimate reason for mortality may be one or several other factors. For instance, a post-smolt with a deadly infestation of salmon lice will likely be eaten by a predator before it dies from salmon lice. This fish would have eventually died from the lice infestation even in the absence of predators; and

- data collected by long term monitoring programs on all life stages of the species across its entire freshwater and marine range can be used by researchers to measure, compare and contrast population trends and are the essential ingredients for river and region specific informed management. These datasets will also be essential to retrospectively assess the impacts of a changing climate to forecast future impacts. Managers should encourage the continuation and possible expansion of such long term monitoring programs.

Advice – marine life of Atlantic salmon

- fisheries managers and scientists should continue studies to understand the magnitude and causes of mortality for Atlantic salmon during the marine phase of their life cycle to identify the importance of reduced sea survival due to ocean ecosystem effects versus human impacts in rivers and near-coastal areas and to predict spawner numbers for management. Such research must also include studies in the beginning of the sea migration (i.e. in estuaries and coastal areas).

Management according to biological reference points

Fisheries managers in different countries have used varying methods to establish conservation limits and evaluate whether conservation limits and management targets are met and developed. In the last two decades, there has been a trend in fisheries management, including the management of Atlantic salmon, to have a better biological foundation for determining conservation objectives based on species needs and capacity to sustain harvest.

Using this management approach implies that the scientific information needed to make management decisions is increased. There is a further need in many rivers and regions to increase monitoring and data collection on population abundance, as well as fisheries effort data.

Using biological reference points to establish conservation limits and management targets, fisheries management assessment processes have the potential to become objective and repeatable, with clearly specified management rules. This has provided a common language for managers, fishers, developers, politicians and scientists to discuss and agree on conservation goals and management objectives. Although improvements are happening, the translation of scientific methods and results, due to their complexity, to easily understandable language remains a challenge.

Conclusions – biological reference points

- fisheries managers should be using biological reference points to provide the scientific foundation for fisheries management decisions;

- there are challenges related to the development of the reference points and to the methods used to assess whether they are reached – and to how the reference points are related to fisheries management and conservation objectives. Information about the methods used in various jurisdictions should to a larger extent be shared between scientists and managers at the international level; and

- the use of catch statistics is, in many cases, the basis for monitoring and assessments of populations. Correct reporting of catches and well-functioning reporting systems are essential. Better catch statistics with the establishment of biological reference points are important activities for future management and conservation of Atlantic salmon.

Advice – biological reference points

- fisheries managers and scientists should continue to meet and to augment the exchange of information and ideas on how salmon management related to biological reference points is done in different regions as a way to encourage greater consistency among the countries in the use of biological reference points, cataloguing habit types and amounts of different habitat. NASCO could facilitate such knowledge exchanges.

Managing salmon is managing people: Human dimensions

Most of the issues facing wild salmon are the result of human activities, either directly (e.g. overfishing; aquaculture; habitat destruction, etc.) or indirectly (e.g. climate change). In many cases, existing scientific knowledge of these issues is sufficient to develop potential solutions. However, as many speakers pointed out, our inability to implement timely and effective solutions is often hampered by socio-economic factors These include conflict of interest, lack of consensus, mistrust, diversity of environmental values and ethics, ineffective governance, failure to consider alternative perspectives (e.g. indigenous perspectives), and difficulties in motivating governments, communities, and individuals to take appropriate action. Thus, restoration and conservation of Atlantic salmon require attention to the human dimensions from both scientific (i.e. understanding human values, attitudes, and behaviours) and management perspectives (i.e. applying human dimensions knowledge to developing and implementing solutions).

Salmon and people are intricately linked through complex social-ecological systems. The persistence of these systems, and the benefits they bring to humans, depend on these systems being resilient and adaptive. Many of the speakers discussed human dimensions that, if addressed, would help to strengthen the relationship between wild salmon and people and enhance our capacity to develop solutions, address constraints, take action, and increase the resilience and adaptive capacity of social-ecological systems in support of salmon conservation. These include: improving the engagement of stakeholders in decision-making; building relationships and increasing collaboration among stakeholders; improving science communication and outreach; exploring novel governance systems; better engagement of the public in salmon conservation through novel stewardship programs; and systematically building public and political will for conservation initiatives.

Representatives for indigenous people in Canada and Norway spoke at the conference, presenting their challenges, perspectives and solution. The importance and value of incorporating indigenous peoples and their knowledge and perspectives in salmon conservation was emphasized. For example, indigenous peoples' knowledge systems capture generational data that can include detailed observations about changes in environmental conditions, species abundance, and species behaviour. Given limits to government resources for data collection and monitoring, these additional knowledge systems make significant contributions to salmon restoration, conservation, and management. The indigenous perspective that 'everything is connected, everything is one' was also discussed. This perspective is consistent with the western concept of social-ecological systems and further emphasizes the importance of embracing the notion that salmon conservation is ultimately a human endeavour that cannot be successful without understanding and incorporating human values, aspirations, and behaviours.

Conclusions – managing salmon is managing people

- human dimensions are of great importance and need to be increasingly emphasised by managers aiming to conserve, restore and enhance Atlantic salmon populations. There is a need for better involvement of stakeholders and local communities, forums to solve management conflicts, clearer dissemination of scientific knowledge, and sound use of multiple knowledge systems;

- co-ordinated and collaborative efforts involving all levels of government, environmental organizations, indigenous groups, academia, and interested members of the public, are needed to mitigate human impacts on salmon populations;

- improving trust and dialogue is essential in these processes. Forming strong networks based on repeated interaction and collaboration can help to build trust. Many concerns are based on a lack of information, which can be addressed through education and dialogue; and

- direct interaction between humans and salmon is needed to succeed in the conservation of salmon. When the resource is reduced or lost, fisheries are reduced and lost, people lose their connection with salmon, and awareness of the species and its conservation is diminished. Better understanding of the broader social, cultural, and economic value of salmon, and connecting and integrating these values to management and engagement actions, are critical to salmon conservation overall.

Advice – managing salmon is managing people

- managers, scientists, conservation organizations and governments should recognise that people are a critical element of the conservation process. Addressing human dimensions requires incorporation of traditional and local knowledge and indigenous perspectives in activities related to salmon science, conservation and management.

Conserving salmon in a changing world: Recommendations to NASCO

The objective of NASCO is to conserve, restore, enhance and rationally manage Atlantic salmon through international co-operation taking account of the best available scientific information. NASCO has an important role in bringing together countries, as well as non-governmental organizations, and indigenous peoples to work collaboratively in support of salmon. To have an inter-governmental body where people from governments and organizations meet, and where the Parties are reporting to NASCO, has substantially changed and improved salmon conservation during the last decades.

Since its inception, NASCO has broadened its initial focus of limiting fishing on the high seas to developing guidelines or agreements on the precautionary approach; habitat protection and restoration; aquaculture, introductions, transfers and transgenics; stock rebuilding, and relating socio-economic factors to the precautionary approach.

Within that context, the IYS Symposium Committee has identified a number of areas where NASCO could either start new initiatives, update and modernize existing guidelines, work with the Parties, or facilitate the development and dissemination of information to promote the future conservation of Atlantic salmon:

1. To remain relevant in a period of rapid environmental and social change NASCO needs a renewed strategy to respond to the challenges facing wild Atlantic salmon. To begin this process NASCO should specifically identify strategic activities to deal with climate change and its cascading effects on salmon and salmon habitat, possibly by updating its 2005 'Strategic Approach for NASCO's 'Next Steps';

2. Given the advances that have been made in the last 15 years in understanding genetic effects of artificial population supplementation, i.e. stocking, and given the conclusions of the 2017 NASCO 'Special Session on Understanding the Risks and Benefits of Hatchery and Stocking Activities to Wild Atlantic Salmon Populations', NASCO should immediately update its 2004 'Guidelines on the Use of Stock Rebuilding Programmes in the Context of the Precautionary Management of Salmon Stocks' with reference to the summary of advice given above (No. 4);

3. Given the importance of habitat and water quality conservation as a key strategy to conserve salmon into the future, NASCO should update its 2010 'Guidelines for the Protection, Restoration and Enhancement of Atlantic Salmon Habitat'. Updated guidelines should not only consider the physical environment and include estuaries but should also seek to optimize water quality by considering the chemical and biological quality (e.g. toxic substances, diffuse agricultural pollution, persistent organic pollutants) as well as availability and distribution of prey in the future;

4. Given the advances in the understanding of human dimensions and the importance of incorporating indigenous and local knowledge into salmon conservation, NASCO should update and modernize its 2004 'Guidelines for Incorporating Social and Economic Factors in Decisions under the Precautionary Approach'. This update should include recent advances in human dimensions and the incorporation of traditional and local knowledge and indigenous perspectives;

5. Recognizing the importance of salmon to indigenous peoples and the role that indigenous peoples play in salmon conservation, NASCO should improve the participation of indigenous people in NASCO;

6. NASCO should continue efforts, begun under the International Year of the Salmon, to raise global awareness about the status of wild Atlantic salmon, the threats they face, potential solutions, and actions that can be taken;

7. NASCO should facilitate co-operation between Parties when there is a need for international collaboration to prevent or reduce the threat to salmon stocks from invasive species;

8. Given the continued impacts of domestic salmon farming on wild salmon, NASCO should strengthen compliance to the agreed international goals of '100% farmed fish to be retained in all production facilities and, 100% of farms to have effective sea lice management such that there is no increase in sea lice loads or lice-induced mortality of wild salmonids attributable to the farms'. This is as stated in the

2009 'Guidance on Best Management Practices to Address Impacts of Sea Lice and Escaped Farmed Salmon';

9. NASCO should establish a new goal to prevent the spread of disease pathogens from fish farms to wild fish consistent with the existing goals on containment and sea lice in the 2009 'Guidance on Best Management Practices to Address Impacts of Sea Lice and Escaped Farmed Salmon', and the 2016 'Theme-based Special Session: Addressing Impacts of Salmon Farming on Wild Atlantic Salmon';

10. Given the need to identify the importance of reduced sea survival due to ocean ecosystem effects versus human impacts in rivers and near-coastal areas and to predict spawner numbers for management, NASCO should support and continue to encourage research on mortality for Atlantic salmon at the beginning and the end of the marine phase of their life cycle in estuaries and near-coastal areas as well as on the high seas; and

11. Given the success of this Symposium and the positive feedback the Committee has received from participants, NASCO should consider hosting similar events in the future.

Conclusion – Conserving salmon in a changing world

This Symposium has demonstrated that the effects of climate change on Atlantic salmon are already evident, and that impacts on salmon and their environments will increase into the future. In general, one of the key themes to emerge from the Symposium is the need for adaptation – by salmon, people, and institutions. In today's rapidly changing ecological, social, and political environments, it is imperative for NASCO – the world's only international body focused on the conservation and survival of Atlantic salmon – to remain adaptable and engaged in the activities that are necessary to ensure the survival of wild Atlantic salmon. This Symposium and the resulting recommendations outlined above are intended to assist NASCO in this regard. Furthermore, the Steering Committee urges NASCO to engage in an on-going process of self-reflection and evolution to ensure the Organization remains a relevant and effective forum for the conservation of wild Atlantic salmon.

Annex

Symposium Steering Committee

The Steering Committee for this Symposium was created by NASCO with the following mandate:

> *'The Council accepted a proposal from Norway, CNL(17)19 to hold an IYS symposium in conjunction with the 2019 Annual Meeting. The Symposium would be entitled 'Managing the Atlantic Salmon in a Rapidly Changing Environment – Management Challenges and Possible Responses'. The Council agreed that each Party and the NGOs should be asked to nominate one person to serve on the Symposium Steering Committee by the end of August 2017. The Committee should report back prior to the 2018 Annual Meeting. The Committee should develop the programme and make the arrangements for the Symposium. This Symposium, at a North Atlantic level, is in addition to the major event to launch the IYS'.*

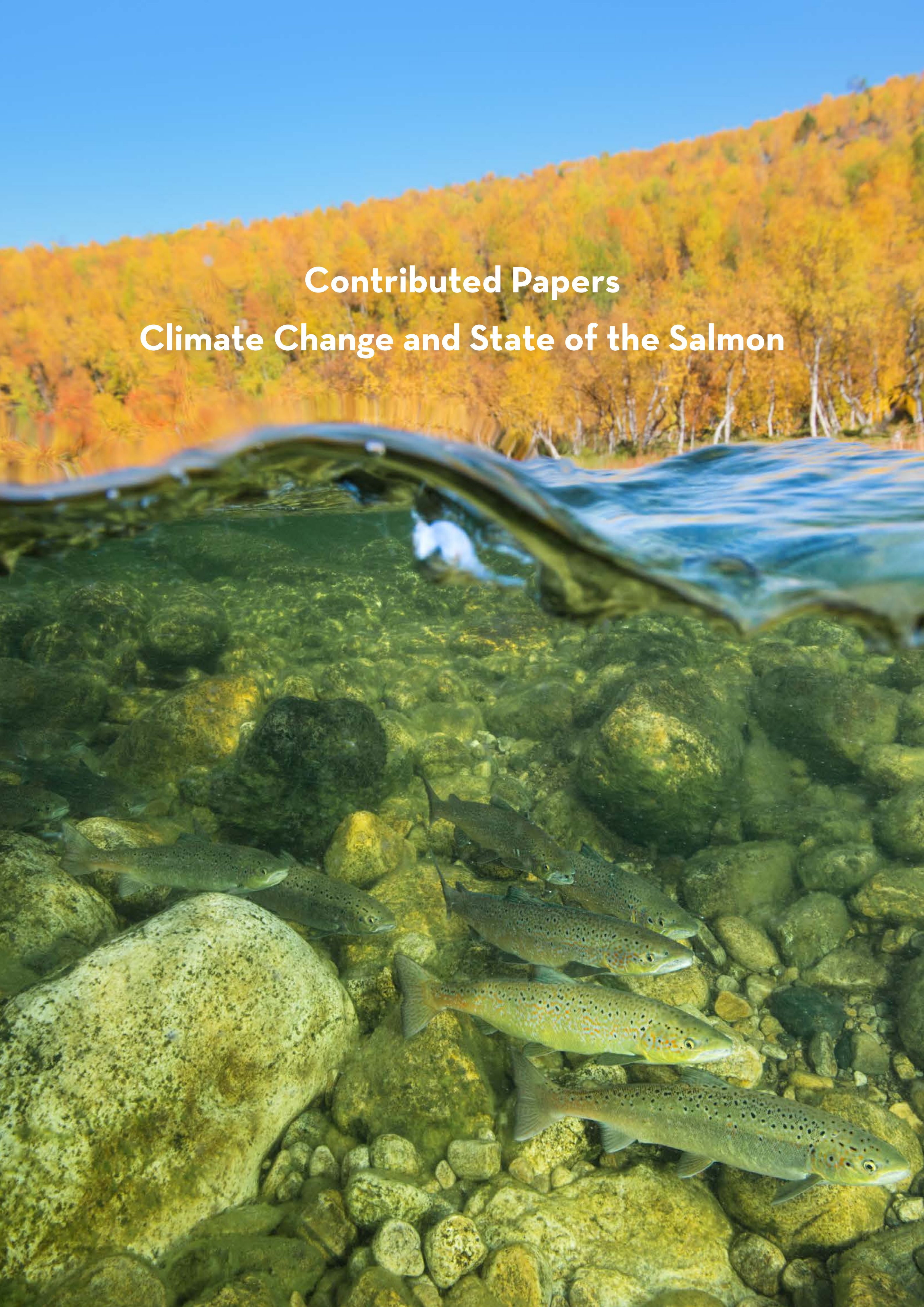
The Committee had its only face-to-face meeting in November 2017 in Trondheim, Norway to begin planning the Symposium. All other planning meetings were done via conference call and video call.

Members of the Steering Committee were:

- Eva B. Thorstad (Norway)
- Doug Bliss (Canada)
- Kim Damon-Randall (United States)
- Grant Horsburgh (EU)
- Heidi Hansen (Norway)
- Niall Ó Maoiléidigh (Ireland)
- Stephen G. Sutton (NGO)

Contributed Papers

Climate Change and State of the Salmon



Climate Change in the North Atlantic

Monika Rhein, IUP-MARUM, University Bremen, Bremen, Germany

The ocean plays a fundamental role in mitigating climate change. The increase of atmospheric greenhouse gases through human activities leaves more energy in the climate system, and about 93% of that heat is taken up by the ocean. Additionally, the ocean stores about 25-30% of the anthropogenic CO2 emissions. Both slowed the atmospheric warming, and led to oceanic changes that have the potential to influence and/ or threaten marine ecosystems in the open ocean and at the coasts. For instance, upper ocean warming increases the vertical stratification of the water column and could lead to reduced nutrient supply into the sunlit zone. Warming also contributes to the observed decrease of the global marine oxygen concentrations. Another stressor is the continuing acidification of the ocean due to the rising storage of oceanic CO2.

These observed changes are not uniform around the globe. Ocean currents transport heat, gases, nutrients and other substances and lead to regional differences. Marine ecosystems react to these local conditions. Depending on the strength of the continued emissions of greenhouse gases, climate change will evolve, enlarging the oceanic trends already observed and partly also increase the regional differences. Furthermore, a warmer climate most likely lead to more marine heat waves and more harmful algal blooms.

Up to now, observed North Atlantic circulation changes cannot be separated into natural variability and anthropogenic trends, and it is also difficult to do that for changes in environmental conditions. The main reason is that oceanic currents in that region have strong fluctuations on interannual to decadal time scales, making it difficult to detect an anthropogenic trend in time series not longer than about 25 years. Till 2100, climate models project a decrease in the North Atlantic circulation between 30% and 50%, and this would also change significantly the contrasting regional conditions.

Impact of Climate change on Atlantic Salmon, Future Challenges

Line Elisabeth Sundt-Hansen, NINA, Trondheim, Norway

Atlantic salmon stocks have declined in the last three decades in their whole distribution range and the underlying reasons for this are complex. Although some factors that have contributed to the decline are known, particularly in the freshwater habitat, there are still knowledge gaps that need to be filled to determine why this downwards trend is occurring. Climate change has already started to impact Atlantic salmon across their distribution range and scientist are concerned that climate change in addition to other anthropogenic factors may worsen the conditions for Atlantic salmon, both in their freshwater and in their marine habitats.

Climate change projections

Some studies indicate that climate change will affect the freshwater systems more than the marine environment, because temperature increases over land are expected to exceed those over the surface of the oceans. Higher temperatures and increased climate variability are predicted to affect all components of the global freshwater system, with the greatest increases at northern latitudes. Precipitation is expected to increase globally, with 'wet' areas typically becoming even wetter, but with increased variability such that the risk of both floods and droughts will increase. In northern Europe and North America, climate change is projected to result in warmer, drier summers and milder, wetter winters with more precipitation falling as rain and less as snow, a decrease in ice covered periods, and more frequent periods with extreme weather events. In the Mediterranean, the projected scenarios for fresh water predicts a worsening of environmental conditions because of higher temperatures and longer droughts. This may put an extra toll on the freshwater habitat as this will also impact water abstraction and irrigation.

How will climate change influence the freshwater stage?

In the freshwater phase, salmon is affected directly by climate change through changes in water temperature and water flow. These two factors govern important biological mechanisms, both for individuals and the entire population. Atlantic salmon spend the first part of their life in the river and it is the life stages from eggs to smolt that are affected here.

Climate-induced changes in water flow is likely to influence the population dynamics of Atlantic salmon in the future. The relationship is also related to the cross sectional profile of the river, because increases in water flow, particularly from low levels, will increase wetted area. Although the average water flow in some areas of the Atlantic salmon's distribution range (northern Europe) are expected to increase in the future, the inter-annual pattern will be variable, with high flows in autumn and winter and periods of very low flows in summer. Thus, future periods of low water flow in the summer are a potential bottleneck for Atlantic salmon production in fresh water. Spatial heterogeneity of resources may influence competition among individuals and have a fundamental role in shaping population dynamics and carrying capacity. Because Atlantic salmon juveniles are territorial, the amount of shelter (interstitial spaces) in a river may limit the carrying capacity of the river for juvenile Atlantic salmon. An increase in wetted area can be positively correlated with the carrying capacity of juveniles if the additional habitat that becomes available provides more shelter for juvenile Atlantic salmon.

Salmon are ectotherms and the water temperature will therefore directly control physiological and biochemical reactions in the body of the fish. During spawning, eggs are laid in the gravel and the timing of hatching and how fast the fry consumes the nutrients from the yolk sack before it emerges from the gravel, is controlled by water temperature. With an increase in water temperature this process will go faster, and the fry will emerge from the gravel earlier. Once the fry emerges, they must acquire a territory and nourishment. When temperatures increase during the freshwater phase, the growth of juvenile salmon in the river will generally speed up and they will reach smolt size at an earlier age. There is great variation in smolt age in the rivers in the distribution range of Atlantic salmon, ranging from 1-6 years of age. Smolt size tends to vary, but the range of smolt size is relatively similar comparing the different stocks of salmon (10-30 cm). Recent studies that have investigated time series of Atlantic salmon populations have observed that smolt age has decreased in the past decades, as water temperatures has increased. Similar results have been found in studies investigating the effect of increased water temperatures as a result of hydropower regulation and in studies modelling future climate change and its effect in the freshwater stage of Atlantic salmon. In addition to smolts becoming younger, the warmer temperature earlier in spring has also influenced the timing of migrations, with earlier annual smolt migration. Smolt that start their migration earlier in the year are generally smaller than smolt that start their migration later. Albeit a small smolt size is correlated with a lower probability of returning as spawners. There is thus a concern that climate change is creating a mismatch between favourable conditions in the river and sea.

Salmon, like other vertebrates, are most sensitive to high temperatures early in the development stage. At the embryonic stage, the upper temperature tolerance is 16˚C. For juvenile salmon in the river, growth will decrease after 15˚C, which is optimal, and stop when the temperature approaches 23˚C. The incipient lethal temperature limit is at 27.8˚C and an absolute mortality occur at 33˚C. In most areas where salmon reside in water with warmer water temperatures (south of Europe), suitable cold-water refuges have been found. Such refuges with colder water can allow juvenile salmon to survive when water temperatures exceed the thermal limits and such refuges should be protected in rivers which are likely to experience extreme temperature events in the future.

Research has shown that northern salmon stocks that are adapted to ice cover in winter lose energy when the ice cover disappears. Such studies have been carried out in a river where hydropower regulation led to the surface ice disappearing during winter, because water was released from the bottom of a reservoir, which is warmer during winter than the surface of the river. The effect of less or no ice cover is lower growth since salmon then have to use more energy to find shelter, search for food and protect themselves from predators. The ice works as an excellent shelter and protection against predation from many predators such as birds and mammals. It is possible that such mechanisms will also affect salmon stocks in the future, and that less or no ice cover in more rivers will increase energy loss. At the same time, it is difficult to predict how adaptation to such an environment will change as the change in ice cover will occur over time and salmon stocks that experience this will undergo selection.

Historically, research on climate effects in freshwater has focused directly on factors such as changes in temperature and water flow, while effects of climate change and salmon in the marine phase have been focused on indices, which we know are important for marine ecosystems. Analysis of time series has shown that marine ecosystems have changed in response to climate change over the past hundred years, which may have influenced the supply of food to the salmon in the marine phase.

The abundance of Atlantic salmon in North America has varied in accordance with the index called the Atlantic multidecadal oscillations (AMOs). This indicator provides information on long-term changes in the climate in the North Atlantic that affect its surface temperature. In warm AMO phases, the occurrence of salmon is lower, and in cold phases it is higher. In Europe, there has been a steady decline in the salmon population since the end of the 1970s, and during the same time the sea surface temperatures have gradually increased. It has been hypothesised that there are different mechanisms governing the recruitment of Atlantic salmon populations from Europe and North American. European recruitment seems to be governed by factors that affect the growth during their first summer at-sea whereas for North American stocks it seems that variation in predation pressure during the first months at sea governs recruitment, not variation in growth. Based on this, climate change may affect salmon during its ocean phase. It is nevertheless important to consider other factors that also affect the Atlantic salmon populations, and which can cause major local differences such as hydropower regulation, fish farming and pollution.

Simulation of future scenarios by the use of models provides an opportunity to study future development of salmon stocks and how they can be affected by climate change. Such research projects have shown that regional differences can occur. For example, a modelling study showed that higher water temperatures (in the period 2071-2100) in three Norwegian rivers could lead to increased growth and earlier smolder age. The modelled results showed a higher salmon production in the freshwater phase in the future in the western and northern river, while the salmon population in the southern river was reduced. This is because future periods of low water flow in the summer will be a bottleneck for the production of salmon in this area. Although models are useful as tools for simulating future development, they are limited by the knowledge gaps that still prevail.

Knowledge gaps

- how fast will a population adapt to climate change? Variation in temperature tolerance may differ among populations and families and this may create a potential for selection;
- how will climate change interfere with other anthropogenic stressors? With an increase in water temperature, new species may inhabit areas where Atlantic salmon has been the predominant species, and this may lead to additional competition for resources for Atlantic salmon (pink salmon). Introduced non-native species and phenotypes;
- changes in freshwater and marine ecosystems and the impact on Atlantic salmon;
- parasites and diseases; and
- water quality and pollution.

Recommendations

Climate change has a major impact on Atlantic salmon both in the freshwater and the marine habitat, directly through changes in temperature and water flow, and indirectly through changes in the freshwater and marine ecosystems.

As we cannot predict all future challenges for the Atlantic salmon we can best prepare for the future by preserving the Atlantic salmon populations and the variety of strains that exists today. This implies:

- protecting freshwater habitats important for Atlantic salmon recruitment;
- protecting vulnerable life stages of Atlantic salmon such as the smolt phase from stressors such as fish farming (salmon lice), when it migrates to the sea;
- gaining more knowledge of survival and mortality during the transition phase from freshwater to the ocean which still has large knowledge gaps;
- gaining more knowledge of growth and potential feed for Atlantic salmon in the sea phase which still has large knowledge gaps;
- it is likely that future climate change and global warming will impact the Atlantic salmon in the southern distribution range stronger due to increased water temperatures and reduced water flow than experienced today; and
- in rivers which are likely to experience extreme temperature events in the future extra effort should be made to protect cold water refuges as they may allow juvenile salmon to survive temporary extreme temperature conditions.

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Salmon in the Ocean

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Conceptually, managing Atlantic salmon is easy. It is one of the better studied species and there are volumes of literature describing its ecological needs and interactions, which help define the essential features necessary to support robust populations. If the impediments to productivity for a population are identified, the tools are generally available to mitigate the threat. Fisheries can be managed, bycatch minimised, obstacles to migration can be removed, negative aquaculture impacts can be mitigated, riparian zones can be restored, acidification impact can be reversed, *Gyrodactylus salaris* can be eradicated to name a few. These efforts may be politically or socially challenging to implement, but the ability to identify and mitigate threats to salmon productivity across its range is available, except for natural marine mortality due to a changing climate and ecosystem.

The quest to understand the marine ecology of Atlantic salmon began in earnest around the late 1950s. The current understanding of its ocean ecology represents a cumulative progression of work performed by countless individuals from numerous countries and institutions across the species range. One event of particular note was the formation of the International Commission for the Northwest Atlantic Fisheries/ International Council for the Explorations of the Seas (ICNAF / ICES) Joint Working Party on North Atlantic Salmon in 1966. The formation of this group, and its evolution into the ICES Working Group on North Atlantic Salmon has fostered the development of true international co-operation and collaboration across the North Atlantic. This group has developed and maintained valuable datasets describing Atlantic salmon populations across the species range and has served as a cornerstone for many of the contemporary studies elucidating the marine ecology of the species. Without all of this prior effort, the understanding of the ecology of the species would be severely stunted.

The diadromous life history of Atlantic salmon imparts particular constraints on population productivity. Juvenile nurseries in freshwater habitats impart upper limits on population abundance due to density-dependent effects (Chaput 2012), and like a drinking glass, the capacity of rearing habitat is finite. Comparatively, there is a lack of evidence of density dependent regulation of salmon populations in the ocean and considering marine survival is typically higher and more variable than freshwater survival, survival at sea has a disproportionate influence on population productivity (Reddin *et al*. 1988; Nieland *et al*. 2015).

The marine phase has historically been considered a black box given the paucity of information generated. Despite decades of research to understand the marine phase of Atlantic salmon the vastness of the range coupled with relatively low ocean abundance (~3 million pre-fishery abundance (PFA) fish estimate, ICES 2018) has resulted in an incomplete mosaic of the species' marine ecology. Marine mortality rates vary both geographically and seasonally and it is assumed that the majority of marine mortality occurs during the first year at sea, but for multi-sea-winter stocks mortality during the second year can also be high (Chaput 2012). Over the past few decades, abundance declines have been noted for all three stock complexes that ICES assesses, in particular the multi-sea winter components of the southern stock complexes (ICES 2018). These declines have largely been attributed to factors acting on survival at sea.

It is exceedingly difficult to provide generalisations of Atlantic salmon marine ecology. Atlantic salmon are native to over 2000 rivers draining into the North Atlantic and range from New England (USA) and northern Portugal in the south to the Ungava Bay (Canada), Russia and north of the Arctic Circle in the north. The species occupies a vast swathe of the North Atlantic Ocean within highly variable habitats, made possible by its diverse suite of plastic life history characteristics. At the ICES stock-complex level (North American Commission (NAC), Southern Northeast Atlantic Commission (SNEAC) and Northern Northeast Atlantic Commissions (NNEAC)) there is synchrony in that population abundances have generally declined over the past five decades (formal assessments by ICES start in the early 1970s for NAC and SNEAC and early 1980s for NNEAC). However, at smaller spatial scales this synchrony can break down as individual regions can have opposite trajectories or adjacent rivers can have opposing conservation status. Optimally, management would occur on a river-specific basis and be grounded with river-specific monitoring data, but this approach is not practical.

Large declines in PFA have been noted for all three ICES stock complexes (ICES 2018). When comparing five-year running averages, the current (2013-2017) estimate of total NAC PFA (1SW / 2SW sea ages combined) is 42% of the peak estimate (1973-1977). For SNEAC, the current total PFA (1SW / MSW sea ages combined) is 29% of the peak (1971-1975) and for NNEAC the total PFA (1SW / MSW sea ages combined) is 47% of the peak (1983-1987). For the southern regions, the decline in the older sea age component has been more severe than in the northern region (NAC 2SW is 18% of peak, SNEAC MSW is 34%, NNEAC MSW is 53%). While changes in the spawning stock biomass and a variety of localised freshwater factors can certainly influence PFA, declines in abundance documented over the past five decades are considered to be largely attributed to decreases in marine survival.

Atlantic salmon marine survival rates are variable across time and space. Marine survival is typically higher for the NEAC stock complexes than the NAC stock complex, for 1SW cohorts than 2SW cohorts, and for wild origin fish than hatchery fish (ICES 2018). Generally speaking, estimated contemporary return rates for both NAC and NEAC stocks are lower today than pre-1990. The decline in marine survival has been more pronounced for 2SW / MSW salmon population segments and is responsible for the non-uniform declines in PFA for the different sea age cohorts, especially within the NAC. Trends in marine survival are not easily interpreted however, as these estimates may also be driven by changes in the age of maturity (Chaput 2012).

Investigations into the marine ecology of Atlantic salmon began in earnest during the late 1950s. Prior to that tagging programs had been implemented on both sides of the Atlantic, but the focus was generally on monitoring exploitation rates and freshwater recaptures (Ó Maoiléidigh *et al*. 2018). When the first Scottish (1956) and Canadian (1960) origin salmon were captured at Greenland, tagging became seen as a tool for elucidating patterns of stock-specific marine distribution and new tagging efforts, both in rivers and at common marine feeding areas such as Greenland and the Norwegian Sea, were initiated (Parrish and Horsted 1980, Ó Maoiléidigh *et al*. 2018). A number of marine surveys targeting Atlantic salmon were also initiated in the Northwest and Northeast Atlantic (Templman 1967, Reddin 1985, Holm *et al*. 2000). These early efforts prompted a number of novel investigations on diverse aspects of salmon marine ecology ranging from basic biology, physiology, age and growth, diet, stock discrimination, etc. (Mills and Piggins 1986; Mills 1993; Mills 2000). Understanding the role of marine climate and the underlying environmental correlates that govern marine growth and survival of stocks from both sides of the Atlantic gained prominence as our understanding of salmon ecology developed (Friedland *et al*. 1993; Friedland *et al*. 1998; Friedland *et al*. 2000; Friedland and Reddin 2000; Friedland *et al*. 2009).

While these past investigations laid a solid foundation of our understanding on the topic, it is important to highlight two seminal papers that first proposed unifying causal mechanisms for the declines of salmon populations in the Northwest and Northeast Atlantic. (Beaugrand and Reid 2003; 2012; Mills *et al*. 2013) report on large scale modelling investigations that disentangle the relationships between Atlantic salmon productivity and a suite of physical and biological parameters.

Beaugrand and Reid (2003; 2012), reported how multi-layered climate related ecosystem changes affected European Atlantic salmon. They found that major declines in NEAC salmon abundance were associated with pronounced increases in the temperature of the Northern Hemisphere and Northeast Atlantic Sea Surface Temperature (SST) during the 1970s. The increased ocean temperature caused alterations in the composition, phenology, biomass, and distribution of the planktonic food of salmon and its prey. Over the time period analyzed, two significant stepwise declines were identified, notably between 1986 and 1987 and between 1996 and 1997 (Beaugrand and Reid 2012).

The relationship between ecosystem conditions and North American Atlantic salmon populations had not been properly characterised despite the documentation of widespread declines in return rates for 2SW salmon population segments (Chaput *et al*. 2005), which were concurrent with an ecosystem reorganization attributed to climate-driven, basin-scale oceanographic changes (MERCINA Working Group 2012). Mills *et al*. (2013) demonstrated that the major declines in 2SW Atlantic salmon populations occurred against a backdrop of physical and biological shifts in Northwest Atlantic ecosystems. Climate, physical, and lower trophic level data directly and indirectly influenced the abundance and productivity of NAC salmon populations. Mills *et al*. (2013) demonstrated that changes in climate factors (Atlantic Multidecadal Oscillation and North Atlantic Oscillation) drove changes in physical factors (sea surface temperature and salinity), which drove changes in lower trophic levels (phytoplankton, zooplankton, and capelin). Significant stepwise declines in salmon population characteristics were also identified, notably between 1990 and 1991 and between 1997 and 1998. The salmon shifts aligned tightly with the step-wise declines noted within the ecosystem datasets, and also with the timing of the declines identified by (Beaugrand and Reid 2012), underscoring the effects of climate-driven changes on Atlantic salmon populations across the Atlantic. The results reported by Mills *et al*. (2013) were largely supported by Friedland *et al*. (2014), who always provided an explanation of the differing recruitment control mechanisms for European and North American postsmolts.

The knowledge that climate is directly and indirectly structuring pelagic ecosystems throughout the North Atlantic basin has facilitated considerable progress in understanding how physical and biological factors affect salmon productivity. For example, by comparing the pre-and post-regime shift diets of salmon feeding at West Greenland, we know that despite similarities in composition over time, the size and energy density of some prey species have declined over the past 50 years, suggesting a considerable increase in a salmons' 'bioenergetic' cost of living (Renkawitz *et al*. 2015). That a reduction in prey quality may be partially responsible for the shift in salmon productivity reported by Chaput *et al*. (2005) is not unique to salmon; Atlantic cod, Bluefin tuna, seabirds, seals, whales and even polar bear populations in the Northwest Atlantic have shown signs of either lower body condition and / or reduced productivity since the 1990s, all of which were attributed to deficiencies in resource acquisition. In the Northeast Atlantic, there are examples of sea bird productivity being correlated with environmental drivers and some of these studies have tied the declines to altered food web structure due to a changing climate. One common feature of these studies is the apparent density-dependent effects in the marine environment due to the reliance of predators on small pelagic fishes as the energy conduit between lower and upper trophic levels.

Many new and exciting research projects are making use of archived datasets, samples, and existing technologies by applying new techniques, approaches and processes. Novel examinations of stable isotope signatures, proximate composition and fatty acid profiles are being conducted to answer important questions about feeding migrations, marine distribution and trophic ecology. Genetic baselines are continually improving along with our ability to assign individuals to finer and finer regions of origin. The limits of telemetry-based approaches to investigate early marine migration of stocks across the North Atlantic are continually being pushed. Data storage tags and pop-off satellite tags are also advancing tracking efforts further out to sea and with older life stages. Projects such as SMOLTrack, the Moray Firth Project, SAMARCH and SeaSalar are combining disciplines into large-scale collaborative projects. New projects that advance our understanding of the interaction among salmon growth, the environment, survival and productivity are being pursued via scale-based investigations. A read through NASCO's Inventory of Research Relating to Salmon Mortality in the Sea will demonstrate the breadth of our current efforts.

These efforts will reveal insights on their own, but will also inform more complex and realistic models to advance our understanding of the mechanisms driving marine survival. Collaborations between salmon researchers, pelagic fish researchers, oceanographers, climate scientists, modelers etc. are needed. The Likely Suspects Framework is a good example of a holistic cross-disciplined approach to investigation salmon mortality at sea. The recently developed hierarchical Bayesian life cycle model for the NAC, SNEAC and NNEAC stock complexes (Olmos *et al*. 2018) is a quantitative tool that can start to address these complex ecosystem questions. These approaches provide opportunities to investigate the environmental drivers of Atlantic salmon marine productivity across the entire North Atlantic at a hierarchy of spatial scales.

Managing Atlantic salmon in the ocean is a daunting task. Large decreases in abundance across much of its range have been noted and although freshwater factors can be important drivers of productivity, marine impacts due to a changing climate have been cited as a primary cause. It is reasonable to wonder if any management actions will be able to counteract these declines. Until we are able to more clearly define and understand the causal mechanisms driving the decreases in marine survival, this question may be wholly rational, but premature. McHugh (1970) summed up the challenge with the following: 'Generally speaking, the degree of success is related inversely to the size of the body of water, the complexity of its flora and fauna, and the degree to which the manager is able to exercise control'.

Managing the recovery of Atlantic salmon to historical levels is a challenging task for NASCO considering the seemingly lack of marine management options (minus marine fisheries) and the more obvious domestic freshwater / nearshore management options. However, there are a number of areas where NASCO is well poised to contribute and support the management and science of the species. NASCO should continue to facilitate science-based discussions on the impacts of marine fisheries, even at their current reduced levels, in all three Commission areas to inform management at all spatial scales. NASCO should facilitate the continuation of the International Sampling program at Greenland. This program provides essential input data for stock assessments. It also provides a five decade long time series of data and samples that can support studies to retrospectively assess the impacts of a changing climate on Atlantic salmon towards forecasting impacts based on future climate scenarios. As new research tools evolve, new insights and resulting management options may develop from analysis of these historic samples. As an example, accurate region of origin assignments for fish harvested at West Greenland were not possible a decade ago, but have become commonplace. As baselines continually evolve and sample sizes increase over time, spatial or temporal-based management options may be identified to protect weaker performing stocks. NASCO should also encourage the continuation, and possible expansion, of long term monitoring programs on all life stages of the species across its entire freshwater and marine range. The data collected by these programs are the meter sticks by which researchers can measure, compare and contrast population trends and are the essential ingredients for river and/or region specific informed management. These datasets will also be essential to retrospectively assess the impacts of a changing climate to forecasting future impacts.

NASCO should also continue to provide a forum for international communication and collaboration and work to encourage, facilitate, and support international collaborative marine research programs across its range. NASCO can facilitate the archiving / protection of valuable historical datasets from marine fishery monitoring programs, can co-ordinate the best use of associated archived samples, and can serve as a resource for other groups conducting similar efforts domestically. NASCO can also serve as a conduit to develop partnerships, especially amongst non-traditional partners, to further current marine research efforts. As an example, Atlantic salmon researchers would benefit from working more closely with marine pelagic fisheries scientists to better understand the marine ecology of the pelagic zone which salmon occupy, with aquaculture experts to better understand the energetics of marine salmon, with oceanographers to better consider the influence of the ocean environment on salmon productivity, with climate modelers to more accurately evaluate future climate scenarios, with engineers to build smaller and more effective tags, etc.

Significant declines in marine productivity have been noted for all three stock complexes, although the dynamics of the declines vary (Chaput 2012). The North Atlantic Ocean in its current state is not able to support Atlantic salmon populations at historical levels. This could be a cyclic phenomenon and salmon productivity could increase again. However, temperatures are expected to increase over the next century and the prospective for Atlantic salmon in the North Atlantic is expected to be challenging with the potential for northerly range expansion and southerly retraction (Beaugrand and Reid 2012; Mills *et al.* 2013; Friedland *et al*. 2014). The ecosystem upon which Atlantic salmon depends is not a static system and our management expectations need to reflect that. The impacts of a changing climate have both local and global impacts and populations located in different regions will respond differently. Given this NASCO should continually support the evaluation of productivity estimates for both fresh and marine waters, which will largely be supported by data from long term monitoring programs. Managers should be willing to modify conservation goals and limits to reflect the reality of their populations and environments into the future. Managers should also support approaches that promote diverse Atlantic salmon populations that produce the maximum number of high quality wild smolts to the ocean to optimise species productivity under current conditions (Windsor *et al*. 2012).

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Pelagic fishes in the ocean, and how they may interact with Atlantic salmon

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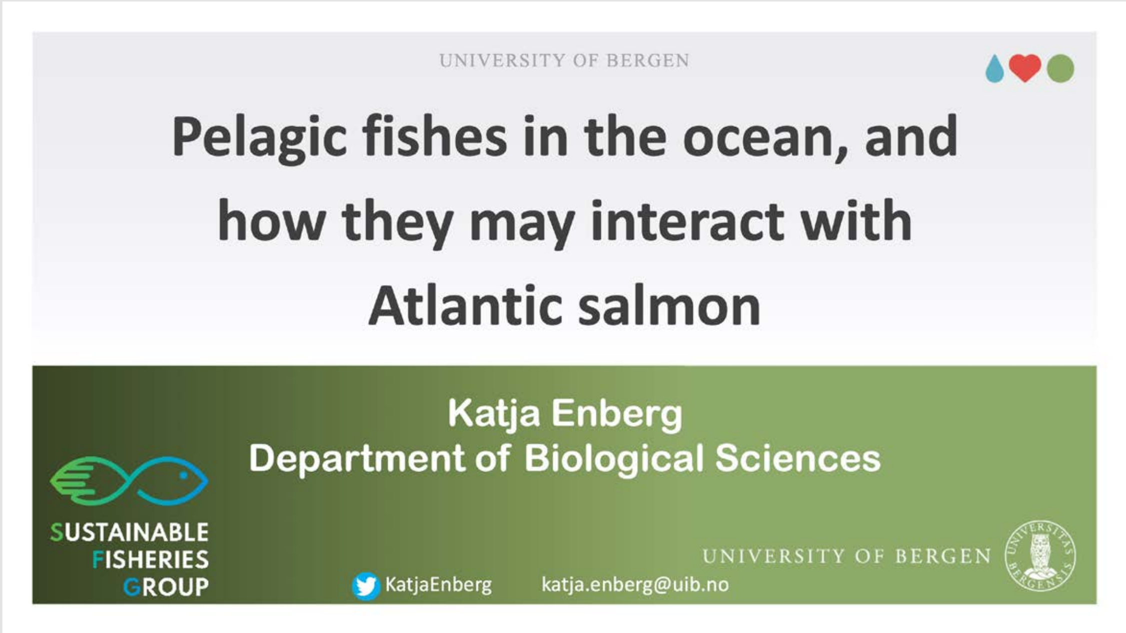
The combined biomass of pelagic fish stocks of Norwegian spring-spawning herring, Northeast Atlantic mackerel and blue whiting in the Nordic Seas increased steadily from the 1980s to the 2000s, after which it has been relatively stable. However, marked changes in the abundance of individual stocks has taken place also within the last 20 years. Herring first increased to record high levels in the recent history at around 2009, but in the absence of any strong recruitment events has been declining since then. On the other hand, the distribution area of mackerel has expanded in the North, Northeast, and Northwest, whereas the abundance of blue whiting has been fluctuating and is currently at high levels again. During the same period, the survival of salmon in the marine environment has been poor. How are these abundant pelagic fishes interacting with Atlantic salmon at sea?

In this presentation, I will integrate data from surveys across the Nordic Seas in order to discuss the premises of interactions between pelagic fishes and Atlantic salmon: the spatial and temporal, and well as vertical and horizontal overlap, which is a presumption for direct interactions between the different species. Such direct interaction explicitly requiring spatiotemporal overlap would be for example bycatch of salmon in pelagic fisheries. However, other forms of interactions do not strictly require exact spatiotemporal overlap, as the effects of, for example, foraging by one species need not to be immediate – if the food is eaten today, it will affect the food availability tomorrow and the consecutive days, too. The diets of post-smolt salmon and pelagic fish partially overlap, and some level of interaction can therefore be assumed.

Unfortunately, the data available to date does not allow for definite conclusions about the nature and importance of interactions between pelagic fish and Atlantic salmon. Nevertheless, I will draft potential consequences for fisheries management caused by the assumed interactions. Ongoing projects investigating salmon at sea will hopefully build more nuanced understanding of how Atlantic salmon is interacting with pelagic fishes in the ocean.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Pelagic fishes in the ocean, and how they may interact with Atlantic salmon
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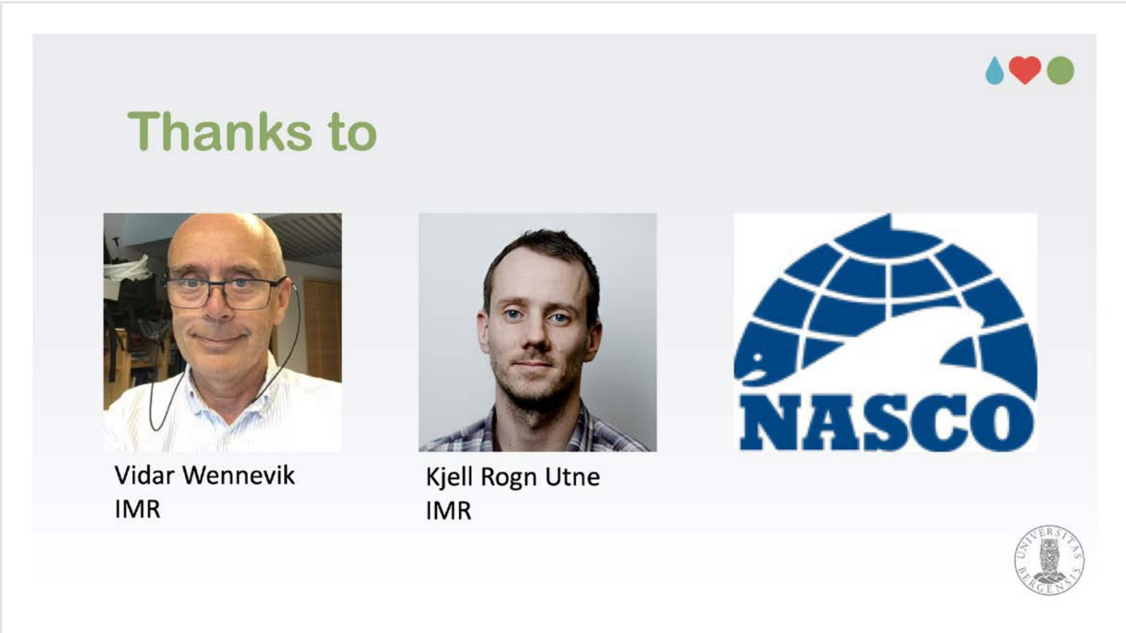
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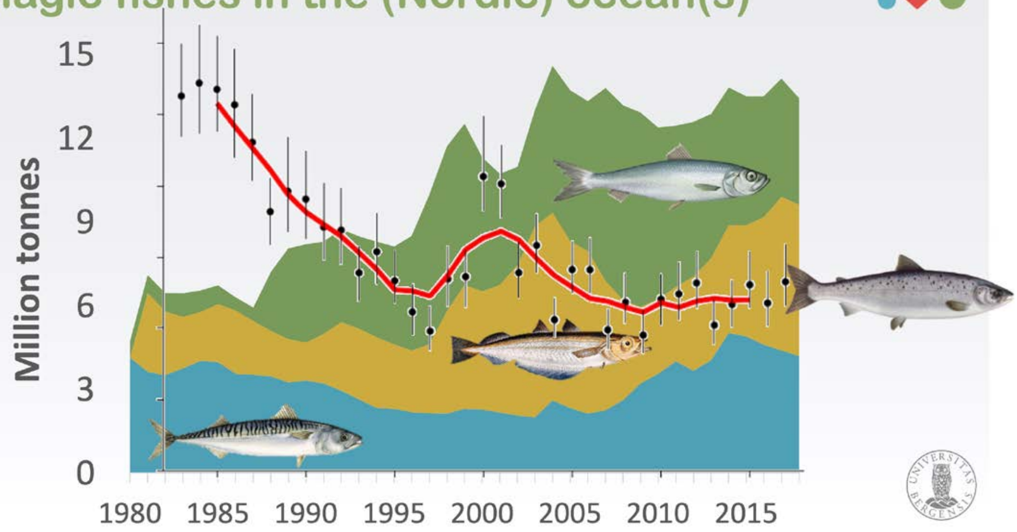
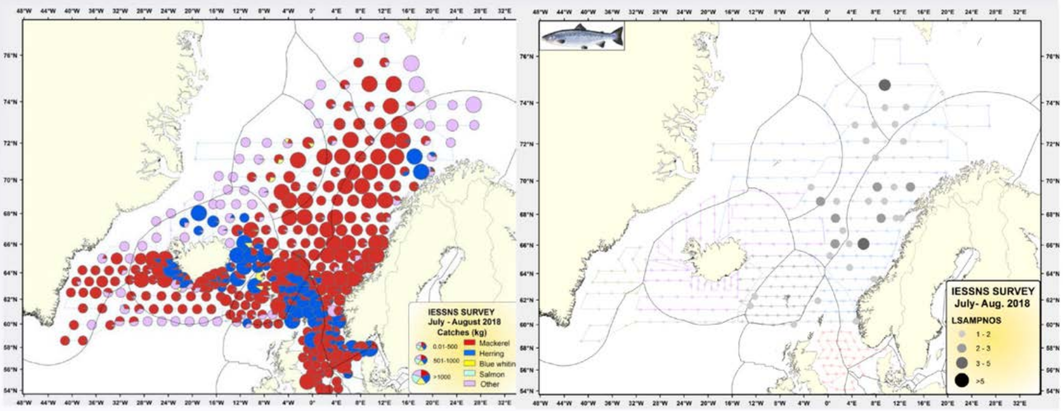
Pelagic fishes in the (Nordic) ocean(s)



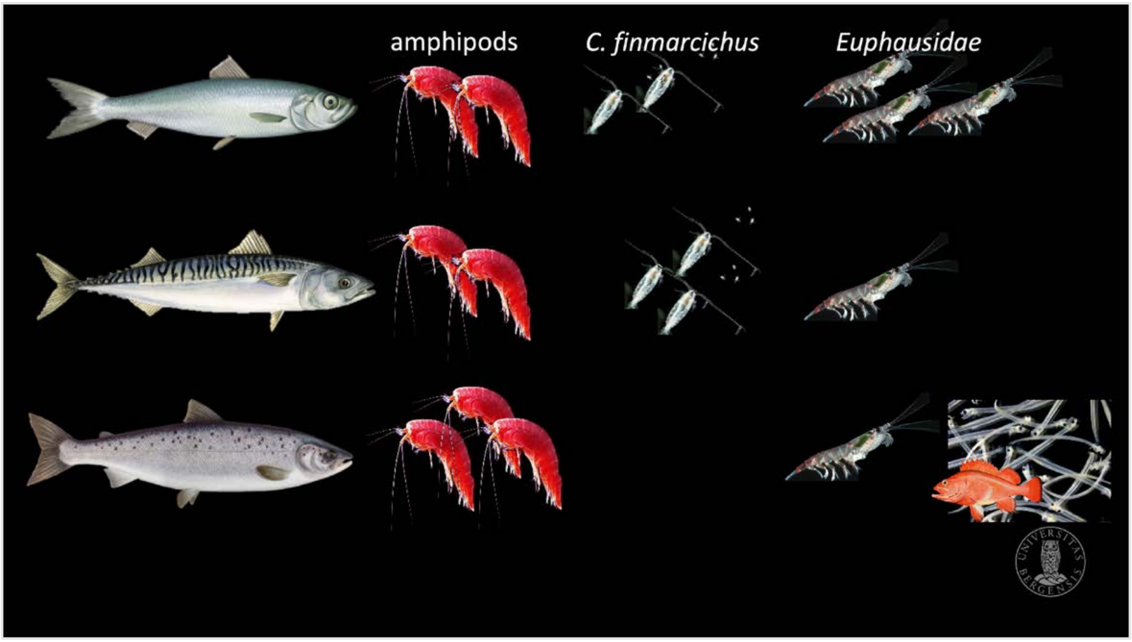
Do pelagic fish and salmon overlap in time and space?

July - early August 2018



In total 80 salmon were caught in 44 stations in the upper 30 m
Weight: 0.06 kg to 4.82 kg (dominated by post smolts weighing 80-200 grams)

Do pelagic fish interact directly with salmon at sea?



PLOS | ONE

RESEARCH ARTICLE

Bioenergetics modeling of the annual consumption of zooplankton by pelagic fish feeding in the Northeast Atlantic

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Abstract

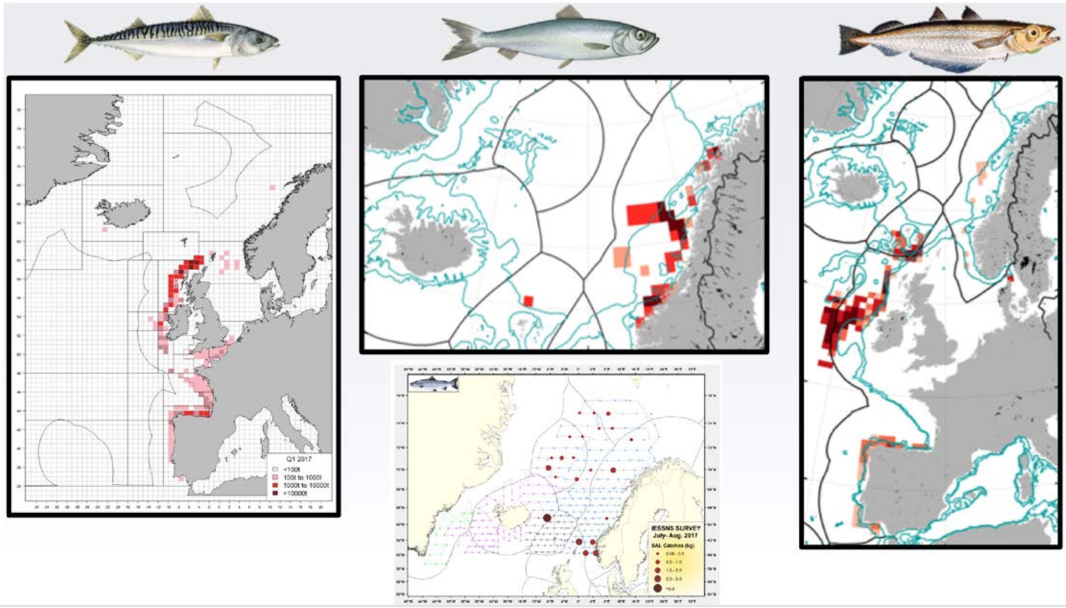
The present study uses bioenergetics modeling to estimate the annual consumption of the main zooplankton groups by some of the most commercially important planktivorous fish stocks in the Northeast Atlantic, namely Norwegian spring-spawning (NSS) herring (*Clupea harengus*), blue whiting (*Micromesistius poutassou*) and NEA mackerel (*Scomber scombrus*). The data was obtained from scientific surveys in the main feeding area (Norwegian Sea) in the period 2005–2010. By incorporating novel information about ambient temperature, seasonal growth and changes in the diet from stomach content analyses, annual consumption of the different zooplankton groups by pelagic fish is estimated. The present study estimates higher consumption estimates than previous studies for the three species and

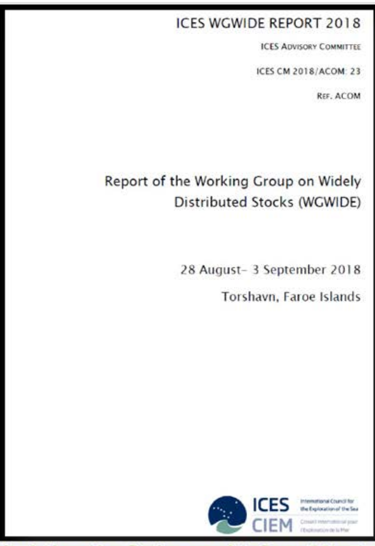
Production of *C. finmarchicus* in the Norwegian Sea is estimated at 190-290 M tonnes/year

*The three species were estimated to consume an average **of 135 million tonnes of zooplankton each year**, consisting of*
53-85 M tmonnes of copepods,
20-32 M tonnes of krill,
8-42 M tonnes of appendicularians,
0.2-1.2 M tonnes of fish

*Our results suggest that the three species **can coexist regardless of their high abundance, zooplankton consumption rates and overlapping diet**.*

Are there indirect interactions due to pelagic fisheries?





ICES WGWIDE REPORT 2018

ICES ADVISORY COMMITTEE

ICES CM 2018/ACOM: 23

REF. ACOM

Report of the Working Group on Widely Distributed Stocks (WGWIDE)

28 August- 3 September 2018

Torshavn, Faroe Islands

ICES CIEM

Workshop for North Atlantic Salmon At-Sea Mortality (WKSalmon)

ICES HQ 24-28 June 2019 (5-day scoping meeting); autumn 2019 (3-day data evaluation meeting); 5-day modelling meeting in 2020/2021

Moving forward...

Registrations of salmon tags in pelagic fisheries

Item	ReleaseArea	ReleaseDate	Recapture Plant	Recapture Area	Recapture Time
Mackerel	48F5	29.09.2011	Skude Fryseri	49E7	19.10.2013 14:53
Mackerel	32D8	14.05.2013	Egersund Seafood	50E8	19.10.2013 14:43
Mackerel	32D9	21.05.2013	Egersund Seafood	50E8	19.10.2013 09:58
Mackerel	33D7	01.06.2012	Norway Pelagic Selje	50E9	18.10.2013 17:37
Mackerel	32D8	23.05.2013	Norway Pelagic Selje	50E9	18.10.2013 17:02
Mackerel	48F5	30.09.2011	Norway Pelagic Selje	50E9	18.10.2013 11:34
Mackerel	32D7	16.05.2011	Egersund Seafood	49E9	17.10.2013 19:58
Mackerel	34D8	12.05.2012	Egersund Seafood	49E9	17.10.2013 16:17
Mackerel	32D7	29.05.2011	Egersund Seafood	49E9	17.10.2013 15:29

SeaSalar

ATLANTIC SALMON AT SEA

The Research Council of Norway

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Concluding remarks

- Pelagic fish and salmon **overlap in space and time** in the Nordic Seas
- Their **diets partly overlap**, but there are no reasons to believe that the salmon is loosing in the food competition
- Indirect effects due to **pelagic fisheries** are likely, but the extent and importance need to be studied further
- Need to coordinate and integrate throughout the whole life cycle – the management recommendations will follow


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Genetic impacts by aquaculture, climate change and stock enhancement activities

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The life history of Atlantic salmon is complex and fascinating. They are born in fresh water, where they also spend their first years, until they migrate to sea to feed. After some years at sea they return to the same river to spawn. There is much variation in the length at which they stay in fresh water and at sea, and some males do not even migrate to sea but mature as parr as an alternative mating strategy. Natural selection is constantly acting to favour the most successful genotypes in the current environment. The feature of Atlantic salmon to return to the same river as it was born; homing and the large variation in environmental conditions in the different rivers allow for local genetic adaptation. The prerequisites for such local genetic adaptation to evolve are genetic variation and restricted geneflow of mal-adapted genotypes that breaks down the genetic integrity of natural populations. On top of natural variation in environmental conditions, the Atlantic salmon must also adapt to rapid climate change. Breakdown of genetic integrity and loss of genetic variation due to genetic introgression of escaped farmed salmon and stock enhancement are likely to pose additional challenges to the viability of wild Atlantic salmon populations.

Since farming of Atlantic salmon started in the early seventies, it has grown to one of the world's most important aquaculture industries, with an annual production of 2.3 million tonnes (Figure 1). The annual production of farmed salmon in Norway is about 1.2 million tonnes and outnumbers the Norwegian wild salmon close to thousand-fold (Glover *et al*. 2017).

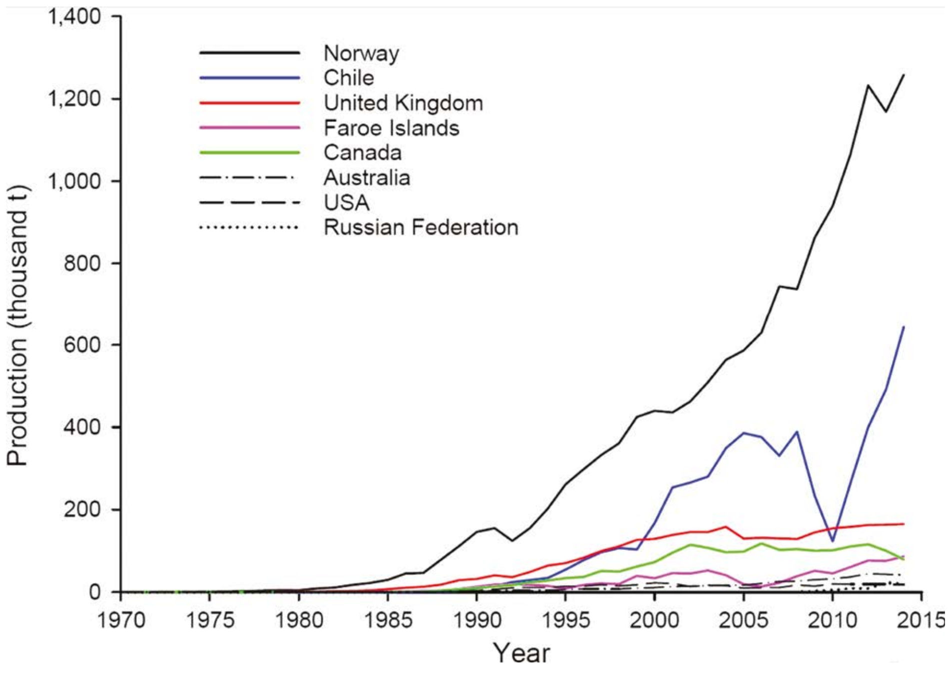

Figure 1. *Production of farmed Atlantic salmon. Figure 1 in Glover et al. 2017 ©.*

Hence, although only a small fraction of farmed salmon escape from their net pens they can make up a large proportion of the salmon at the spawning ground in the rivers (Figure 2) (Diserud *et al*. 2019; Glover *et al*. 2019).

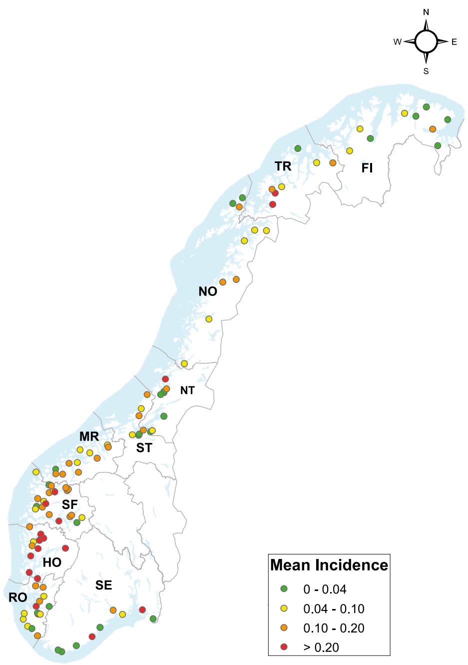

Figure 2. *Mean proportion escaped farmed salmon in 107 rivers in Norway in the period 1989 – 2013. From figure 5 in Diserud at al. 2019 ©.*

Molecular genetic markers (Karlsson *et al*. 2011) have made it possible to trace and quantify (Karlsson *et al*. 2014) the extent of genetic introgression of escaped farmed salmon in wild salmon populations (Figure 3) (Karlsson *et al*. 2016a). Among 175 populations analysed in Norway so far, about two-third have changed genetically due to farmed genetic introgression, while only one-third of the populations do not appear to be affected (Diserud *et al*. 2017).

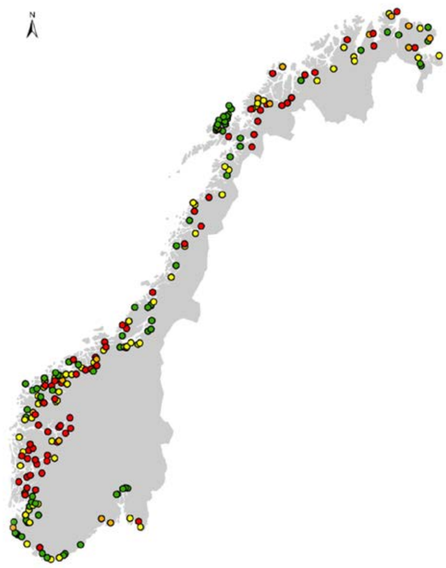

Figure 3. *Genetic introgression of escaped farmed salmon in 175 Norwegian wild salmon populations. Red is large and significant genetic introgression, orange is moderate and significant genetic introgression, yellow is weak indications of genetic introgression, and green is no introgression observed. From Diserud et al. 2017 ©.*

Due to intentional and unintentional domestication selection in the breeding kernels, farmed salmon is genetically different from its wild origin, and less adapted to the natural environment. Genetic introgression of escaped farmed salmon therefore represents the largest current threat to the viability of wild salmon populations (Forseth *et al*. 2017), as it breaks down local genetic adaptation by introgression of mal-adapted genotypes and changes important life history traits in wild salmon populations (Bolstad *et al*. 2017).

Deliberate release of hatchery produced salmon as a means to enhance salmon stocks has long traditions and is practiced worldwide. Because of evidence of potential negative genetic consequences of stocking (Laikre *et al*. 2010), the motivation for stocking has gradually shifted from enhancing population size for recreational fishing towards conservation of endangered populations. Potential genetic consequences are: 1. reduction of effective population size and loss of genetic variation due to an unproportionally large contribution of stocked individuals from a limited number of broodfish (so called Ryman-Laikre effect, Ryman and Laikre 1991; Christie *et al*. 2012; Hagen *et al*. 2019a), 2. breakdown of local genetic adaptation from the use of non-local broodfish (Hagen *et al*. 2019b), 3. unintentional domestication selection of hatchery produced fish (Arakai *et al*. 2007; Christie *et al*. 2012b; Hagen *et al*. 2019b), 4. epigenetic effects from the rearing of fish under artificial hatchery conditions (Christie *et al*. 2016; Le Luyer *et al*. 2017; Hagen *et al*. 2019b). Based on this knowledge, the Norwegian Environment agency has developed clear guidelines for when stocking might, or might not, be justified, and if regarded necessary how stocking should be practiced to minimise potential negative effects. Stocking is currently regarded as a last resort to preserve endangered populations, after other negative impacts on the populations have been improved. General guidelines for stocking include the use of only local broodfish, stocking of the earliest possible life stages to minimise the risk of unintentional domestication selection and epigenetic effects, balancing the number of stocked fish to the number of broodfish and the number of naturally reproducing fish, and lastly, to make sure that all hatchery produced fish are traceable such that the effects of stocking can be evaluated (Jøranlid *et al*. 2014; Karlsson *et al*. 2016b).

The ability of Atlantic salmon to adapt to changing environments is challenged and tested by rapid climate change. Genetic introgression of farmed salmon and uncontrolled stocking impose an extra load on the process of adaptation. We see the need to stop further genetic introgression, preferably by preventing further escape, or by the use of sterile farmed salmon. Stocking of natural population should be a last resort for preserving endangered populations awaiting improvement of the natural conditions, and if necessary, conducted in a way that maintains genetic integrity and genetic variation.

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Contributed Papers

Management Challenges and Solutions – Perspectives from Different Groups and Viewpoints

Providing the link from science to management: Overview of how humans, management institutions, and social ecological systems respond and adapt (or not) to environmental change

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Parts of this work were prepared while being funded by the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie project IMPRESS ('Improved production strategies for endangered freshwater species'; grant number 642893; http://www.itn-impress.eu*) at the Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB), Müggelseedamm 310, 12587 Berlin, Germany*

Introduction

Climate change already affects ocean ecosystems and fish populations. It is a driver that is progressing steadily and that cannot be addressed effectively within the scope of fisheries management. In order to preserve fish population and the ecosystem services that people receive from them, it is therefore necessary from the point of view of fisheries management to respond and adapt to climate change. In this paper, I give a short overview of how adaptation is conceptualised in the natural resource use literature. Using the case of Atlantic salmon (*Salmo salar*), I argue that adaptation to climate change is an inherently political and conflictive process. Finally, from a better understanding of the underlying mechanisms, I deduce what future management decisions can contribute to the adaptation of people, institutions, and social-ecological systems in the salmosphere.

I use *adaptation* here as a term for measures to reduce harm caused by climate change in order to differentiate it from mitigation measures that would directly address climate change and e.g. try to reduce emissions. In the research on natural disasters (National Research Council 2012) and ecological cycles (Holling 1973; 1986; 1992), the concept of adaptation is considered one of three states. In the first state, measures are taken to essentially maintain or return to the original state. Adaptation, the second state, is about making appropriate choices, adjustments and incremental change. The third state is transformation, a fundamental change of the system. The focus here is on adaptation, as preserving the status quo is unlikely if climate change impacts on fish stocks are already being observed, and a complete overhaul of the system is undesirable as it would likely be associated with a loss of ecosystem services from fish stocks. Positioned between the status quo and transformation, adaptation thus describes the difficult task of reacting flexibly to challenges and accepting some modifications while at the same time avoiding a profound transformation of the system to a less desirable state.

Adaptation of coupled social-ecological systems

Natural resource use systems such as fisheries can be understood as coupled social-ecological systems (SES). Social-ecological systems differ from social system in the way that 'some of the interdependent relationships among humans are mediated through interactions with biophysical and non-human biological units' (Anderies *et al*. 2004). Taking the example of fisheries, fishing modifies not only the resource system itself, but also the current and future possibilities of other actors to benefit from the system (Ostrom 2009). Salmon conservation activities not only benefit the ecosystem and create psychological benefits for the activists, they also create new social bonds within and between actor groups (Harrison *et al*. 2018). The main aspect differentiating social-ecological systems from ecological systems is the element of human intent. Ecological factors restrict human activity, but people navigate through these structures and can, to some extent, use and transform them; they have the capacity to 'manage' environmental change (Walker *et al*. 2006).

In a coupled social-ecological system, alterations of the social system can exert pressure on the ecological system and vice versa. For climate change impacts on Atlantic salmon, this means that climate change acts as *driver* and exerts *pressure* on the *state* of Atlantic salmon. Dependent on the vulnerability context of the salmon population at hand, the ecological system the burdens from climate change to some extent before the *impacts*, such as declining fish stocks, manifest themselves. Following this conceptualisation of the driver-pressure-state-impact-response (DPSIR) framework (EEA 1995), the impacts then trigger a management *response*.

Changing the disciplinary lens and focusing on the social system instead, the decline in fish stocks acts as a pressure on the social system because people face the loss of a valued species and associated ecosystems services. The impact of this pressure on the social system depends not only the ecological factor, but also on the assets of the community and its dependency on Atlantic salmon. For example, a Norwegian national program to prepare salmon rivers for climate change would be informed by the high cultural and economic value of Atlantic salmon for Norwegians as well as by the scientific, technical and economic capacity to implement such a program. Other countries in Europe might have a similar capacity for implementation, but lack the socio-cultural appreciation of salmon. Accordingly, the impact on these countries caused by decreasing salmon stocks and thus their response will differ. In summary, climate change is a driver for both the ecological and the social system and the human response to its impacts undergoes its own cycle before feeding back into the ecological system.

The political space between individual action and social structure

So far, I have described how ecological and social systems are linked to each other and presented the concept of adaptation as the tension between a system's need to preserve itself and its identity while being flexible enough to deal with pressures and to change accordingly. Human efforts to adapt to impacts such as decreasing fish stocks can be divided into an immediate, short-term component, the coping strategy, and a repeated, long-term component, the adaptive strategy. For example, the short-term responses of hunting communities that have to cope with climate change could be modifying the what, where, when or how of hunting; the corresponding adaptive strategy could be called flexibility in seasonal hunting patterns (Berkes and Jolly 2002).

An important aspect is that there is a difference between adaptation as individual human behaviour (coping and adaptive strategies) and adaptation of social-ecological systems which is effectively an outcome of the individual strategies. It is always individual persons who choose and execute coping and adaptive strategies. The sum of all strategies and their successes and failures determine whether the overall characteristics of the resource use system are maintained or changed in the desired way. Only then has adaptation occurred at the system level.

People are bound in their behaviour by the conditions of the ecological system and rules of the social system (e.g., by laws). However, there is scope for action within and beyond the rules of the system, which is why management does not function mechanistically (Fulton *et al*. 2011). Management decisions are challenged and often implemented differently than expected and with unexpected consequences. This realisation can be summarised with the phrase 'managing fish is managing people' (Hilborn 2007) and has led to an emerging literature on understanding (Haapasaari *et al*. 2007; Riepe *et al*. 2017) and influencing (Fujtiani *et al*. 2016; Mackay *et al*. 2018) individual motivation and behaviour of fishers and other stakeholder groups.

However, people do not only act purposefully within the ecological and social system; they also shape the social system and thus the rules that govern their own actions. The link of how individual actions create, maintain, or change stable system patterns, while at the same time being restricted by them, has been described under the headline of *social emergence* (Sawyer and Sawyer 2005): it is a process in which individuals with different intentions, experiences and personalities interact with each other. These interactions can take e.g. the form of discourses, negotiations or collaboration. These interactions result in ephemeral outcomes such as the emergence of a topic or the assignment of a role. Their repetition results in stable structures such as roles, subcultures, collective memories and social practices; and eventually in material structures such as written texts (Sawyer and Sawyer 2005). Each of these levels may also affect the lower levels, e.g. topics and roles can determine a discourse; or existing infrastructure the scope for action of an individual.

The concept of social emergence and the description of the various levels can be used to understand how coping and adaptive strategies of individuals responding to climate change result into an adaptation (or the lack of adaptation) at the level of the social-ecological system. The negotiation and development process that turns interactions into roles and decides which topics dominate the discourse or which common social practices become written laws, is an inherently deeply political process.

From conflict to solutions

In order to trigger action in the social system, climatic change impacts first need to be perceived as a problem. Once this hurdle has been overcome, I argue that there are only three types of problems (Figure 1): First, unsolvable problems, leaving the options of either accepting the situation or searching for a solution. Second, problems with a non-controversial solution, meaning that a technical solution exists and that there is no significant opposition, so that the solution can be directly implemented. Third, problems with a controversial solution. Solutions already exist to address many of the effects of climate change and it is likely that we will find more. However, these are usually not win-win solutions, so that many solutions for climate change impacts on fish populations fall into the category of 'solvable, but contested'.

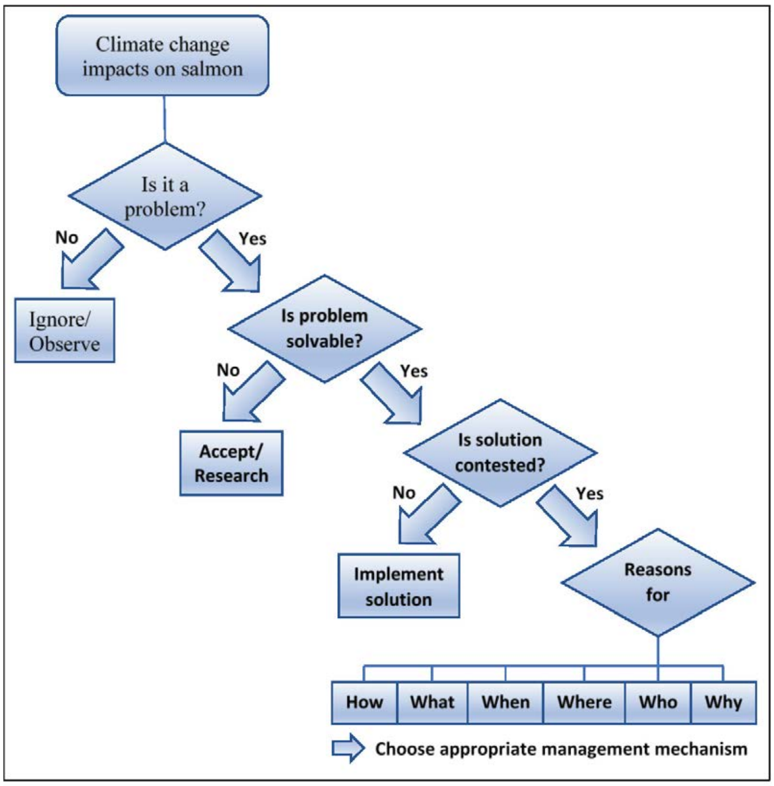

Figure 1. *Conceptual model of different types of problems.*

Once we believe that a problem is solvable, we also have an idea of who could make that solution a reality or who is in their way. That is, for climate adaptation problems, there is usually a sender (the person who chooses a coping or adaptive strategy) and a receiver (the person who is believed to be able to solve the problem) positioned in a conflictive relationship. Generally, it appears that the discourse on climate change adaptation is focused on the 'what is the solution' and less on the 'who could implement / who is prohibiting the implementation of the solution'. Fisheries management in contrast often involves institutions that are in a position to solve problems, so that conflicting interactions are often targeted at these institutions. But how can fisheries management institution succeed in climate change adaptation?

My view is that conflicts are not automatically a negative process that need to be avoided. Instead, fisheries management can choose the right instruments to implement solutions by identifying why people disagree. In salmon management, I suggest that people agree on the how, what, when, where, who and why:

- *How?*; These are disagreements about which management measures to choose. It can come to surprisingly strong disputes around management measures. The disagreement can be based on people having different information or evaluating the same information differently. They might have had different experiences and developed a preference for certain measures. However, conflicts about management measures often are actually a different type of conflict (e.g., different underlying goals and values).
- *What?*: These are disagreements about the goals for salmon conservation and climate adaptation. There is widespread agreement that Atlantic salmon should be maintained as a species. However, there is discussion about what a good fish is and whether fish derived from mitigation projects raised in hatcheries or fish containing genetic material from aquaculture fish are also worth preserving. There also exist different opinions about the desirable size of salmon stocks, e.g. whether it is enough to have a self-reproducing salmon stock in the river, or whether a stock needs to produce enough fish for fishing and needs to be of a similar size to historic levels.

- *When?*: These are disagreements about the required speed to implement changes. For example, older stakeholders have been found to prefer management measures such as stocking that might enable a faster recovery of salmon stocks. Younger stakeholders are likely to be more concerned about climate change impacts that manifest in the future.

- *Where?*: These are disagreements about where to concentrate efforts for salmon conversation. With the multiple pressures on salmon populations, there are already decisions being taken about which rivers are rehabilitated or restored in a way that they can once again carry a salmon population, and which are not. With the effects of climate change further discussions will be needed to decide in which rivers adaptation measures can be successfully carried out and for which populations there is no viable solution.

- *Who?*: These disagreements are about personal relationships. Fisheries management can be a small world. Conflicts between people in management positions who have had a problematic relationship in the past can have an impact on the whole system. What is more common is that personal attitudes toward one group (such as a mistrust towards management, or management's distrust of a stakeholder group) then influence the interactions between these groups and thus the system-level outcomes.

- *Why?*: These disagreements refer to value conflicts. In salmon management, there is a shared understanding of the value of salmon; but people do not agree on the role of different ecosystem services, and for example, whether salmon should be preserved for their own sake or for their use by fishermen. For this type of value conflict, it is often not possible to find a compromise. Changing values is one of the most effective leverage points for changing a system (Meadows 1997), but it is also one of the hardest steps to take.

For the implementation of climate adaptation measures, it is essential to understand why this is discussed controversially as this is the basis for choosing the best course of action. I suggest:

- conflicts about the *how*: information sharing and joined fact finding; transdisciplinary adaptive science and finding the best solution together through common action;

- conflicts about the *what*: Identify different goals and make trade-offs transparent; agree on shared values and negotiate compromise;

- conflicts about the *who*: understanding the social network of salmon management; forming strong networks based on repeated interaction and collaboration to build trust; and

- conflicts about the why: Reflect on different values and accept deviant positions.

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European indigenous people's perspectives and traditional knowledge

Silje Karine Muotka , the Sámi Parliament in Tromsø, Norway

Allow me first to thank the organizers for providing me, as a representative of the Sámi Parliament in Norway, the Sami people's elected body, the opportunity to address this Symposium on managing the Atlantic salmon in a Rapidly Changing Environment. I also take this opportunity to congratulate NASCO (North Atlantic Salmon Conservation Organization) and NPAFC (North Pacific Anadromous Fish Commission) and all of us on the initiative for the International Year of the Salmon.

I bring you greetings from our president, Ms Aili Keskitalo. Unfortunately, she was unable to be here today. She asked me to wish everyone good luck with the symposium, and to tell you that she hopes it will be a great success.

On behalf of the Sámi parliament, it is my pleasure and honour to welcome all of you to Sápmi, the homeland of the Sámi people. Our settlement area extends over four national states, Norway, Sweden, Finland and Russia. I hope you will have a great time her in Tromsø, or Romssa as it is called in the Sámi language.

Romssa has been traditionally and still is an important gathering place for Sámi's. There is a high number of Sámi's living here. The university has many Sámi students. In addition, you can find many institutions in the city that researches and work on Sámi issues.

At Tromsø Museum, there are exhibitions of the Sámi, separated between the traditional Sámi and way of life, and the modern Sámi and how it is to be Sámi today. I recommend you visit the Tromsø Museum during your stay.

As we know, the Sámi people are one of several indigenous peoples in the Arctic, with differences in language, social organization and influence on our own future. However, the indigenous peoples in the Arctic have at least one thing in common: the basis of our lives and culture are tied very much to gathering of renewable resources. Quite a lot of identity and cultural self-understanding is related to how we make use of and connect ourself to resources and landscapes.

This is also the case in the relationship between the Sámi people and the Atlantic salmon. Sámi and others who live along the coast are entitled to fish for salmon in the sea and in the rivers against the background of settlement and based on use since time immemorial and local and Sámi customs. Our homeland, Sápmi, includes many of the famous salmon rivers in this area, like the Tana-river, a border river between Norway and Finland. Sea-salmon fishing in our fjords has long traditions.

Today, salmon fishing is of importance as well as income, often in combination with other traditional industries such as fresh and seawater fishing, small scale farming, hunting and gathering, and reindeer husbandry. The salmon's central position is made visible through our vocabulary and the food we eat. We also have traditional knowledge about the salmon life cycle. The Sami Parliament aims to ensure that our Sámi salmon fishermen will be able to continue to harvest as they have always done.

Traditional knowledge is clearly visible in the practices of salmon fishing. It makes visible the continuity in practices and communities of practice. The knowledges are expressed by the observations that people make, and through the relations that they have to the salmon. Different kinds of relations are established through different kinds of fishing methods. Both in the fjords and in the rivers. The rivers is for example experienced differently by different actors. The Sámi concepts that describe the water levels in the rivers can have different meanings. They are dependent on how people fish and where in the river the fishing takes place. Traditional knowledge is expressed through practices, observations and stories.

It is our experience that state regulations on the management and exercise of the fishing do not take into account traditional knowledge. Even if the regulations facilitate a local, rights-based management of the fishery resources. Traditional knowledge practices are different from the public management practices which are mostly based on scientific knowledge. If traditional knowledge is to be brought into such management, the differences between knowledge practices have to be recognised. Those differences require space for expression. Traditional knowledge will only become available to public management if this can be achieved.

Climatic change is taking place more than twice as fast in the Arctic as elsewhere in the world. In our area, we are not talking about 1.5 or 2 degrees of warming, but perhaps of 4 to 6 degrees already by 2050.

Changes in temperature drive many of the changes underway in the Arctic. Rising air, surface and ocean temperature accelerate the melting of snow and ice, including glaciers, and affect the chemical and biological systems in direct and indirect ways. Marine environments are affected. We know that ocean acidification and other environmental stressors may affect specific Arctic ecosystems and ecosystem services, and are affecting the livelihoods of Indigenous Peoples.

The Sámi way of life and our traditional livelihood, especially in relation to fresh and seawater fishing, is therefore seriously threatened by climate change. Sámi traditional industries are a cornerstones of Sámi culture, such threats can have fatal consequences for the future of our Sámi culture and community life.

The Sámi Parliament agree with the aim of the International Year of the Salmon. We must build resilience for the salmon and the communities that relay on the salmon fisheries. It is time to bring people together and share knowledge, raise awareness and take action. We recognise that salmon fishing must take place in a sustainable manner.

Finally, Mr Chair, I must address our major concern. We cannot longer live with the disproportional reducing of the Sámi salmon fisheries in favour of tourist fishing and other states considerations. We simply ask for justice.

The Sámi Parliament ascertains that the current sea salmon fishing regulations are very strict and that in 2016, the authorities introduced further restrictions in the fishing season in certain areas, so the very basis for the existence of salmon fishing in the sea is seriously threatened.

In 2017, the relationship between human rights and the Norwegian authorities' regulation of salmon fishing in the Tana watercourse became strained. Following vehement protests from the Sámi Parliaments in Norway and Finland, the Tana watercourse fish resource management, the municipalities involved, and all of the rights holders' organizations, with narrow majorities, the Norwegian and Finnish Parliaments ratified a new agreement in 2017 between Norway and Finland on fishing in the Tana watercourse and related watercourse regulations. The agreement has both procedural and material shortcomings that run counter to human rights.

The Sámi Parliament is of the opinion that efforts must continue to be made to renegotiate the Tana Agreement, so that it safeguards rights in relation to the watercourse and is experienced as legitimate and fair by the rights holders.

Ollu giitu - Thank you for your attention!

Perspectives, challenges and opportunities for Indigenous rights-based fisheries in a modern context

Shelley Denny, Unama'ki Institute of Natural Resources, Nova Scotia, Canada

Today, Indigenous rights-based fisheries for Atlantic salmon in Eastern Canada are a result of a complicated, legal intersection of colonial governance and legal victories for Indigenous nations across Canada. To appreciate the complexity, a brief overview of the historical and legal landscape of Indigenous peoples in Eastern Canada will provide the foundation for Indigenous perspectives, challenges and opportunities experienced in today's context of salmon governance. In particular, Indigenous perspectives of salmon management, conservation and values will be highlighted alongside the challenges arising from *Indian Act* legislation, legitimacy of governance, and power imbalances. Current and future opportunities available to address salmon management challenges in Eastern Canada may arise in current governance processes, proposed amendments to the *Fisheries Act*, and willingness of both parties to collaborate and co-develop conservation strategies.

PERSPECTIVES, CHALLENGES, AND OPPORTUNITIES FOR INDIGENOUS RIGHTS-BASED FISHERIES IN A MODERN CONTEXT

Shelley Denny (Canada)

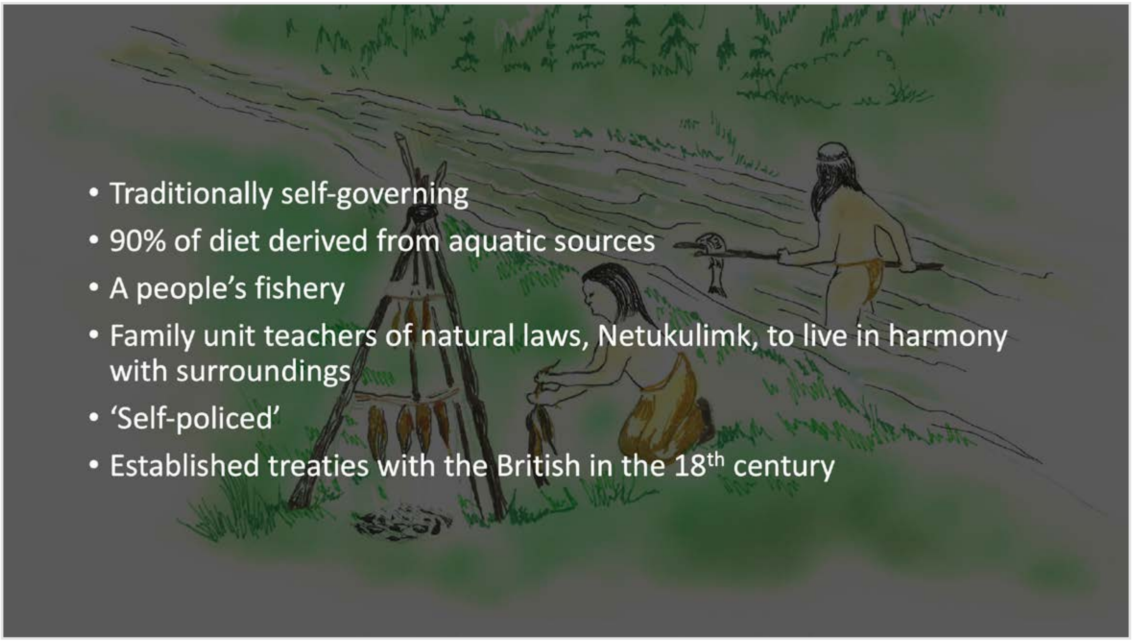
Illustration: 'Midnight Run' by Loretta Gould

Overview

- Context
- Historical, Legal & Political Landscape
- Indigenous perspectives
- Challenges
- Opportunities
- Recommendations
- Fisheries Western Indigenous Knowledge Systems research partnership - fishwiks.ca

Historical Landscape

- >60 Indigenous nations
- <3% of Canada's population
- Eastern Canada
  - Mi'kmaq
  - Wolastoqey
  - Peskotomuhkati
  - Innu
  - Inuit



Legal Landscape

- *Indian Act*, 1876
- *Constitution Act*, 1982 s. 35
- *Simon v. The Queen, [1985] 2 S.C.R. 387*
  - Recognized treaties were not extinguished
- *R. v. Sparrow, [1990] 1 S.C.R. 1075*
  - Aboriginal right to fish for food, social and ceremonial needs
  - Priority of access
- Duty of Crown to Consult

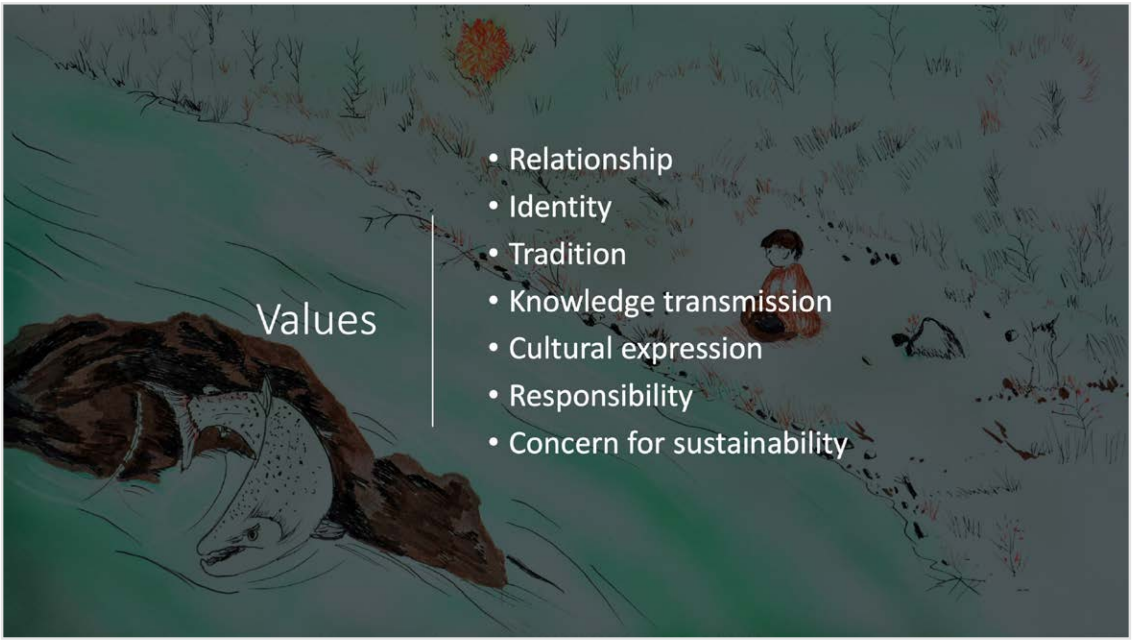
Legal Pluralism

- Overarching CHALLENGE for managing Indigenous relations to salmon
- Incredible OPPORTUNITY for governing Indigenous relations to salmon

Perspectives

Kluskap was so glad for his nephew's arrival to the Mi'kmaq world, he called upon the salmon of the rivers and seas to come to shore and give up their lives. The reason for this is that Kluskap, Netawansum and Nukumi did not want to kill all the animals for their survival, so in celebration of his nephew's arrival, they all had a feast of fish. They all gave thanks for their existence. They continued to rely on their brothers and sisters of the woods and waters, and on each other, for their survival.

Excerpt from the *Mi'kmaq Creation Story*



WESTERN PERSPECTIVE	MI'KMAQ PERSPECTIVE
Worldview * Western, scientific based reflected in belief of human superiority * Application of single rule to multiple watersheds	**Worldview** * Multiple ways of knowing * Equality of life with humans as part of the ecosystem * Mi'kmaq knowledge place-based
Management Philosophy * Species specific * Surplus production model * Policy based; written	**Management Philosophy** * Customary laws: Oral tradition and practice * Applies to all resources, habitat included * Relationship, respect, reciprocity
Beneficiaries * "Resources" for human benefits	**Beneficiaries** * "Gifts" extend beyond human needs
Management * Hierarchical and segregated structure of science and management * Prescriptive	**Management** * Holistic – includes habitat and spirituality * Preventative * "Netukulimk"- no waste, take what is needed
Conservation Measures (e.g salmon in NS) * Zero retention * Max daily limit for "catch & release" (C&R) * Prior to 2015, targeted smaller portion of the population (grilse; <63 cm); no retention of MSW	**Conservation Measures** * Rotational fishing – sharing of rivers * Opposed to C&R fisheries * Do not target one stage (balance) with emphasis on taking what Mother Earth "offers"
Knowledge Used in Decision Making * Quantitative, scientific assessment * Advisory committees * Open to IK only as TEK as information to feed into science	**Knowledge Used in Decision Making** * Quantitative and qualitative * Open to science as a tool but fishing methods don't "fit" assessment criteria (spear vs reel)

Challenges: The *Indian Act*

- Nations separated into First Nations
- Competition for resources
- Imposed Western governance
- Lack of recognition of traditional governance
- Create operational challenges between Mi'kmaq-Mi'kmaq and Mi'kmaq-Federal/Provincial

Challenges: Legitimacy of Governance

- Difference in management based on differences in beliefs, values, and practice
- As rights-holders, decisions to fish rests with the fisher
- Communities lack consultation processes regarding impacts of signing agreements
- Processes used by DFO are legitimate to DFO, not Mi'kmaq rights holders

Challenges: Power Imbalances

- Legal recognition of treaties reinforces Mi'kmaq sovereignty
- Disempowered and marginalized
- Role of Indigenous peoples in co-governing resources
- Imposed agreements
- Limited access
- Lack process for input
- Strained relationships

Excluded from conversations that directly impact Indigenous relationship to salmon

Opportunities: Current Governance Processes

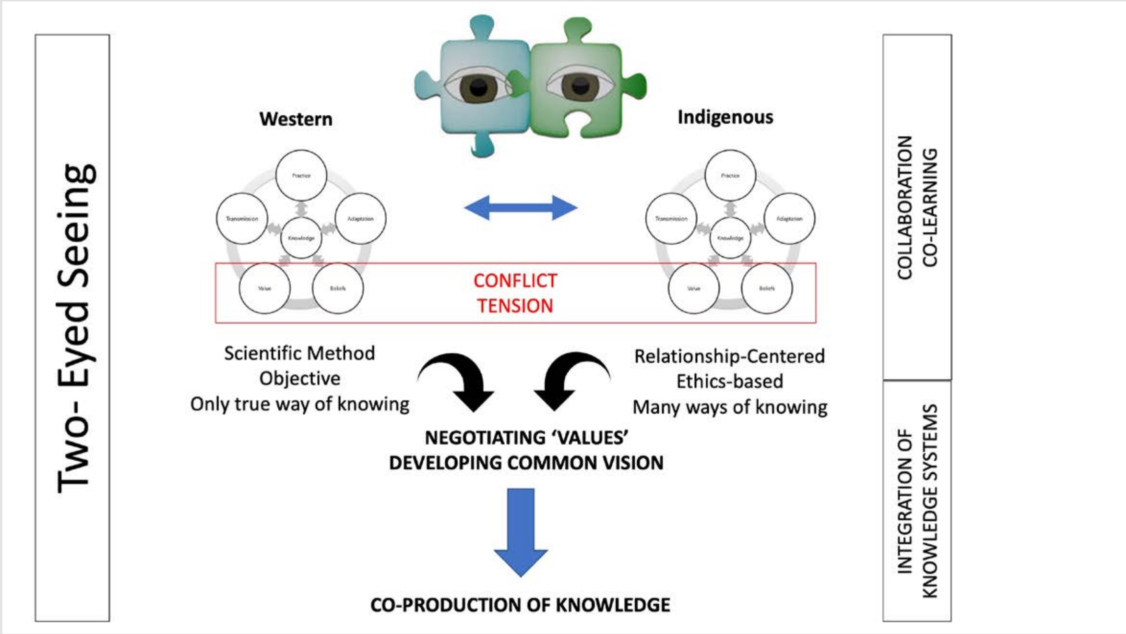
- Tri-partite consultation process
- Terms of reference (TOR) lays out the rules of interactions
- Aboriginal Aquatic Resources & Oceans Management (AAROM)
- Requires other processes to enhance legitimacy

Opportunities: Amendments to the *Fisheries Act*

- Proposed amendments to
  - consider effects of decisions impacting Indigenous rights,
  - provisions to consider and protect traditional knowledge, and
  - authorize agreements with Indigenous governing bodies to further the purpose of the Fisheries Act
- Create opportunities for governance - interactions needed to solve problems and create opportunities

Opportunities: Collaboration and Co-Developing Conservation Strategies

- Willingness
- Explore perspectives through interactions
- Two-Eyed Seeing – an approach and tool
- Applied in Nova Scotia
- Respecting values of both Mi'kmaq and DFO within Conservation Harvest Plan



Summary

- Salmon is integral to identity of Indigenous peoples – it's in our best interest to sustain salmon
- Salmon 'management' is complicated by historical, political & legal context
- Recognition of legal pluralism and demonstrated more than one way to achieve conservation goals
- For the most part, opportunities are addressing specific challenges
- Exception: power imbalances

Recommendations to NASCO

1. **Management** → GOVERNANCE
    - This requires reconceptualizing governing 'players'
2. **Encourage member countries to acquire Indigenous perspectiveS**
    - This requires developing collaborative processes through structural change
3. **Make room for Indigenous REPRESENTATIONS in NASCO**
    - This requires structural change


Illustration: ‘Midnight Run’ by Loretta Gould
SAVE THE DATE
Honouring Salmon through Ceremony
June 21, 2019
INTERNATIONAL
YEAR OF THE SALMON
UINR

The Greenlandic subsistence fishery

Rasmus Nygaard, Greenland Institute of Natural Resources, Nuuk, Greenland.

This paper has been produced in connection with the International Year of the Salmon symposium held in Tromsø 3-4 June 2019. The paper provides an overview of the Greenlandic historic fishery and the current subsistence fishery and the basis for Greenland's presentation during the symposium for the session *Management Challenges and Solutions – Perspectives From Different Groups and Viewpoints*.

Historical overview

The fishery targeting Atlantic salmon around Greenland developed during the 1960's and involved vessels from several nations, including Greenland, fishing with drift nets off the West coast of Greenland. The fishery peaked in 1971 with a catch of more than 2,600 t. The fishery was quota regulated from 1972, but due to declining stocks, in June 1998 NASCO agreed that no commercial fishery for salmon should be allowed, and catch at West Greenland should be restricted to internal subsistence fishery. Since then, both export of salmon and drift netting outside the 12 nm zone has been banned by law. A commercial 'non-export' quota was set in the years after, but in 2002 KNAPK[1] and NASF[2] agreed to stop the landings of salmon to factories and instead NASF provided funding to seek alternatives to the salmon fishery. From 2002, licensed fishermen were allowed to sell salmon to institutions, local markets and restaurants only. After public pressure, the agreement was cancelled in 2012 and the Government of Greenland allowed factory landing at a few selected settlement factories producing exclusively for the Greenland home market in 2012-2015. In 2016 and 2017, factory landings were not allowed by the government and in 2018, a new KNAPK and NASF agreement was made for the 2018-2030 period.

About Greenland

The total area of Greenland is 2,166,086 km^2, of which the Greenland ice sheet covers 1,755,637 km^2. The total population is around 56,000 inhabitants making Greenland one of the least densely populated areas in the world. About 80 % of the population lives in one of the 16 cities and the rest lives on one of the 60 smaller settlements. One third of the population live in Nuuk, the capital and the majority of the population lives in east Greenland. A little agriculture and farming does exist in south Greenland, but the traditional way of life is fishing (shrimp, cod, Greenland halibut, snowcrab, Salmon, char and more) and hunting (marine and terrestrial mammals) and fishing and hunting still constitutes the major part of the Greenland economy.

Biology and current fishery

Salmon caught in Greenland are mostly 1SW salmon migration to feed on capelin, squid and Themisto along south and west Greenland. With the closure of the offshore fishery, the current fishery mainly takes place in the coastal zone close to cities and settlements. The only documented spawning population of Atlantic Salmon, is the Kapisillit River salmon located in the inner part of the Nuuk fjord, in West Greenland. A monitoring program for the Kapisillit river was initiated in 2017.

Management of the fishery

The Government of Greenland sets the quota and the conditions / rules for the subsistence fishery each year, after consulting stakeholders and scientists. The conditions for the fishery is laid out in an executive order, the latest is the *Government of Greenland Executive Order no. 5 of 21. September 2018 on fishery for salmon.*

The salmon fishery has in later years been restricted to a period from 15 August – 31 October or until the quota is utilised. The quota and the conditions for the fishery covers all of Greenland – and not just West Greenland. Even though, hunting is the main occupation in East Greenland, a small number of people also fish both for private consumption and professionally.

Since 1997, it has been also been mandatory to report private catches of salmon, which is unique for this fishery. Fishery for private consumption for all other species are not regulated or conditioned by reporting requirements as it is essential for the livelihood that people can fish, hunt and collect food in nature. The new *Multi-annual Regulatory Measure for Fishing for Atlantic Salmon at West Greenland* agreed at the 2018 NASCO Annual Meeting outlines the following regulatory measures:

[1] KNAPK - Kalaallit Nunaanni Aalisartut Piniartullu Kattuffiat (fishermen and hunters association).
[2] NASF - the North Atlantic Salmon Fund.

- total allowable catch for all components of 30 metric tonnes;
- in case of over-harvest in one year, an equal reduction in the TAC will be introduced in the following year;
- all fishermen, including private fishermen require a license;
- only licensed full-time professional fishermen can sell salmon at open air markets in communities;
- all licensed fishermen are required to report on their fishing activity and harvest, including zero (0) catch;
- licensed fishermen who have not reported on their fishing activity, including zero (0) catch reports cannot get a new license until the reporting from the previous season is received;
- follow-up with fishers who have not provided a full accounting of their fishing activities after the season;
- as a condition of the license, fishermen must allow samplers from NASCO sampling programme to take samples of their catches upon request.

Besides the NASCO regulatory measures, there are additional regulations and criteria for the fishery depending on which component that the fishermen belong to. For the professional, full-time fishermen the following criteria and regulations apply;

Criteria that you need to fulfil, in order to be eligible for a commercial license:

- only fishermen with the majority of the income from fishery and hunting and a permanent association to Greenland can obtain a commercial license;
- a license must have been owned in the previous year;
- full accounting of fishing activities and harvest, including zero (0) catch for the previous year must have been reported;
- own salmon nets and a vessel not longer than 42 feet;
- information on number of salmon nets, type and brand must be reported in connection with the application for a license;
- only hooks, fixed nets or up to 20 nets tied in a driftnet can be used;
- nets must be marked with the owners/vessel name with external identification code;
- nets must be tended on a regular basis;
- full-time licensed fishermen can sell their catches at the local open air market or used for private consumption;
- sold catch must be reported separately.

For private fishermen, the following criteria and regulations apply;

- permanent association to Greenland[3];
- if a license was available in the previous season, a full accounting of fishing activities and harvest, including zero (0) catches must have be provided;
- private licensed fishermen can only use hooks or 1 anchored gill net (2000 knot ~60m);
- all nets must be marked with the owners name; and
- nets must be tended on a regular basis.

[3] Executive Order on Fisheries: *Landstingslov nr. 18 af 31. oktober 1996 om fiskeri, §3, stk. 4:* " 'permanent association to Greenland' is understood in this law as persons that by purchase of a household, by renting or buying a home or by other arrangements indicates intension to have Greenland as a place of residence.

Control and Monitoring

All control and monitoring is carried out by the Greenland Fisheries License Control Authority (GFLK). The GFLK employs 11 fishery inspectors that control the inshore fishery besides a number of observers on offshore vessels. Hunting and fishery officers cover the entirety of the coast of Greenland – with one fishery inspector covering East Greenland. The fishery inspectors report irregularities and infringements to GFLK but it is the Ministry of Fisheries, Hunting and Agriculture that take legal action together with the police. During the salmon season, the fishery inspectors patrol intensively and they also remind fishers to report their catches as well as handing out reporting templates. All catches, including zero (0) catch must be reported to GFLK and the fishers have to report in a predetermined reporting template, which is provided together with their license. During and after the salmon fishery season, GFLK officers runs a series of targeted campaigns in order to remind fishermen to report on their fishing activity in a timely manner to ensure a real-time closure of the fishery.

Management challenges and responses

The salmon fishery poses several challenges to the management and control of the fishery. Besides the wide-spread population and the limited number of hunting and fishing officers available to cover this massive landmass, salmon is the only species where both licenses and reporting is mandatory for both private fishery and direct sales. Normal commercial fishery for all species in Greenland relies on haul-by-haul logbooks for all vessels larger than 30^{ft} operating both inshore and offshore. Besides the well-established logbook system, factories report every landing on a daily and individual basis for all vessels, boats, dog sledges and the like. This way all commercial fishery is registered one way or the other every time a gear is set. Since salmon are not landed to factories, but sold directly at open markets, hotels and institutions or caught for personal consumption, the catches of salmon fall outside the normal well-structured systems. Obviously, these issues pose special management challenges.

Instead reporting has had to rely on people reporting to either local municipality offices or directly to GFLK via phone, phone answering machine, fax, mail, email, or text messages. Since not all people living in settlements have internet available at home it has not been possible to develop a universal system so far. Reporting to local municipality offices has also led to confusion where reports have been sent several times or delayed. In the last decade, reporting % has been limited to about 1/3 professional fishermen having commercial license to sell salmon during the season and to less than 50-100 private fishermen reporting catch out of an unknown pool of participants. For this reason, there has been speculation about the accuracy in the official landing numbers and this has led the ICES Working group to add 10 t to the official landings to account for unreported catches mainly from the private segment when providing advice.

In order to improve reporting and accuracy of the catch statistics, the Government of Greenland and GFLK has continuously worked to improve reporting through various initiatives. For at least a decade TV and radio spots has been sent daily through the national broadcasting service KNR in both Greenlandic and Danish. For the seasons 2014-2016, ***phone interview surveys*** among licensed fishermen were conducted by GFLK to increase knowledge about the 2/3 of licensed fishermen failing to report. Since 2016, fisheries officers have ***increased patrolling*** of known salmon fishing locations, ***talking to fishermen, controlling licenses*** and ***removing gill nets*** if they failed to apply with regulations or were not properly marked. Fisheries officers also increased the frequency of ***visits at local markets*** and held ***meetings with local representatives of the fishermens unions*** in cities and settlements.

For the 2018 season, ***license requirements for the private fishery*** were introduced, thereby introducing license requirements for all salmon fishery both private and professional. To ensure a strong implementation of the new regulatory measures - demanding zero catch reporting and full reporting to be eligible for a new license - GFLK and the Ministry of Fisheries, Hunting and Agriculture made ***press releases*** and sent ***letters to all licenses holders*** that had not reported on their fishing activity after the season.

The 2018 season initiatives seem to have been successful, as the reporting percentage for the commercial license holders increased to more than 70 % and the number of private fishermen reporting catch increased to 322 or 70 % of private fishery license holders. However, the increase in number of people reporting catches of salmon did not lead to a proportional increase of total reported catch and it does seem that a lot of the fishermen (private and commercial) that now report catches are reporting fairly small amounts or simply no fishery. Indeed the phone surveys and license requirements for private fishermen does imply that there has previously been some unreported fishery in the past, but not revealed a significant underreporting much different from the estimate used by ICES.

Future efforts

Although the recent initiatives have been successful in several ways, they have also revealed several shortcomings and issues. By the end of the 2018 season only 18,4 t had been registered by the GFLK thereby not reaching the quota set at 30t and closing the fishery. By the end of March 2019, it was clear that actual landings were closer to 40 t due to catch reports delayed in municipalities or in other ways. In fact, most of the delayed reports seem to have been handed in during the season and reports handed in after the season were either small or 0 catch reports. This implies that without delays in the system, it would have been possible to close the fishery.

In the coming season it will still be possible to report fishing activities via fax, phone, mail or through local municipal office, which sometimes delays the reporting to GFLK. This issue will be discussed with the municipalities as part of an evaluation of the 2018 salmon fishery and continuously followed up, in order to ensure timely reporting. However, the evaluation of the 2018 salmon fishery will also look into new ways of reporting that might increase usability for fishermen. The evaluation will be conducted by the Ministry of Fisheries, Hunting and Agriculture, GFLK and the Fishermens' Association - KNAPK.

Perspectives on wild salmon management from a salmon fishing lodge in Norway

Vegard Heggem, Rennebu, Norway

Catch and release as an important tool in local salmon management

River owners have acted on the decline in the number of returning salmon in recent decades by reducing the exploitation. This is attained not by reducing the already short fishing season (3 months), but by introducing strict bag limits, reducing the number of salmon killed.

A management regime aimed at reducing the exploitation and at the same time upholding the length of the fishing season, leads to a higher share of the caught salmon being released back to the river. On the river Orkla, the share of released salmon in relation to the total catch has gone from virtually 0% to 60-70% during the last 15 years, both as a result of statutory regulation and through voluntary practice.

A steadily growing knowledge base on the effects of catch and release on salmon, show that the released salmon have a very high survival rate, given that the fish is handled correctly. River owners are taking the responsibility of informing anglers about how to conduct catch and release in a proper manner very seriously.

In my opinion, the single most important factor in succeeding in the conservation of the salmon, is to keep as many people as possible in close relation to the wild salmon, either through recreation or work. A direct consequence of statutory regulations restricting the practice of catch and release, will be a reduction of the fishing season on Norwegian rivers. This will in turn lead to fewer anglers/less recruitment and fewer workplaces based on salmon angling tourism.

Norwegian regulatory agencies are discussing if and how to act in light of the increased practice of catch and release. Limitations on, and even a full ban of, the practice of catch and release is being discussed.

I urge NASCO to acknowledge catch and release as a vital management tool to conserve the salmon and sustain river fisheries. Strong limitations on anglers' freedom of practicing voluntary catch and release will be doing the wild salmon a huge disservice.

A shorter fishing season leads to fewer wild salmon stakeholders (anglers and tourism entrepreneurs), which leads to less vigilance aimed towards other anthropogenic factors (like salmon farming, hydropower production etc.), which in turn leads to decimation of / suffering for wild salmon at a scale that dwarfs the influence that catch and release in river fisheries can ever induce.

Impact from salmon farming

In their report 'Status of wild Atlantic salmon in Norway 2018', The Norwegian Scientific Advisory Committee identify escaped farmed salmon, salmon lice and infections from salmon farming as the major anthropogenic threats to Norwegian wild salmon. In light of the widely expressed wish for further growth in the production volume of farmed salmon, both from the industry itself and from most political parties, this is a major concern for river owners.

In order to regulate growth in Norway's aquaculture industry a colour coding scheme – green, yellow and red, hence the 'traffic light' system – has recently been put in place to identify regions where expansion can take place (green), and where production must be reduced (red), based on to what degree salmon lice from salmon farming induce mortality on wild salmon populations in the region.

River owners were shocked to learn that regions where salmon lice from salmon farming is likely to inflict mortality on up to 30% of the migrating wild post smolts, would be given yellow status (meaning no action to be taken / status quo). A possible reduction of 30% in adult wild salmon returning to the rivers will have a dramatic effect on the robustness of the salmon stock and the quality of the fishing.

The production technology of open net pens in the fjords allows water to flow freely through the pens, and thereby carry salmon lice and pathogens into the surrounding environment where the wild salmon migrate.

Production technology with closed cages is in operation and proving to be very promising. Water taken from the deep sea, which is free of salmon lice, is circulated within the cages, and the salmon is farmed free of exposure to salmon lice, hence solving the problem of infecting wild fish in the surrounding environment.

Closed containment technology also allows for collecting the enormous amounts of waste from the salmon farming, which can be recycled into biogas and fertilizer. These are valuable benefits in a time when climate change forces nations to focus on new sources of energy production and circular economy.

The salmon farming industry must be given incentives by authorities for the continued development of and transition to production technologies that do not carry parasites and pathogens into the wild surroundings.

Reflecting on challenges associated with turning science into policy

Janina Gray, Salmon & Trout Conservation, Salisbury, UK

Salmon, the king of the fish, have been keystone species across the North Atlantic and Pacific regions for thousands of years. The fish have been fundamental to humans, providing food, recreation and a special place in our cultures, every bit as iconic as polar bears or tigers. Yet, now, many salmon populations across the Northern hemisphere are at crisis point, and people who have historically relied on the fish for their food, business or recreation are looking to all of us in the scientific and political salmon sectors to act now to reverse the potentially catastrophic decline.

One of the saddest events on recent NASCO field trips followed the Annual Meeting in Happy Valley, Canada, in 2016, when we visited the small coastal village of Rigolet, inhabited almost entirely by an indigenous population, whose historical industry had been salmon fishing. We visited the ruins of the Victorian salmon factory which had been the mainstay of the economy for years, but now we were told that conservation regulations meant only seven salmon could be killed each year per household. Talking to one of the inhabitants, he lamented the fact that the closure of the salmon fishery had led inextricably to a loss of identity within the community, and that the collapse of a species upon which they had relied for centuries for food and the local economy was now leading to a break-up of their traditional culture.

So, if we are to restore salmon populations to anything like their former status, saving what is left of cultures that once relied on them, or reopening commercial fisheries that historically brought prosperity to local and national economies, or protecting recreational angling into the future, we all have a responsibility to address the bottlenecks that have led us to this state.

Catch stats, while not being entirely accurate, when coupled with fish counters, should give national policy makers a wake-up call that all is not well. For instance, it is now estimated that for every 100 salmon that leave our North Atlantic rivers, less than five return as adults– a decline of almost 70% in 25 years. However, NGO experience suggests that, with some notable exceptions, we are lacking political commitment on a hemisphere scale to protecting wild salmon and their habitats. There are many examples of this, such as;

- Norway is prepared to see 30% of its wild salmon smolts killed by fish farm lice before any serious regulation is used, while Scottish, Irish and Canadian governments seem prepared to support the commercial interests of the salmon farming industry rather than prioritise the protection of wild salmon;
- in England, successive Fisheries Ministers have promised a new Fish Passage Order for the past 12 years, each minister accepting that barriers to migration are a major bottleneck for migrating salmon. However, no such order has yet been enacted and won't be now until after Brexit – whenever that may be;
- intensive agricultural practices are widely accepted as having a serious impact on water quality and freshwater juvenile salmon habitat, yet regulation is rarely strong enough to prevent extensive damage from poor land management – despite increasing evidence that there are win-win solutions that will benefit farmers and protect the environment, if only there was the political will to drive them through; and
- while it is internationally accepted that mixed stock netting for salmon is bad management practice, controlling exploitation by First Nation people, who have caught salmon for thousands of years and their cultures are inextricably linked with the species, is politically difficult.

Governments have to make judgements as to whether to support development or the environment. All too often, we have examples of environmental degradation being acceptable because of 'overriding public interest'. But is allowing an English chalkstream to be impacted by chemicals, or forestry in Wales, or acidification of salmon spawning streams headwaters in Norway and Canada, or allowing salmon farming to impact natural resources, or hydro schemes to block passage, truly in the public interest? This short-term view resonates with the past agricultural boom which led to the nitrogen legacy our groundwaters are still impacted from today, and which continue to leach excess nutrients and chemicals which upset the balance of salmon ecosystems.

So, how does the NGO world try and influence governments that the environment, and in our case, wild Atlantic salmon, should be protected rather than dismissed when making decisions over development, or water abstraction, or farming regulations, or any other potential stressor?

We need data as evidence – because without it, we are merely individuals with an opinion, and it is just too easy for decision-makers to disregard lobbying that is not supported by sound scientific evidence.

For example, NGOs in several jurisdictions are conducting tracking programmes looking at the migration routes of wild salmon, from their freshwater juvenile habitats downstream to estuaries and the open ocean. With this data, we can then determine where fish are being lost, and what are the most obvious bottlenecks in their survival. With that data, we then have the evidence on which to base measures that have the best chance of improving salmon survival, prioritising actions that address issues over which we have some control.

In Scotland last year, two Parliamentary Committee Inquires were held into the operation of the salmon farming industry and its impact on wild fish. It was an NGO petition that was responsible for the Inquiries in the first place, and we provided the bulk of pro-wild fish evidence, both written and orally, at the Inquiry sessions. This included a Salmon &Trout Conservation (S&TC) commissioned report from the Norwegian Institute for Nature Research (Prof Eva B. Thorstad and Dr Bengt Finstad) on *Impacts of salmon lice emanating from salmon farms on wild Atlantic salmon and sea trout*. It was a classic example of how NGOs are collaborating across countries in the North Atlantic Region with academia to ensure that the evidence we produce is as scientifically robust as possible. The NGO evidence resulted in the Inquiries reporting that salmon farming in Scotland must be far more rigorously regulated in order to protect wild salmonids, and that the industry should be encouraged to move into closed containment production units that provide a physical barrier between farmed and wild fish.

In 2015, S&TC launched the Riverfly Census in England to collect high-resolution, scientifically robust data about the state of our rivers and the pressures facing them. Two of the Census rivers – the Test and Itchen – were specifically chosen because of their genetically distinct wild salmon stocks, and the need to protect the ecosystem around their freshwater stage if salmon were to continue to survive there.

River insects spend the majority of their lives in the water as nymphs, making them brilliant indicators of river health. The River Itchen is a Special Area of Conservation (SAC), world-famous chalkstream and fly-fisherman's dream for both salmon and trout. However, concerns with low *Gammarus* numbers and species richness in our Riverfly Census monitoring of the upper Itchen led us to conduct supplementary invertebrate sampling directly downstream of a salad washing plant and watercress beds. The biometric SPEAR (SPEcies At Risk), which uses invertebrate trait information to identify chemical pressure and ecological effects in rivers, suggested there was a chemical input entering the river from one or both of these sources, which subsequent chemical monitoring has confirmed.

This has led to:

- the washing plant replacing the overnight chlorine-based cleaning products with alternatives (Note the replacement chemicals are still being discharged to the river rather than the sewage system); and
- the regulator conducting extensive pesticide monitoring in the watercress farm discharge, where the presence of multiple potentially toxic compounds were found. The concentrations were also below EQS standards, but this again raises the question as to whether the cumulative impact and legacy effect of these chemicals is impacting the river's ecology.

This is ongoing, but an example of how we will use scientifically sound evidence to drive action to protect the environment for wild fish.

So, between the North Atlantic NGOs, we already have some good hard evidence over many of the issues impacting wild Atlantic salmon, but we need more targeted and strategic data so threats can be assessed, and action prioritised. For instance, while predation is considered by many to be a major factor, what evidence do we actually have of the impact – over and above what could be considered natural? And which predators – birds, seals, fish, cetaceans – man?

Once we have our evidence, the biggest challenge remains in convincing policy-makers that they need to take some decisions which sometimes the public might find unacceptable –like paying more money for salmon farmed in closed containment systems, or predator control, or more funds for enforcement of farmers who continue to pollute rivers. To do this we all need to be better at selling why it matters and why people should care. We need to sell the iconic Atlantic salmon, as Sir David Attenborough would, because if we lose salmon, we lose a food source for many people, a cultural icon, an indicator for the way in which we are managing our rivers and oceans, as well as a commercial and recreational asset.

The major management challenge remains the fact that we need to manage ourselves, and our impact on the habitats and resources on which salmon depend. We need to put the environment at the core, because long-term economic growth and healthy human populations require a healthy environment – a fact that far too many decision-makers fail to grasp. And as far as freshwater health is concerned, there is no better environmental indicator than the abundance, or otherwise, of wild Atlantic salmon.

Whilst we wait and hope for a social shift in its prioritisation and value for the environment, in the short-term we need to:

- manage, and where necessary enforce, agricultural inputs to freshwater such as excess fine sediments and phosphorus, so that spawning gravels remain healthy;
- eliminate toxic chemicals such as pesticides entering watercourses, so that water quality and the freshwater food-chain are both healthy and provide healthy habitats and an abundance of invertebrate food for juvenile fish;
- remove, or where this is not possible reduce, barriers to migration, so movement is free and predation does not get exacerbated beyond natural levels;
- use water wisely as a society; by reducing our water footprint, as well storing water where appropriate to reduce water abstraction; and
- be prepared to pay more in order to have salmon farmed in an environmentally sustainable way- closed containment.

We need to stop looking to 'solve' the salmon's problems with mechanisms such as hatcheries. Salmon can and will recolonise if given the opportunity but reducing their genetic diversity and evolved adaptations in the meantime does not help. Effective management requires political commitment to work with the water environment and restore nature's own hatchery, rather than try and recreate it artificially. This is a difficult perception to get across to people, especially those depending on salmon for food or for income from recreational angling. It is intuitive that by stocking hatchery fish into a river, more fish will return as adults but the science tells a different story and national regulators have a duty to act on that.

So, do we really want to be the generation that sees wild Atlantic salmon slide into irreversible decline, lost to all of us as food, recreation, an iconic indicator of the state of our freshwater and marine environments and gone from our cultural heritage? If not, governments – including those attending this seminar and the NASCO annual meeting – have to commit to policies which genuinely protect wild salmon and the habitats on which they depend. We can do nothing without political commitment. The NGOs can help provide the evidence and lobby the salmon's case, but ultimately it is government action – or the lack of it – that will decide whether salmon survive and thrive or are lost for ever…

Challenge of maintaining viable Atlantic Salmon populations into the future for food and social cultural needs

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Atlantic Salmon are an iconic species, not just in Ireland but right throughout the extent of their range. Why one species evokes so much passion amongst such an eclectic range of people from indigenous communities to commercial fishers, recreational anglers, scientists, policy makers and the general public is not immediately clear. There is something about the salmon, the king of fish, its epic ocean migration and the struggle it goes through to survive and spawn in its native river, which fascinates us.

It may be that in earlier times salmon was a very important part of the diet, and its annual return into freshwater to breed signalled times of plenty? In more recent times we began to understand its freshwater lifecycle and the full scale of the marine migration and began to really respect the hardship and trials that this fish endures and defies to come back to its natal river to spawn. But for whatever reasons, possibly different in each region, salmon has woven itself into the culture and heritage of practically all of the communities across the North Atlantic. In Ireland one of our most famous myths relates to 'an Bradán Feasa' - the salmon of knowledge. This fable celebrates the value of knowledge and embodies the virtue of the pursuit of wisdom and learning in the Salmon. Such tales are most likely duplicated in the traditions and practices of a host of other communities around the Atlantic basin.

It is, therefore, with a heavy heart that the extensive salmon 'community', which includes all stakeholders with an interest in salmon, are witnessing the ongoing decline of this majestic species. It is this decline and a strong focus on conservation that resulted in 2019 being nominated as the focal year for the International Year of the Salmon (IYS). This is 'an initiative to inform and stimulate outreach and research that aspires to establish the conditions necessary to ensure the resilience of salmon and people throughout the Northern Hemisphere. It is the intention of the IYS to bring people together, share and develop knowledge, raise awareness and take action'.

It would of course be preferable if the need for an IYS was based simply on celebrating its international iconic status, in a world where stocks are healthy and abundant throughout its range. But sadly the focus of IYS is also on addressing its dramatic decline.

This paper focuses on the challenges we are facing to maintain salmon populations throughout their range. Written from an Irish perspective, it outlines the actions taken by the Irish authorities to maintain salmon populations and the challenges faced in pursuit of this goal. The second part of this paper focuses on the importance of salmon for food and culture. It is not that these considerations are necessarily less important, but if we have healthy and abundant salmon populations then there should be fewer restrictions on how we seek to exploit them.

What exactly does viability mean?

Like so much to do with salmon, the term viability is open to interpretation, and stakeholders from different background often have very different views on what exactly this concept means. One of the more common conflicts we witness in salmon management is that between commercial salmon fishers and recreational salmon anglers, who can often have diametrically opposed views as to what viability actually means.

Conservation biologists consider the concept of a minimal viable population (MVP), which in its simplest form is the lower bound of a population such that it can survive in the wild. Or, to use a more technical definition, MVP is considered the ecological threshold that specifies the smallest number of individuals in a species or population capable of persisting at a specified statistical probability level for a predetermined amount of time. Conservation biologists often talk about a population big enough to have a 95% probability of survival for more than 100 years. For salmon, we have to consider a much shorter time frame given the speed of the decline being experienced in population abundance and also the generation time of the species. By way of example the total recorded harvest of salmon in Ireland in 2001 was 259,475 salmon, whereas the equivalent figure in 2006, the year before there was a compulsory cessation of drift net fishing at sea, was 108,661 salmon (CFB 2004; CFB 2008). In 2017 the total recorded harvest of salmon was 21,845 salmon. This represents only 8.4% of the harvest figure in 2001. This is however not an entirely accurate comparison, as one figure is pre the cessation of drift net fishing in 2006 and restrictions on inshore netting and angling and the second figure is post the cessation of drift netting. But of concern is the fact that the current estimated Pre Fishery Abundance

(PFA) for Ireland is between 250,000 and 300,000 salmon. Thus the current PFA is similar to the recorded catch less than 20 years ago.

In fisheries the term maximum sustainable yield (MSY) is used to identify what a viable population is and can be defined as the highest possible annual catch that can be sustained over time by keeping the stock at the level producing maximum growth. Thus, a sustainable fishery is one that is harvested at a sustainable rate, where the fish population does not decline over time because of fishing practices.

We know salmon return to their native rivers to spawn, and that most rivers have genetically unique salmon populations this occurs even in rivers which share a common estuary or are in close proximity. A manifestation of this can be the stark differences in marine survival of salmon coming from neighbouring river systems. But to further complicate matters, many river systems have a number of distinct sub-populations, which can often have different life history strategies and survival rates. This complexity poses the question for managers – at what level should we be conserving salmon? At the national level, the individual river level or the sub-population level? This question can have profound impacts on the type of management and conservation strategies deployed and the supporting resources required.

However, what is clear is that all fisheries should agree to adopt and apply a Precautionary Approach to the conservation, management and exploitation of salmon in order to protect the resource and preserve the environments in which it lives. The absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures to preserve salmon stocks for future generations, and to avoid potentially irreversible damage to populations – in fact the reverse should be the benchmark. The application of a Precautionary Approach should involve all parties concerned with salmon conservation, management and exploitation. The Precautionary Approach should also apply to freshwater habitat protection and restoration issues and the by-catch of salmon/fish in other fisheries.

What is the current situation?

Earlier in this paper the decline in the recorded salmon harvest in Ireland since 2001 has been referenced. This decline is mirrored when other data sources such as the Irish salmon fish counter time series are examined and all confirm a declining trend in the abundance of salmon at the national level. For example, when the long term data on marine survival of salmon is examined it ranges from a high of 32% survival in the mid-1980s to a low of about 3% in 2013 (Figure 1). While these represent the high and low points, the data indicates step changes (decreases) in marine survival between the 1980's, where the average was approximately 18%, to the 1990's where the average was 13%, to the 2000s where the average was 6%, and the current decade where the average is in the region of 5%. Survival rates of hatchery reared salmon released to the wild are considerably lower than those for wild salmon in all years over the time series and have been hovering around 1% since 2008.

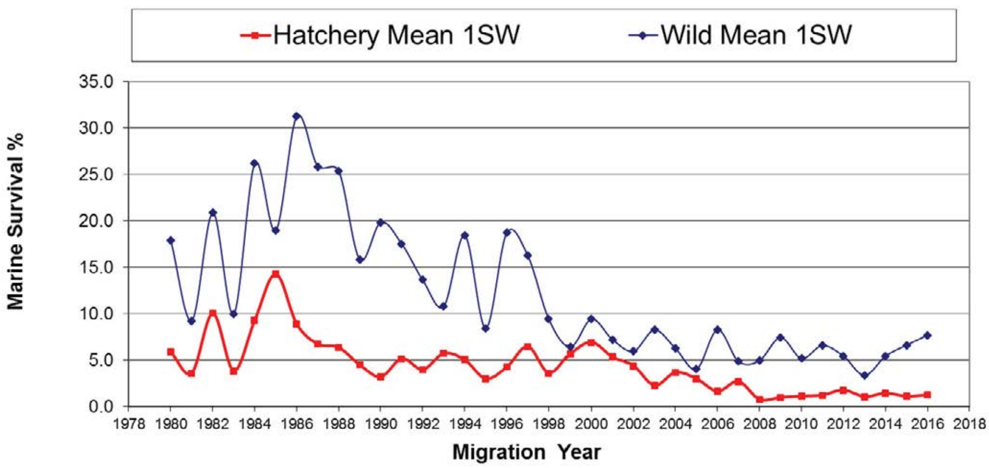

Figure 1. *Data on the long term marine survival for Irish Salmon.*

A similar trend is apparent when the long term figures on estimated pre fishery abundance were examined, with highs of almost 1.7 million salmon in the mid 1970s to the current period when the estimate is between 250,000 and 300,000 salmon.

Controlling the Controllables

One of the phrases currently in vogue in salmon management, is about controlling the 'controllables'. There are a multitude of factors which impact on the survival of wild salmon, and while there is scientific merit in understanding all of them and their relative contribution to salmon mortality, from the salmon manager's perspective it is really about what we can actually control. Thus, while understanding the impacts of global scale issues such as climate change, or availability of prey species on the high seas, or ocean warming are important there is little which can be done to resolve these issues at a national, regional or even a global scale. The focus of management and conservation measures must necessarily be on what we can control. In this context Ireland has taken a number of steps to try and arrest the decline of salmon coming back to our coast.

At successive meetings of NASCO, Ireland came under increasing pressure to comply with international best practice and to eliminate indiscriminate mixed stock fishing at sea. This culminated with Ireland committing to the elimination of theses fisheries at the NASCO 2006 Annual Meeting. Also, the European Commission took the view that by allowing drift netting (high seas mixed stock fishery) for salmon to continue in 2006, Ireland disregarded the scientific advice of the standing scientific committee of the National Salmon Commission. This is the group charged with providing scientific advice to support the management of the salmon fishery in Ireland. In their reasoned opinion delivered in July 2006, the Commission indicated that Ireland had to comply with the EC habitats directive and eschew drift netting (mixed stock fishing) in 2007 (Collins *et.al*. 2006).

Consequently a comprehensive review of the status of salmon stocks in Ireland was undertaken in 2006, the results of which advised that the most precautionary way to meet national and international objectives is to operate fisheries on individual river stocks that are shown to be within precautionary limits i.e. those stocks which are exceeding their conservation limits, and to only allow exploitation in estuaries and rivers where there was a high probability that these would only be targeting single stocks.

In summary the review also advised that:

i) fisheries should only take place on salmon stocks that were meeting their conservation limits;

ii) the management of wild salmon should be based on the individual rivers as the fundamental unit of management;

iii) harvesting should be permitted only on stocks that are classified by the Standing Scientific Committee on salmon as meeting their conservation limits;

iv) harvesting should be managed in such a way that the quantity of fish harvested does not exceed the surplus allocated in-advance of the season; and

v) the harvesting of salmon was only allowed in rivers that had an identifiable surplus and was prohibited in rivers which did not have an identifiable surplus or have inadequate information to allow an appropriate assessment or where the average rod catch is less than 10 salmon per annum.

This was a fundamental change to the management of the salmon fishery and was taken in difficult circumstances and at significant cost, €30 million, to the Irish exchequer. It also had profound impacts on those involved in the fishery. For example in 2005 there were 1,553 commercial salmon fishing licences issued in Ireland, approximately 877 of which were for drift net fishing and 518 for draft net fishing. By 2007 all of the drift net licenses and a significant majority of the draft net licenses were extinguished. The hardship scheme introduced to support this change in management direction was mandatory for drift net fishermen and optional for draft net fishermen. While a number of draft net fishermen opted not to avail of the hardship package hoping that salmon numbers would improve allowing them to re-commence fishing, in 2007 only draft net fishermen adhering to the scientific advice, as outlined above, were allowed to prosecute a fishery.

In addition to the measures imposed on the commercial fishery, a number of commensurate measures were imposed on the recreational salmon fishery. The cost of all categories of recreational angling license was doubled, so an annual national license went from €64 to €128, and all salmon fisheries were managed in line with the scientific advice. The increased license fee was directed at a salmon conservation fund concentrated at catchment based conservation efforts. Where no harvestable surplus was predicted to be available the river was closed for all harvest angling and only rivers achieving 65% or more of their conservation limit were opened for catch and release angling. Also, the precautionary approach was adopted and many smaller rivers where there were insufficient rod catch records or other data to provide information on whether a harvestable surplus was available, were closed to all exploitation.

If one is to think about 'controlling the controllables' it could be argued that in Ireland since 2007 in rivers which have not been reaching their conservation limits, salmon have had unhindered (from netting) access back to their natal river to spawn. In rivers above the conservation limit with a harvestable surplus where netting has taken place, this has been on strictly quota controlled basis. In 2001 a national salmon carcass and tagging scheme was introduced for all sectors exploiting salmon, and recreational anglers were required to attach a blue carcass tag to all salmon caught by angling. Post the cessation of the drift net fishery where there were concerns that the recreational angling effort might exploit more than the available surplus for harvest, in addition to the required blue carcass tag anglers were required to attach an additional brown carcass tag. The number of brown tags allocated to anglers was set at or below the harvestable surplus. Despite all of these measures which have had significant negative impacts on participation in both the commercial and the recreational salmon fisheries, there has been no recovery of salmon stocks and the downward trend in abundance has continued.

Given the above scenario, perhaps the question now may not be about 'controlling the controllables' but rather, what more can be done? In this regard there appears to be quite a lot that more that can be done, both in Ireland and other jurisdictions to protect and restore our salmon populations for the future. The following should be considered as basic menu of ideas which jurisdictions could consider implementing, or redoubling their efforts, to improve their salmon populations.

Sea Lice Management

Entire symposia have been dedicated to this topic, indeed there is a wealth of published scientific literature outlining the detrimental impact of sea lice emanating from marine salmon farms have on wild salmon populations, so this subject is not going to be discussed in detail in this paper. We know that sea lice can add up to an additional 39% mortality to migrating wild salmon smolts, so clearly better management of sea lice would have an immediate and significant benefit on wild salmon populations. The question then for Ireland and all other jurisdictions involved in aquaculture is, are we doing enough, and if not why not? And given the proven detrimental impact of sea lice is having on declining numbers of wild salmon why are we not making more progress on moving salmonid aquaculture into closed containment facilities to eliminate this risk?

Water Quality

Ireland, like all EU Member States, is obligated to implement the Water Framework Directive (WFD) (200/60/EC). The Directive requires all Member States to protect and improve water quality so that catchments achieve good ecological status originally by 2015 or, now at the latest, by 2027. Achievement of the water quality targets set out in the Directive will undoubtedly benefit salmon, as they require highest quality water in which to spawn and for their young to grow. Unfortunately, long term Irish data shows that while there has been an increase in water quality generally there has been a precipitous decline in the number of the highest quality, pristine, sites. These pristine sites represented 13.4% of monitored sites between 1987 – 1990, yet only 0.7% of sites between 2012 – 2015. Clearly there is much more which can be done to improve water quality. Like other Member States, Ireland has prepared a Programme of Measures (POM) for the second cycle of the WFD. This plan, the River Basin Management Plan (RBMP) contains significantly more stretched targets and action plans to improve water quality, and crucially, specific plans to both protect and restore high ecological status to a network of river and lake catchments, the 'Blue Dot' programme.

Illegal Fishing

It would not be unreasonable to say that when the salmon fishery was at its height in Ireland during the 1970s and 1980s there was a significant issue with illegal fishing. This is not unique to Ireland but is an issue in almost any jurisdiction or fishery in which there is a valuable commodity to be harvested. Considerable resources were, and currently are, expended by Inland Fisheries Ireland (IFI) supported by the Irish Air corps and Navy, who have a fisheries protection brief, to protect wild salmon. Unsurprisingly incidences of illegal fishing are linked to the abundance of target species, in this case salmon, and also the market for the species. Thus in the 1980s salmon were relatively abundant and they were a high value fish species. The salmon aquaculture industry had not yet developed to anywhere near current levels, and there was also a significant legitimate commercial fishery off the coast of Ireland. All of these factors created the ideal conditions for illegal fishing. However, since 2006 there has been no commercial drift net fishing, resulting in a significant number of fishermen no longer being on the water with drift nets, salmon abundance has declined substantially and farmed salmon have flooded the market such that salmon is no longer considered a premium product for the typical consumer. These changes have been reflected in the amount of illegal fishing detected at sea which has been declining in the latter part of the decade, with just over 30km of illegal net seized in 2011 compared to 10.4 km of net seized in 2018. Notwithstanding this, IFI, in the run up to and during IYS, have invested over €3 million in a new state-of-the-art, fit for purpose Rigid Inflatable Boat (RIB) fleet to ensure the continued and enhanced protection of the declining salmon resource. It could be argued that in the face of declining salmon numbers illegal fishing is even more pernicious and does proportionally more damage than at times when salmon abundance levels are higher, thus necessitating even more effort at protection.

Predation

At first glance predation seems like an easy problem to solve and could have immediate benefits for migrating salmon. However, it is more complex than it first appears. The predators of salmon are numerous and operate at all stages of their life cycle, however salmon are at their most vulnerable when they are on their outward migration journey as smolts. Even on this journey it is at certain 'pinch points' where predation is at its highest. Although many of these points are known, they have proved extremely difficult to resolve. In Ireland this is certainly related to the regulatory framework which is used to manage both salmon and its common predators. Salmon are managed for exploitation and therefore we have management targets, conservation limits, for every river. We know how many salmon are allocated for commercial (draft net) harvest, for harvest by recreational anglers and how many are needed to satisfy conservation objectives. Salmon are managed and legislated for under the Fisheries Acts which provide for appropriate sustainable exploitation. In contrast the main predators of salmon in Ireland are protected under the various Wildlife Acts and this legislation is focused on protecting the species, and that is where the dichotomy lies.

To manage a species for sustainable exploitation necessitates understanding its population dynamics and developing management and conservation targets which has been done for salmon. But for a protected species this is not done, certainly not in the same manner. So a simple question might be, how many cormorants do we need in Ireland? 3, 000 pairs, 10,000 pairs? And more importantly what happens if you exceed the number? None of these questions can currently be answered in Ireland. Certainly there are periodic wildlife censuses to estimate population numbers and ascertain population trends but they are not undertaken from the perspective of managing a species but rather protecting it.

It would be inaccurate to suggest that there are no provisions within the Wildlife Acts to allow for the removal or culling of nuisance animals or birds, but these provisions have been remarkably difficult to utilise by stakeholders on the ground. Therefore, there is a real sense of frustration in certain areas as to the level of predation by species, such as cormorants, on migrating salmon smolts and how this predation has the capacity to impact the conservation status of wild salmon. However even within the fisheries sector where there are predatory fish such as pike, which can at certain times and certain places, such as when salmon smolts are entering a lake on their migratory route, have a real impact. There has been significant opposition to the management of pike. Of deep concern is new research emerging from the recent series of smolt telemetry experiments supported by the EU and NASCO, which suggest that freshwater and nearshore mortality of smolts from predation is much higher that was previously thought. These results may act as the clarion call to redouble efforts to manage predation on vulnerable outward migrating salmon smolts.

The above represent only some of the additional measures which can be taken by Ireland and other jurisdictions to improve salmon populations. It is by no means an exhaustive list and jurisdictions will likely have very different perspectives on each of the measures and how they might apply in their own regions. Along with barrier removal, better regulation of water abstraction and more recently, implementing climate mitigation measures, there is much more which we can do to improve salmon populations and the critical habitats in which they live. We know that salmon have a remarkable ability to bounce back if given the right conditions, and there are many examples of their resilience. However, the long term trends should be a source of deep concern for all. In the Irish context there have been stepwise downward shifts in key metrics such as marine survival and pre fishery abundance, and if significant additional measures are not taken there is a strong possibility we will see the extinction of salmon in some of our rivers.

Finally, we would like to address the latter part of the title of this paper and that is to do with food and social cultural needs. This element has been kept to the end of the paper not because it isn't important - the opposite. It is the social and cultural factors which provide the emotional link between humans and salmon. Ultimately it is going to be this emotional connection which will provide the impetus to increase our efforts to protect and restore salmon populations. In the Irish context salmon are part of our mythology and heritage and every school child learns the story of the 'salmon of knowledge'. Salmon appear on our earliest manuscripts, was depicted on national coins and it was a valuable source of food right through the ages. It would, consequently, be inconceivable that an 'addendum' to the salmon of knowledge myth might suggest that despite all our knowledge we no longer have any salmon left. This emotional and cultural link is extremely strong.

Conservationists have identified four distinct stages in the journey to getting people engaged in a particular issue. They are making them…. 'aware'; making them …. 'care'; taking… 'responsibility' and then; taking….

‘action’. In Ireland we have not yet gone past the first step of making people aware that there is a crisis in salmon populations. Most people have no idea that wild salmon have been going through such a sustained period of decline, and much of this is due to the fact that people can buy farmed salmon so cheaply in the supermarket. The perception is that there is plenty of salmon available. It will be this emotional connection with salmon through food, social and cultural needs which will help to generate the population level awareness needed to really impact on salmon abundance.

The underlying thesis of this paper is that if we take the measures needed to restore salmon populations then there will be sufficient resources available for any particular group to exploit salmon in whatever way is appropriate to their food, social and cultural needs. This is the rationale for discussing this very important topic last.

We have dealt in a very factual way with the challenges currently facing salmon, what Ireland has done to address them and the areas for further additional work. Yet despite all we know about salmon and what needs to be ‘done’ to restore salmon populations, and what has already been ‘done’, salmon numbers continue to decline at a national level. This then brings us to a very interesting place and that is the relationship between conservation and food, social and culture needs, and more particularly where the balance lies between them. Following the cessation of off shore mixed stock fishing in Ireland in 2006, Ireland prioritised scientific advice above all other factors - if there was no harvestable surplus then no salmon were killed for any purpose.

A number of papers presented at the Symposium have looked at salmon through a specific social and cultural lens and have provided valuable insight into how they regard the salmon. The importance and richness of these experiences cannot be underestimated and ignored, however in the face of continuing declines in salmon populations the balance between conservation of salmon and their use in food cultural and social practices will undoubtedly come under increasing scrutiny.

Conclusion

Despite the considerable reductions in catches, following the closure of the mixed-stock fishery at sea in 2007, only 50% of Ireland’s 89 assessed salmon rivers are currently estimated to be meeting biologically based CLs. While 40 more rivers could open for catch and release only angling as assessments indicate relatively high juvenile densities or the stocks are meeting ≥50% of CL, it is clear the overall proportion of rivers with good population status is low. Fish counters provide the most direct assessment of salmon stock status in rivers. The number of counters installed and used in stock assessments has increased from 9 in 2002 to 28 in 2018. There has been variation in the mean count since 2002, with highest numbers recorded in 2007 coinciding with the closure of offshore drift netting. However, there has been a marked decline in salmon counts subsequently with 2014 and 2015 being the two lowest values in the entire time series. A minor upturn was evident from the series low of 2014 until 2017 but this trend has not continued into the most recent year 2018. These counter data can be considered as an index for other rivers nationally and probably reflect the national trend.

Marine survival values in the past five years are amongst the lowest recorded since the coded wire tagging programme commenced in 1980. Changes in oceanic conditions leading to poor recruitment of salmon have been implicated by NASCO following international investigations into the decline of salmon stocks (e.g. SALSEA Merge). Recent stock forecasts from ICES for stocks in the southern range of the North-east Atlantic, indicate that this low stock situation will prevail at least until 2021. Given the current poor survival, the expectation of large catches is unrealistic at present and priority should be given to conservation objectives rather than catch increases until there is a noticeable improvement in stock abundance.

In this regard, the ongoing management policy of adopting the scientific advice to only allow exploitation on stocks above CL is central to aid the recovery of salmon stocks nationally. With this policy in place, any improvement in marine survival would be reflected in greater numbers of rivers achieving CL. This will contribute to complying with ICES and NASCO advice of providing for the diversity and abundance of salmon stocks.

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Challenges Faced in Protecting and Restoring Freshwater Habitat for Endangered Wild Atlantic Salmon in the State of Maine, United States

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Introduction

Wild Atlantic salmon have been extirpated from the majority of the rivers in the United States that they historically occupied. The small runs that remain occur in approximately a dozen rivers, all located in the State of Maine, the northeastern most state in the U.S. These last remaining Atlantic salmon are protected under the federal Endangered Species Act and are considered critically endangered and at a high-risk of extinction in the near future (NOAA 2016).

The major threat facing salmon in the freshwater environment is dams, along with other barriers to migration, particularly road stream crossings. Beginning with the removal of the Edwards Dam from the Kennebec River in 1999, there has been an increased focus on addressing these threats and progress has been made. Nonetheless, there are a variety of legal, regulatory, social, and economic constraints that make it difficult to achieve the solution – dam removal – that Atlantic salmon ultimately require to have the greatest chance of persisting in the U.S. a century from now.

Background

Historically, wild Atlantic salmon were native to rivers in all 6 New England states located in the northeastern corner of the United States. Shortly after the arrival of European colonists to the region in the 1600s, the decline of salmon and a dozen other species of native diadromous fish began. Forestry, over-fishing, and mill dams took their toll and as these activities intensified over the decades, the effects on our rivers and sea-run fisheries became pronounced and obvious. By the time the Industrial Revolution was in full-swing in the mid-1800s, Atlantic salmon were extirpated from nearly all of their natal rivers in southern and central New England and greatly reduced in number in Maine. In essence, as the writer David Montgomery (2003) succinctly stated in his book King of Fish: The Thousand Year Run of Salmon, 'New England traded salmon for milldams and factories.' The same was true for sturgeon, shad, alewives and several other ecologically, socially, and economically important fish species.

The rivers of Maine, particularly those from the Kennebec eastward to the Canadian border, became the last stronghold for Atlantic salmon, though use of the word 'strong' is a major overstatement. Dams were built on Maine's rivers as early as the mid-1600s and by the end of the 1700s, local communities across the state lamented the serious decline of salmon, shad, striped bass, and alewives. By the mid-1800s, large mainstem dams on our biggest rivers were constructed, and the decline of salmon and other species accelerated with lost access to habitat, over-fishing and poor water quality. Human intervention, in the form of the nation's first Atlantic salmon hatchery and in new laws requiring fish passage at dams – plus high marine survival – prevented the extinction of Maine's salmon, though these efforts were far from adequate with respect to rebuilding the populations. Habitat degradation and fragmentation were ignored, and today our salmon runs are at historically low levels and at great risk of extinction.

Management Challenges

Today, with an average return of less than 1,000 adults over the last decade, the endangered Gulf of Maine Distinct Population Segment (GOM DPS) of Atlantic salmon is at less than 0.5% of its historic abundance. These salmon have unimpeded access to only 8% of their historic freshwater habitat due to more than 400 dams, the majority of which lack fish passage (NOAA 2016). National Oceanic and Atmospheric Administration and United States Fish and Wildlife Service have determined that dams are the most significant threat to the GOM DPS of Atlantic salmon in the freshwater environment (NOAA 2019). Additionally, the lack of adequate regulatory mechanisms under federal law to address dams and their impacts on Atlantic salmon has also been identified by these agencies as a significant threat impeding conservation and recovery of salmon.

Further contributing to the problem are the thousands of road-stream crossings that exist on the landscape that are also barriers to migration for salmon, preventing them from reaching essential spawning and rearing habitat as well as thermal refugia. Together, dams and inadequate road crossings are a lethal one-two punch to salmon, as pointed out in the Final Recovery Plan for Atlantic Salmon (NOAA 2019, p12):

The amount of accessible freshwater habitat is a fraction of historical levels; this was initially caused by building dams and later by road stream crossings that created barriers to upstream migration. Fish passage barriers continue to prevent fish from reaching essential spawning and rearing habitat. Undersized culverts create hydraulic barriers that sever habitat connectivity within the range of the GOM DPS. Improperly placed and undersized culverts create fish passage barriers through perched outlets, increased water velocities, or insufficient water flow and depth within the culvert. Poorly placed or designed road stream crossings reduce access to habitat necessary for Atlantic salmon spawning and rearing and alter stream processes including transport of sediment and materials. These barriers also impair ecological complexity and increase the salmon's vulnerability to higher rates of extinction from demographic, environmental, and genetic stochasticity.'

There is an obvious immediate need to increase salmon survival, abundance, and diversity. To do so means we need to allow salmon to reach diverse, high-quality habitats on the salmon's time schedule. This means addressing dams (and other barriers) so that they have negligible impacts on the species. Building fishways at the hundreds of dams that currently lack fish passage is not the solution. Fishways are, at best, half-measures that even when 'successful' at passing salmon and other species at target efficiencies still fail to remediate all of the other negative impacts that dams have on riverine habitat and the biological, chemical, and physical processes and functions of rivers and their associated fish and wildlife communities. Certainly, some dams will never be candidates for dam removal, and good fish passage may be the best we can achieve, but we must reconcile this with the fact that salmon need free-flowing rivers in order to survive.

Addressing Dams

In 2004, the National Research Council of the National Academy of Sciences recommended that 'a program of dam removal should be started' in order to reverse the decline of salmon populations in Maine and prevent their extinction. This has not happened. Major dam removals have occurred on Maine's salmon rivers – most notably the Edwards Dam from the Kennebec River and the Veazie and Great Works Dams from the Penobscot River – but hundreds of dams remain, and it is a herculean task to deal with them.

While there are some legal and regulatory avenues to address impacts of federally regulated hydroelectric dams on Atlantic salmon, these laws can typically only be used to require construction or improvements in fish passage, improvement in minimum flows, or changes in project operations. Dam removal has never been required to help recover an endangered species. When it comes to small, non-federally regulated dams – which are the majority of dams on the landscape – there are few regulatory or legal means to force changes to benefit salmon or other species. Even the direct appeal to these dam owners by fisheries agencies to work with them to reduce their impacts on Atlantic salmon was largely unsuccessful, revealing only a few people who were willing to remove their dam or have a fishway constructed at no cost to them.

Dams are particularly troublesome and difficult to deal with from a social perspective. As dams have been present on our rivers for centuries, there are very few places where anyone can remember what any stretch of river looked like before it was dammed. Thus, dams are often seen as permanent structures on the landscape and are also symbolic of past industrial and human history, and many people are intensely connected to 'their' dam, much more so than they are to 'some fish' that may not have been present in their river for decades or even centuries. Thus, there is often a strong, negative emotional reaction to a proposed dam removal, particularly by the residents within the community where the project would happen.

While there are numerous reasons for opposition to dam removal, in my experience a lot of the apprehension can be traced-back to a general resistance to change, fear of the unknown, or uncertainty about the future. Many concerns are based on a lack of information, which can be addressed through education and dialogue. Other concerns are value-based and some of these may ultimately be impossible to reconcile. Unfortunately, both types of concerns are often intertwined and hard to tease apart.

Dam removal is a complex and emotional decision for a community. It is fundamentally about change and people are generally resistant to change and may have intense emotional reactions to it, especially true when it is perceived that change is being 'forced' upon them from others, particularly government or environmental non-governmental organizations. In any process that may lead to dam removal, there needs to be many opportunities for education and discourse – people need to ask questions, voice concerns, and be acknowledged. Ultimately, public understanding and involvement are critical components of any dam removal or habitat restoration or protection project.

Despite the substantial social and regulatory hurdles, progress has been made to restore access to historic spawning and rearing habitats for Atlantic salmon and other diadromous fish species across Maine. Success has been more likely to happen when dam removal projects incorporate other socioeconomic concerns, such as recreation, historic preservation, and public safety. Unfortunately, this drives up the cost of these projects and requires significant public and private investment.

Social Attitudes and Values

Ultimately, our ability to persuade dam owners to remove their dams and restore salmon habitat and to get local communities to be supportive of dam removal – which is often a major hurdle – is directly and inextricably tied to human values and attitudes. Thus, better understanding of the broader social, cultural, and economic value of salmon, and connecting and integrating these values to management and engagement actions, is critical to salmon conservation overall.

From my experience over the last two decades dealing with politicians and decision-makers and working on-the-ground to implement dam removal, fishway construction, and road stream crossings replacement projects under ASF's Maine Headwaters Program, I have come to believe that loss of direct human interaction with Atlantic salmon is one of our biggest barriers to saving the species. Salmon were once enormously important –economically, socially, and symbolically – in New England, but this connection has waned over time. This is far from surprising since we have been losing our salmon for more than 300 years and most were gone 150 years ago. Most people living today in the historic range of salmon in the U.S. have never seen an adult salmon in the wild. As each generation grows further disconnected from salmon, and as the salmon themselves continue to decline in number, we are faced with growing apathy, disinterest, and even hostility toward continued efforts to save the species.

While a strong constituency remains for Atlantic salmon in Maine and the New England region, this is a very small segment of the population and largely comprised of recreational anglers. Far more people care about species like brook trout or striped bass, and many more care about wildlife in general or recreational opportunities on their river. People often care most about their local environment and have a complex 'sense of place' that can both be a challenge – dam removal may be seen as destroying the meaning of that place – and an opportunity for salmon restoration by reframing 'issues and solutions in ways that motivate and align with the shared values of people, including their sense of place' (Liebich 2018). This opens new approaches for appealing to the public to support activities that will enhance their sense of quality of place and those environmental aspects that they do value.

Salmon habitat restoration has increasingly been accomplished using a more holistic multi-species and ecosystem-based approach that focuses on restoring the entire diadromous fish community and restoring natural ecological processes within a river system. Populations of other native diadromous fish species that co-evolved with Atlantic salmon have also been greatly impacted by dams. These include alewives (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), American shad (*Alosa sapidissima*), sea lamprey (*Petromyzon marinus*), American eel (*Anguilla rostrata*) and rainbow smelt (*Osmerus mordax*). Even if salmon is a key driver of these restoration efforts, the adoption of a multi-species approach not only makes sense ecologically, but it also attracts various other constituencies and stakeholder groups that may not care about salmon but do care about river herring, sturgeon, eels, or the scores of other fish and wildlife species in the riverine, estuarine and marine environments (e.g., eagles, osprey, otters, seals, whales, groundfish) that benefit from healthy rivers and revitalised runs of diadromous fish.

We have been tremendously successful at restoring river herring – alewives and blueback herring – to Maine's rivers. With runs across the state now numbering in the tens of thousands to the millions, revitalised river herring runs – which are highly visual, tangible and awe-inspiring – have served a vital public engagement purpose that other species, particularly salmon, are unable to play:

For Atlantic Salmon, low numbers and an elusive nature make observation difficult, but they could benefit from species like Alewife that are seeing a resurgence in abundance and piquing public interest. Once people start seeing and feeling a greater connection with and value toward fish and their habitats on a daily or seasonal basis, there may be greater receptivity and recognition that acting on their behalf is worthy of investment (Liebich 2018).

Even though the pace of restoration is not as rapid as we would like, every year we are restoring access to more and more habitat. Our rivers, fish and wildlife are responding. Success builds upon success and demonstrating this to people is a key approach to building social and political support for continued restoration efforts.

Role of NASCO

NASCO has already established mechanisms in place related to habitat protection and restoration via the Implementation Plans and Annual Reporting on Progress. NASCO also has established Guidelines for Protection, Restoration and Enhancement of Atlantic Salmon Habitat, CNL(10)51. NASCO can contribute further to this important facet of Atlantic salmon conservation by holding Parties accountable to their commitments to show progress in implementing NASCO agreements on habitat protection and restoration. Within the next round of reporting, NASCO should ensure that the annual progress reports demonstrate progress and commitment to achieving habitat protection and restoration goals and objectives.

NASCO could assist further progress in this area by encouraging collaboration and involvement of the Parties in existing public education and engagement campaigns around river restoration and fisheries restoration. For example, participating in the biennial World Fish Migration Day and encouraging Parties to host Atlantic salmon focused events across the North Atlantic could be a very powerful way to generate a lot more attention on salmon conservation efforts.

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Challenge faced in protecting and restoring habitats – an NGO perspective focusing on coastal / marine habitat and issues associated with marine survival

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The migrations of anadromous fishes have fascinated scientists for decades. The marine migration of Atlantic salmon (*Salmo salar*) is still surrounded in mystery with many unknowns associated with this stage of their lifecycle. To provide protection and/or restoration to habitats for salmon, in marine and coastal environments, it is essential that there is a good understanding of their spatial and temporal use of such environments. Currently there is relatively little robust data on the migration routes of Atlantic salmon in the early marine migrations, thus protecting such habitats is challenging. The SALSEA programme facilitated significant advances in understanding the migration routes of salmon in the marine environment. There is a still a lack of knowledge for many river systems around North-East Atlantic Commission for example the East coast of Scotland. Although these fish have been caught in pelagic samples in the Norwegian sea, the route(s) taken to get there remains unknown.

Aquaculture has been extensively linked with increased lice abundance on wild salmonids, ultimately reducing wild salmon populations. The effects of aquaculture on wild salmon populations are potentially wide ranging, and the topic itself is deserving of the extensive current research themes on the subject. This paper and subsequent presentation will not deal with the implications of aquaculture on salmon habitats, it is a subject deserving of its own discussion and by individuals with far more expertise than this author on the subject.

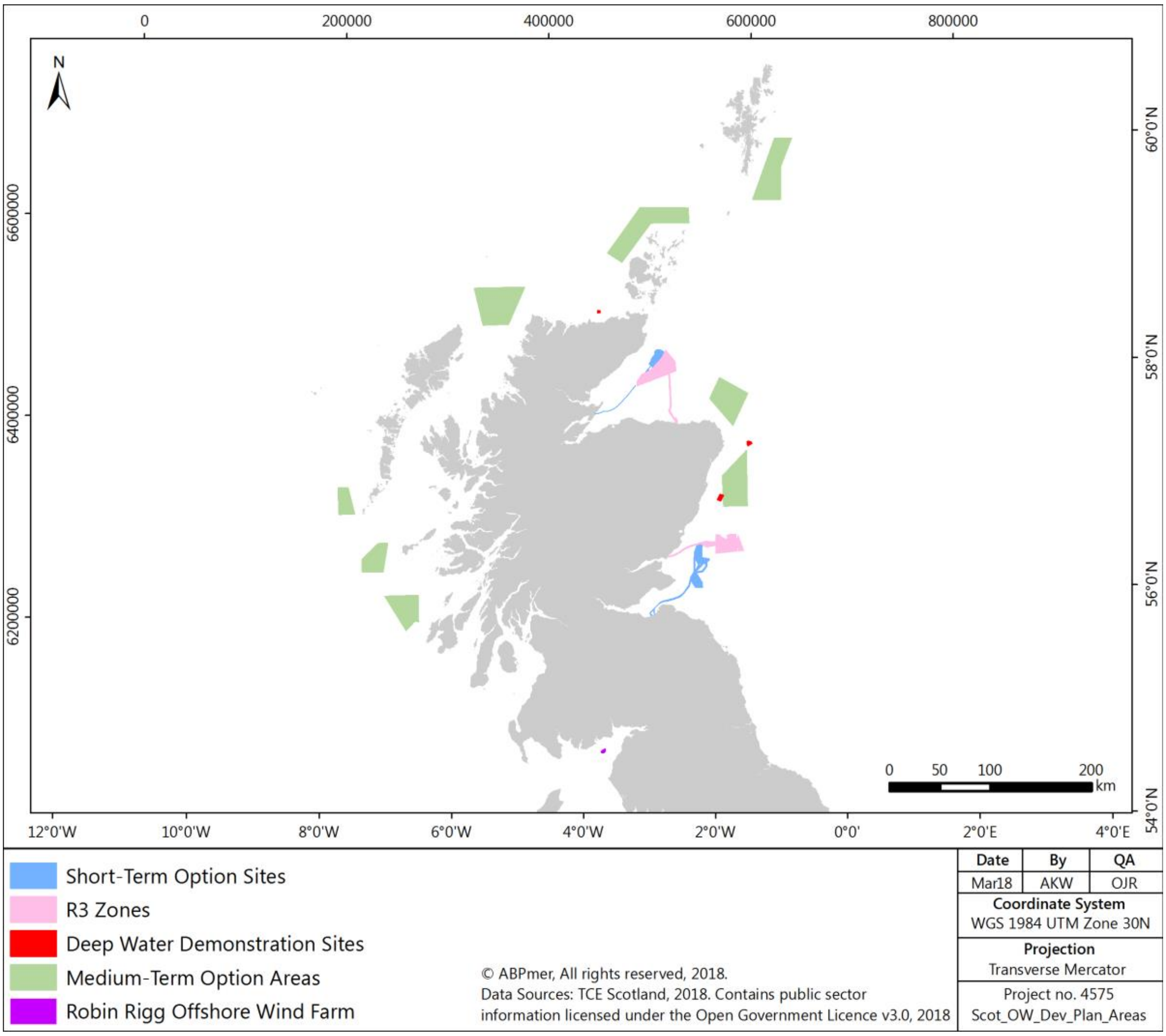

Figure 1. *Existing and planned offshore wind development in Scottish waters. From: Marine Scotland Science, Sectoral Marine Plan for Offshore Wind Energy (encompassing Deep Water Plan Options)*

The coastlines of many European countries are being developed at a phenomenal rate. Scotland alone (Figure 1.) has identified large swathes of ocean suitable for renewable energy development, primarily offshore windfarms. Currently there is such little information available on the marine migrations of salmonids in the near shore coastal areas that they are poorly considered within environmental impact statements, with identification of any potential effects on populations virtually impossible. Marine developments effectively create small reef habitats which may be colonised by various fish communities. Similarly, marine mammals may be drawn to such structures due to concentrations of prey. Harbour seals have been shown to repeatedly forage around windfarms (Russel *et al.* 2014.), with the development of marine renewables, the number of top predators encountering such structures is likely to increase. The consequences of such behaviour is likely to depend on such artificial reefs actually increasing prey numbers or simply concentrating this prey (Production versus Attraction) (Russel *et al*. 2014). Should such structures alter the natural predator prey relationships, they could potentially have severe impacts on fish communities. Should renewable energy structures facilitate greater efficiency in foraging of marine predators or an increase in fish communities, it could be at the cost of migrating Atlantic salmon. If emigrating smolts are following the primary marine currents (Flowing South along the Scottish coastline) they may encounter multiple windfarm developments, with potential cumulative impacts being imposed, where previously no such impact was present (Figure 1). However, the lack of data on migration routes makes such suggestions speculative, with the true impact, if any, being unknown.

The lack of information regarding specific marine migration routes and potential impacts of various developments is raising concern within Salmon management communities. There is now a strong desire to understand such migrations, indeed numerous large international programmes are underway, all with an underlying theme aiming to identify habitat use and migration routes of migratory salmonids: SAMARCH (€7.8million: https://samarch.org), Moray Firth Tracking Programme (£1.3million in year 1: https://www.atlanticsalmontrust.org/themissingsalmonproject/), COMPASS (€6.28million: https://compass-oceanscience.eu), Sea Monitor (€4.6million + match funding: http://www.loughs-agency.org/seamonitorlaunch/).

In parallel with the lack of information relating to migration routes, direct causes of mortality on Atlantic salmon in the coastal zone are equally lacking. There are many theories, with NGO's regularly questioned over the impacts of specific predators on Atlantic salmon populations. It is essential that good robust data exists so that it can be taken to policy makers, and river managers can use that data to effect change (if necessary). The management of marine mammal interactions with fisheries is particularly challenging when both predator and prey populations are protected (Fraker and Mate 1999; Read and Wade 2000). This is the case in Scotland where Atlantic salmon, harbour seals, and grey seals are protected by Special Areas of Conservation (SACs) designated under the European Commission Habitats Directive. Making any policy management strategies in these areas is often difficult and highly controversial. From an NGO perspective, the interaction between predators (Fish eating birds and marine mammals) is currently highest on the agenda, with members pressing considerably for action in this area.

The Atlantic Salmon Trust (AST)

The AST currently have two significant work streams which are being utilised to tackle two of the most pertinent questions relating to Atlantic salmon; causes of mortality and migration routes in marine environments.

The Likely Suspects Framework (LSF)

Led by Professor Ken Whelan, the likely suspects approach as applied to Atlantic salmon seeks to explain the main sources of additional mortality at sea, to try and account for the observed reductions in sea survival in recent years compared to earlier periods of higher survival. To this end it places candidate mortality factors within an overall spatio/temporal framework covering the freshwater migration/sea entry phases and the marine phase of the life cycle. The objective is to identify the various mortality factors involved and quantify the potential for each factor to influence survival (i.e. the 'likely suspects'). In an approach more akin to financial accounting than mathematical modelling, the cumulative effect of these factors is made to account for the observed overall marine survival variations between particular periods. This can be used to identify the likely impact both individually and cumulatively of the 'likely suspects.'

The Moray Firth Tracking Programme

The Moray firth tracking programme is a highly ambitious and collaborative project being delivered in partnership by the Atlantic Salmon Trust (AST) and the University of Glasgow (UoG). It will track 800 Atlantic salmon, and 50 seatrout smolts from seven river systems flowing into the Moray firth (North East Scotland) out into the North sea. Over 350 acoustic receivers have been deployed through river systems, estuaries, sea lochs and the marine environment with the aim to determine mortality and migration routes from the coastal zones. It will facilitate the tracking of migrating smolts further offshore than has previously been accomplished in the UK, and possibly even Europe. This will facilitate the identification of migration routes from seven different rivers systems out through the early marine zones, and partition mortality across the entire study system.

NASCO Support

Gaining funding for work which is out with river systems is difficult, stakeholders do not always see the importance of such work or realise the difference it may make to salmon populations. Emphasis on the importance of such work, and acceptance of the lack of data in the area may help focus future work into delivering on some of the aspects highlighted above. Such emphasis coming from NASCO would help significantly in NGOs being able to influence others and highlight the importance of such work. Similarly some governments do not appear to see the importance of such issues, thus support from NASCO and potentially even pressure on such groups would aid in filling the vast knowledge gaps of salmon in the near shore environments.

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Atlantic Salmon in a warming environment: Challenges to salmon, considerations for managing fisheries

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Environmental temperature regulates body temperature in ectothermic organisms with biochemical reactions and physiological processes adjusted to the optimal temperatures that will maximise growth, reproduction and ultimately fitness (Hari *et al*. 2006). Environmental change acts on the physiology of these organisms and thus the population's vulnerability (Seebacher and Franklin 2012). The greatest scope for aerobic activities in ectotherms is species-specific (often population-specific) (Eliason *et al*. 2011) and the aerobic capacity declines as temperatures approach lethal limits. The upper critical temperature, the temperature at which aerobic scope collapses, is 6 - 7°C above the optimal temperature (Fry 1947). Beyond these critically high temperatures, survival is maintained by anaerobic metabolism although this response is time-limited if conditions do not improve (Pörtner and Farrell 2008). Cardiac collapse was shown to be the mechanism limiting thermal tolerance in Sockeye Salmon at high water temperatures (Farrell *et al*. 2008). Thus, environmental changes can directly affect the physiology of ectotherms leading to consequences on reproductive success and individual fitness.

Predictions are for a rapidly warming and changing climate (IPCC 2018) which will have direct effects on performance of ectotherms (Anttila *et al.* 2014). Water temperatures in many rivers are expected to exceed the upper limit of thermal tolerance for salmonids, and many salmonid populations are already encountering water temperatures near or exceeding lab-determined lethal limits. Migratory fish are particularly vulnerable to warming environments as the transitions between habitats are finely tuned to specific environmental cues and these transitions have consequences on subsequent life stages (Crozier *et al.* 2008). The vulnerability of salmonids in a rapidly warming environment is of concern with much uncertainty as to whether salmonids will be able to adapt. Salmonids have some capacity to respond and potentially adapt to variations in the environmental conditions but there are limits to these capacities. In the following, I discuss the physiological, behavioural, and phenological capacity of wild salmonid populations to respond to increasing warming conditions.

Phenotypic plasticity

Phenotypic plasticity is defined as 'the ability of individual genotypes to produce different phenotypes when exposed to different environmental conditions' (Pigliucci *et al*. 2006). These environmentally induced changes could be physiological, morphological, behavioural or phenological. Temperature acts directly on metabolism of ectotherms and physiological plasticity may well increase their resilience (Seebacher *et al*. 2014). Thermal tolerance, thermal reaction norms for growth, and spawning time are traits shown to evolve rapidly in fishes in a rapidly changing environment (Norin and Metcalfe 2019).

Although limited, there is evidence for phenotypic plasticity in response to high temperatures at the population, family and individual level in Atlantic Salmon. At the population level, two wild Atlantic Salmon populations (southern and northern Europe1an rivers) with similar acclimation regimes showed similar cardiac responses to acute warming (Anttila *et al*. 2014). Eyed-eggs acclimated at 12°C from both populations had cardiac collapse at 21-23°C with acute warming, whereas the two groups acclimated at 20°C had cardiac collapse at 27.5°C. Fish displayed similar cardiac plasticity and acclimation capacities even though acclimation history differed between populations. This suggest that the northern population may have more capacity for acclimation in the wild because current river temperatures are lower than the upper lethal limit. This may allow the fish to acclimatise to an increase in temperatures. It is important to note that populations already experiencing these higher temperatures will likely have greater difficulty coping with increasing temperatures because their capacity for cardiac acclimation has reached the upper limit and acclimation may thus be limited (Anttila *et al*. 2014). Variations in thermal tolerance are also present at the family level. (Anttila *et al*. 2013) found variations in thermal tolerance and hypoxia tolerance among 41 Atlantic salmon families with critical thermal maximum (CTmax) correlating with hypoxia tolerance at the family level. Individual fish with higher CTmax (upper temperature tolerance) had larger ventricle mass and ventricular myoglobin level. Basal metabolic rate (the minimum energy requirements to meet basic life demands) in ectotherms also vary among individuals (Sandblom *et al*. 2014) and may possibly be modified by natural selection to lower the energetic demands associated with increasing temperatures. These results support the idea that genetics play an important role in thermal tolerance in salmon. This plasticity may aid salmon to cope with increasing water temperatures.

In addition to direct genetic effects, maternal contribution to thermal tolerance of young of the year Chinook Salmon was shown by Muñoz *et al*. (2014). In this study, females with larger eggs produced more temperature tolerant offspring. Consequently, one might expect wild female Atlantic Salmon with larger eggs to have greater fitness and contribute more to a population in a warming environment. If a positive association between egg size and body size exist, the role of repeat-spawners, which tend to be larger than maiden fish and hence with larger eggs, may become increasingly important under rapidly warming conditions. These results support the idea that repeat spawners and larger maiden female salmon may have an important population-level contribution in the face of climate warming.

Bioenergetics

Lennox *et al*. (2018) developed a bioenergetics model for adult Atlantic salmon based on fish fitted with archival temperature loggers. The study demonstrated that Atlantic salmon in Lakselva River (Norway) which experienced water temperatures ranging from 11.5˚C to 18.5˚C in July and August maintained body temperatures within a similar range (11.5 to 18˚C). Body size and swimming speed were important determinants of energy depletion, more important than the range of temperatures experienced by salmon in the study system. Nonetheless, energetic costs and depletion increased with temperature.

Energy depletion was greater in small salmon than large salmon which suggests that small salmon may be more impacted by high temperatures than larger salmon in a warming environment. If so, one may expect long-term phenotypic change in salmon populations experiencing high temperatures. The effects of high temperatures on the energy depletion of salmon spawners needs investigation.

Adult salmon cease feeding during their spawning migration and energy requirements are entirely fuelled by endogenous energy reserves (Crossin *et al*. 2009) such that efficient energy allocation and expenditure is essential (Crozier *et al*. 2008). The limited energy budget of salmon must therefore provide the energy required for migration to spawning sites, development of gonad and secondary sexual characteristics in males, competition behaviour for mates, and spawning activities including digging of redds by female salmon. Lipid stores are essential for gonad production and development (Hendry and Berg 1999). However, during high water temperatures, lipids may be used for metabolic maintenance resulting in less energy available or mobilised for investments in gonads. Temperature also controls the development of gametes (Pankhurst and King 2010), which can inhibit specific gamete developmental processes when temperatures exceed optimum values (Taranger and Hansen 1993).

Exposure of female salmon to elevated water temperature prior to reproduction may also have detrimental effects on fertility and egg survival. Under controlled conditions, female Atlantic salmon exposed to elevated temperatures inhibited and altered various reproductive processes which led to reductions in final egg size, fertility and survival of offspring (Pankhurst and King 2010). Both maiden and repeat-spawning Atlantic salmon exposed to 22˚C during months prior to spawning had delayed maturation and reduced fertility compared to maiden and repeat-spawning fish exposed to 14˚C (Pankhurst *et al.* 2011). However, repeat spawners at 22˚C had higher fertility and their offspring had higher survival to the eyed-egg stage compared to maiden salmon exposed to 22˚C. In a more northern Atlantic salmon stock, females exposed to water temperatures of 13-14˚C during the spawning season compared to the expected 8-10˚C, suppressed ovulation and had decreased gamete quality (Taranger and Hansen 1993).

Behavioural thermoregulation

The spatial heterogeneity of water temperatures in streams provides relief during warm water conditions. Atlantic salmon, as other salmonids, is known to behaviourally thermoregulate to maintain a body temperature close to optimal (e.g. Breau *et al*. 2007) to minimise energetic costs associated with high temperature (Breau *et al*. 2011). Wild adult Atlantic salmon in the Sainte-Marguerite River (Qc, Canada) were implanted with temperature-sensing acoustic tags to monitor use of cool water sites during warm water conditions (Frechette *et al*. 2018). Tagged adult salmon maintained their body temperature within a narrow range of temperatures (16-20˚C) during warm water days. Interestingly, the onset of behavioural thermoregulation occurred when daytime water temperatures approached 23˚C and when water temperatures remained above 20˚C over consecutive days. The results are aligned with the warm water protocol to manage Atlantic salmon recreational fisheries in the Miramichi River set by Fisheries and Oceans Canada, Gulf Region (DFO 2012; Breau 2013; Breau and Caissie 2013).

Results from Frechette *et al*. (2018) demonstrate that adult salmon try to maintain body temperature within a narrow range to conserve energy.

Not discussed here is phenological plasticity which is known to occur and likely plays an important role in population persistence of salmonids in rivers. As an example, the delayed river entry of Atlantic salmon spawners may offset energetic costs related to high temperatures (Dempson *et al*. 2017). Also not discussed, but presumably a concern, are the potential challenges posed by warming incubation temperatures. This was shown in Pacific salmon where in years with warmer incubation temperatures, hatched offspring were smaller (Braun *et al*. 2013).

Considerations for management

To date, focus has been on managing fish mortality, especially adult fish, from angling and on conserving cold water refugia. These are appropriate interventions that should not be ignored. The preservation of habitat heterogeneity provides a variety of habitat characteristics (including temperature and flow) to reduce energetic costs of fish in a warming climate.

Other important considerations

- there is no single temperature range that applies to all populations. Juvenile Atlantic salmon from different populations have optimal and critical temperatures that match river-specific regimes (Gradil *et al*. 2016). Maximum aerobic scope for populations of migrating Pacific salmon is associated to the historical river temperatures experienced by the given population (Farrell *et al*. 2008; Eliason *et al*. 2011). Based on current knowledge, closures of recreational fisheries for Atlantic salmon during warm water event should have population-specific temperature thresholds to limit fishing activities near population-specific upper tolerances. By doing so, a precautionary approach method would be applied to warm water protocols;
- in addition, physiological and metabolic costs related to high water temperature during the summer prior to spawning cannot be ignored. Future research topics should include the sub-lethal effects of high temperatures on the energy budget of spawners and potential effects on offspring in populations that experience water temperatures beyond the optimal range. More precaution may be warranted in management considering the consequences to metabolism, lipid reserves, and fish energy budget of higher temperatures;
- to maximise resilience in salmonid populations, maintaining genetic diversity of wild populations and the complex life histories characteristics (e.g. proportion of small and large salmon, multiple sea-age) by natural reproduction is essential; and
- discussions need to go beyond fisheries impacts to salmon to include all human activities occurring on rivers warm water events.

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Perspectives from a Canadian NGO on challenges of implementing a multi-reference point system for wild Atlantic salmon management

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Returns of wild Atlantic salmon to North America have declined when compared to the 1990s, with greatest changes in the southern portion of their range. Recreational angling continues in all provinces of eastern Canada, with the federal Department of Fisheries and Oceans (DFO) responsible for management of fisheries in the four Atlantic provinces. DFO has committed to implementing a new management framework known as the Precautionary Approach (PA), a multi-reference point system to replace the previous single-reference point Conservation Limit (CL) system. With clear and needed improvements PA approach implementation on a river-by-river or region-by-region basis requires scientific analysis and management consultation to determine reference points and remains a work in progress. Several challenges to fuller implementation exist including overcoming legacy issues of the previous model, ensuring understanding of the framework by conservation and angling groups, the requirement to feed the more intense data requirement of the framework, and differing methods of implementation of the framework across regions of Canada. Canada should extend conservation of wild Atlantic salmon further than a new management framework through coordinated protections of aquatic, estuarine, and marine systems that are high value to the species. NASCO can contribute by holding Parties accountable to their commitments to show progress in implementing NASCO agreements on salmon fisheries management. NASCO needs to ensure that annual report progress and implementation plans show clear advancement toward goals and objectives and to reject those that do not.

Introduction and Canada's Multi-Reference Point System

Canadian wild Atlantic salmon abundance has steadily declined even with closure of high seas fisheries, Canadian offshore commercial fisheries (1972), and inshore commercial fisheries buyouts by the year 2000. North American salmon abundance has declined by 66%, from estimates of 1.6 million spawners in the 1980s to approximately 440,000 adult salmon and grilse returning in 2017. Several individual rivers have experienced more dramatic declines recently. For instance, the Miramichi River system in New Brunswick has experienced alarming declines in the past decade with, for example, a 68% decline in one-sea-winter salmon (grilse) returns over the last 12 years (DFO. 2018). Recreational fisheries take place in all eastern Canadian provinces with varying regulations around retention and catch and release fisheries. In 2017, Canada reported a total harvest of 112 tonnes (approx. 44,000 fish), of which 48.9 tonnes was from recreational fisheries, 61.3 tonnes from Indigenous food, social, and ceremonial fisheries, and 1.6 tonnes as by catch in the Labrador resident food fishery.

There are significant differences between management approaches across eastern Canadian provinces and regions. In Quebec rivers are managed at a local/river-specific level by organizations known as 'ZECs' (Zone d'Exploitation Controllee) or Societies. They manage angling access, collect fees, perform population estimates and counts, and make decisions on any retention angling as guided by the provincial management plan. In the maritime provinces of New Brunswick, Prince Edward Island, and Nova Scotia, rivers are managed by two separate DFO regions. In one region, salmon abundance permits angling and in the other, nearly all rivers are closed to angling including catch and release, due to extremely low numbers of returning adult salmon. Abundances are determined by varied systems including mark-recaptures, counting fences, visual observations, and angling report extrapolation. All have their assumptions and biases, so accuracy is a criticism, although attempts are made to be as precise as possible. In Newfoundland and Labrador rivers are assigned by class (size of river, number of returning salmon) and decisions made across classes based on previous years' runs relative to 5-year running averages and mid-season reviews. Abundance estimates come from a series of 17 counting fence facilities across the province (>180 scheduled rivers).

Canada has committed to implementing what is termed 'The Precautionary Approach' as a decision-making framework for managing wild Atlantic salmon and harvest strategies (DFO. 2009). This is an effort to replace the previous spawning escapement model (a single reference point management system) with a multi reference point system that includes a biological minimum, called the Limit Reference Point (LRP), and an upper target, the Upper Stock Reference Point (USRP). The previous Conservation Limit (CL) identified the point above which enough spawners could fully seed a river. Often referred to as 'minimum spawning escapement/requirement', resource users saw this level as the target; when the number was reached, the river was healthy. This became ingrained into the lexicon of conservation groups, resource users, anglers, and the general public and its legacy is strong today, even several years after DFO's move toward the multi-reference point system. Although DFO has started to move toward this multi-point system, it has been a slow transition and Canada is only part way there.

The PA is a better management framework – it's intended to be based on river specific data and stock recruitment curves. A fundamental component of the PA is that the framework must include all fisheries removals including Indigenous food, social, and ceremonial harvest as well as mortality associated with angling. Two reference points results in three stock status zones within the framework. Below the LRP is the critical zone; above the USRP is the healthy zone; and between them is the cautious zone. The LRPs are not analogous to the old CL, although many of the calculations put them close together. The USRP identifies the point above which the stock is considered healthy and there can be a relatively high harvest rate without generating conservation concern. Aside from being an important numerical point, its value extends far beyond – it says something about potential and that we cannot be content with a low baseline. Management needs to aim for the upper target.

Determining reference points

In PA, the LRP is a biometric calculation based on population demography, egg deposition, and estimates of productive watershed area (riverine vs lacustrine areas). Therefore, data inputs should strive to be at the same scale as the management level, but this can be reasonably mitigated, at least for demographic data, by use of data from neighboring rivers or from rivers with similar characteristics. Geographic data cannot be 'borrowed'.

The USRP can be a combination of a calculated value modified by determining the management objective, presumably through some sort of outreach and advisory process with stakeholders. Already we are seeing differing approaches to USRP determination between management regions in Canada. One approach is to generate USRPs for individual river systems through specific biometric calculations and modify the final target based on local input. This seems to be the approach in areas with fewer individual rivers. Conversely, in areas with numerous rivers like Newfoundland and Labrador, a more standardised approach has been taken with USRPs being a percentage over and above the LRP. It remains to be seen what complications might arise from these differing approaches.

Whichever approach is selected, the separation between LRP and USRP should be such that we avoid seeing population assessments jumping from healthy to critical zones, or vice versa, over short time periods particularly in successive years. While not sure if this will be something that happens frequently, we need to consider how such situations will be managed because they will happen.

River / stock specific management

The PA will be applied to individual rivers, or river assemblages, but it is widely understood that such implementation will only be possible at some point likely years into the future. Data in support of management needs to at least be at, or close to, the same resolution as management. One PA approach is based heavily on egg deposition calculations that include ratios of salmon vs grilse and associated sex ratios. This approach is certainly quantitative, based on science and requires data inputs, and is defendable. But from conservation biology and evolutionary ecology points of view, it can be criticised, and, in my view, there needs to be considerable communication across conservation organizations to explain the framework.

For instance, on the Miramichi river system DFO (2018) has said the management target will be at the level of its four main sub-systems that enter tidal water: Northwest, Little Southwest, Renous, and Southwest. The Southwest Miramichi river has an approximate ratio of 80% MSW and 20% grilse, and 80% of the grilse are male. Assuming there is no catchability difference between male and female grilse, and that 30% of the grilse will be caught in a season, we can calculate that removing 100% of landed grilse in the recreational fishery will result in less than 2% reduction in egg deposition for the river. These calculations have been used to advocate for a grilse retention recreational fishery on the river, even with returns to the river barely into the cautious zone in most years. Those advocating for this approach are not incorrect in their math. To some, the PA in this example suggests that male grilse particularly are essentially reproductively irrelevant and do not contribute to population sustainability. They further suggest that the advantage of having increased fishers on the river and continuing their connection and interest to the river and Atlantic salmon conservation is crucial to political and management decisions.

There is merit to these arguments, but only IF we feel that maintaining the demography of the population is not a management objective. Evolution (the process) by natural selection (the mechanism) does not result in reproductively useless population segments. Indeed, the life history of Atlantic salmon is a study in bet-hedging. When we consider age at smoltification, MSW vs grilse return intervals, and repeat vs consecutive spawning, any one spawning run on a river system like the Miramichi can be made up of at least 8 different year classes and cohorts. We need to be extremely careful in how the PA framework is communicated, interpreted and used by stakeholders to make recommendations.

Challenges

As mentioned above, much work is needed to shift the psychology within the salmon conservation community through many years with the previous management model. Its use resulted in management toward minimal numbers and reduced population resilience where returns above the CL reference point were predominantly viewed by resource users as surplus and available for harvest. Over time this skewed particularly angler perception of abundance and heavily influenced resource users' views of reference points. It created pressure to manage populations toward lower levels. We have at least a generation of resource users, anglers and the general public that have lost the knowledge of what abundant salmon populations and their annual spawning runs can look like. And in my view the new PA model will struggle if we fail to acknowledge this and be explicit in what the management objectives and targets can be.

In the interim and on those rivers where reference points are not established, the way in which annual count data from various rivers is presented continues to reinforce mediocrity. Returns of salmon in one year are directly compared to those from the previous year as well as to a running five-year average, and judgements on stock health are made. If we're lucky, sometimes reference is made to a recent year when salmon were generally considered to be abundant as a yardstick, but again this eventually leads to acceptance of reduced numbers as the norm. Really what I am describing here is nothing new – this 'ratchet-effect' in natural resource management is widespread. The baseline shifts over time.

The major immediate challenge to the implementation of this multi-point reference management system is a commitment of the resources required to implement the framework. There are hundreds of rivers and tributaries where there are currently no data collected on salmon abundance, or even somewhat reasonable angling statistics from which to extrapolate patterns of abundance. Even if huge strides were made to remedy this now (and these absolutely needs to happen) their value lies in the longitudinal nature of the data and is of more limited value in the short term. Stock assessment requires considerable planning, infrastructure, staff, and timely analysis capacity and there is simply no possibility for this to occur without significant influx of funding to support its development. Partnerships with Indigenous groups and First Nations, conservation organizations, watershed groups, and anglers can help and will be crucial to success, but these groups simply do not have the resources currently. Further, there needs to be a willingness by DFO to accept data collected by partners. Canada has committed to the PA management framework, and that commitment requires investments to support framework requirements. We are hopeful that Canada will approve an Implementation Plan for its Wild Atlantic Salmon Conservation Policy (WASCP) with that includes resources for implementation as well.

During consultations to establish USRPs, DFO needs to be prepared to proactively provide options to stakeholders on the fishery regulations needed to achieve the management objectives. Stakeholders will need to understand the management landscape required to result in their preferred resource state. Management agencies will need to continually reinforce that PA aims to increase salmon numbers beyond that which is now often viewed as numerous. Uncertainties need to be explained and incorporated into the models and plans. Similarly, since the USRP determination is at least partially based on the management objective arrived at through outreach and consultation activities, there is the probability that rivers in different areas with similar demographic characteristics will have different resource objectives. When stakeholders start to compare management in different regions, we need to be prepared to explain how river-specific objectives drive the differences, or the framework and its implementation will be heavily criticised.

But I believe management agencies need to go further. Canada has announced they will protect 10% of marine areas under Marine Protected Areas designation, and 17% of freshwater areas through yet-to-be determined mechanisms. Healthy rivers, of which abundant and resilient wild Atlantic salmon are a crucial component, as well as adjacent marine areas and critical portions of migration corridors need to be a cornerstone of conservation policy. A solution to the myriad impacts of human activities is to establish protected watersheds where the overarching goals are ensuring wild Atlantic salmon abundance and resilience. Such areas will act as strongholds, buffering against low marine survival rates and the predicted impacts of climate change. These areas would also preserve the full socio-economic benefits of healthy and resilient wild Atlantic salmon populations primarily in rural areas of Canada where sustainable economies continue to be a challenge. A recent economic analysis estimated the value of wild Atlantic salmon in Canada at $255 million CAD with almost 4000 full-time equivalent jobs directly created annually (Gardiner Pinfold 2011). The study also clearly showed public support for options that expand conservation and restoration efforts beyond the *status quo*. Wild Atlantic salmon are a perfect integrator to tie together these two significant targets with the benefits to local communities.

How Can NASCO contribute?

Canada needs to ramp up implementation of their multi-point reference management system including monitoring its effectiveness, how goals and objectives were fulfilled (or not), why (and why not), and plans to address any problems. They need to adaptively implement the new management framework. For instance, in Canada's new IP, section 2.9 (Actions planned to implement NASCO resolutions, agreements, and guidelines for salmon management), there is no mention of implementation of the new framework.

NASCO needs to continue to hold Parties accountable for implementing multi-point reference systems in their jurisdictions. Canada and other Parties have agreed to report annually to NASCO on their experiences applying Precautionary Approach Decision Structure and on the extent of its implementation, and progress in implementing NASCO agreements on salmon fisheries management is assessed through Implementation Plans (IPs) and Annual Progress Reports. Canada has committed to do so under the NASCO IP framework. Certainly, the new approach of having NASCO review and, if necessary, send IPs back to Parties if sections are insufficient, is an important lever. NASCO needs to ensure reviews are top-notch, and that recommendations are followed up. We cannot afford slippage.

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Practical Management of Atlantic Salmon Stocks in England and Wales using Biological Reference Points: Benefits, Uncertainties and Risks

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Introduction

A major challenge facing salmon fisheries management is how to evaluate and compare the status of stocks. This is an essential first step in almost all rational management decisions and therefore needs to be done effectively and consistently. Stock evaluation is usually based on Biological Reference Points (BRPs). This paper is about the development and application of BRPs, specifically the Conservation Limit (CL), to salmon fisheries in England and Wales. It will give a brief history, which accounts for the system that we have today, outlines its benefits, discusses some challenging areas for improvement and concludes with some suggestion for NASCO's role in advancing this topic.

History

The stimulus for developing salmonid BRPs in England and Wales came from the decline of sea trout (*Salmon trutta*) and Atlantic salmon (*Salmo salar*) fisheries at the end of the 1980s. This coincided with the marked marine regime change in the north Atlantic compounded, in the Western British Isles, by impacts of marine salmon farming. Faced with important and often contentious decisions it was clear that a more structured, objective and evidence-based approach to assessment and decision making was needed.

It rapidly became apparent that sea trout presented more complexities than salmon, such as partial migration, greater life history flexibility and poorer reliability of assessment data. Salmon took over the focus of policy attention because those stocks had more political importance than sea trout as a result of greater economic value and the effective lobbying of stakeholders. This also coincided with the ICES development of Minimum Biologically Acceptable Levels (MBAL) for salmon stocks to aid the management of the distant water fisheries and the emerging drivers from the North Atlantic Salmon Conservation Organization (NASCO) for the application of the Precautionary Approach to salmon management (NASCO. 1998). From this came the Environment Agency Salmon Strategy in 1997 which set four objectives within the context of the existing fisheries legislation and set the imperative for BRPs.

1. Manage individual stocks and environment to optimise recruitment;
2. Maintain diversity and fitness of stocks;
3. Exploit surplus to optimise economic yield; and
4. Beneficiaries meet costs and polluters pay.

The first objective, referring to individual stocks and optimising recruitment, needed to have BRPs set for individual rivers and a government Ministerial Direction in 1998 made the setting of 'Spawning Targets' obligatory for principal salmon rivers in England and Wales.

Deriving Conservation Limits and assessment

A system was developed that derived Conservation Limits (CL) through a two-part life cycle with a Ricker stock-recruitment (S/R) model for the freshwater phase (eggs to smolts) and a density-independent model for the marine phase (smolts to spawners or eggs) incorporating life history traits of marine survival sex ratio, growth and fecundity (Wyatt and Barnard 1997a). Combining the two gave the same parameters as for a single egg to egg S/R, but the partition was retained as a convenient way to display and explore the processes operating through these very different life cycle phases and to present options for alternative BRPs. The CL defined as the Maximum Sustainable Yield (MSY) can be unambiguously derived from the model and followed emerging ICES and NASCO terminology and practice.

The MSY CL is an arbitrary choice for the BRP; but its mathematical clarity, its common usage and its conformity with the NASCO (2009) Guidelines have let it survive. Many other BRPs are available, although not discussed here, apart from one obvious and commonly suggested alternative of maximum smolt production, i.e. freshwater production, output, as defined by the peak for the freshwater Ricker curve, or some function of the asymptote in other S/R models. This has merit because it forces attention on to the quality and quantity of the freshwater habitat, improvement of which is one of the few management options at times of marine climate change.

Defining a CL was comparatively easy; but deriving one for each of 64 principal salmon rivers in England and Wales was much harder in the absence of S/R models for any of them. Our colleague, the late Dr Robin Wyatt found a way around this based on the one good S/R relationship for British Isles at that time, that for the River Bush, Northern Ireland (Wyatt and Barnard 1997b). His method partitioned the S/R of the Bush into constituent parts defined by habitat types with a simple habitat model of stream order and altitude; then used those relationships to reassemble the whole river S/R for each recipient river based on their habitat, calibrated for juvenile abundance taken from the national electrofishing database. This allowed the derivation of CLs for each of the 64 principal salmon rivers in England and Wales which are used to evaluate stocks annually.

Annual egg depositions are estimated from reported rod catch numbers and size distributions, incorporating assumptions for exploitation rate, in-river survival, sex ratios and fecundity (Environment Agency 2003). An element of precaution is introduced through an arbitrary management objective (MO) defined as the achievement of at least that stock level which would exceed the CL on average in 4 years out of five, or 80% of the time. Thus, on the assumption of no systematic trend, the distribution of the last 10 years' egg deposition allows the calculation of its 20 percentile point (the CL) and the 50% percentile gives the corresponding Management Target (MT), which is the average stock size if the CL for a river is just achieved. The MT is simply related to the CL by MT = CL + 0.842 SD, where SD is the standard deviation of the last ten years' annual egg deposition. Recognising that trends are a reality in salmon stock dynamics and an inherent component of assessment forecasting, a complementary test was introduced in 2004 that projects attainment in 5 years' time using a Bayesian estimate of the last 10-year linear trend of the annual 20 percentile abundance with Bayesian credible intervals. In turn this permits stock status to be presented probabilistically within one of four categories for the current reporting year and for five years ahead.

1. >95% chance of achieving the MO: 'Not at Risk';
2. 50-95% chance of achieving the MO: 'Probably Not at Risk';
3. 5-50% chance of achieving the MO: 'Probably at Risk'; and
4. <5% chance of achieving the MO: 'At risk'.

This is the basis of current salmon stock reporting to ICES and NASCO for individual rivers (Environment Agency, 2003; Cefas/EA/NRW 2018).

Benefits

Benefits derive from two main themes of (1) improved practical assessment and advice, and (2) objectivity, clarity and communications.

- the 1997 objective to optimise recruitment was a major advance in the definition and objectivity of the regulator's aims, despite some lingering ambiguity in what 'optimise' meant. By introducing a specific definition linked to quantification of population dynamics the assessment process became objective and repeatable;
- the Management Decision Structure, used by the Environment Agency and Natural Resources Wales for making choices about regulations, aligns with NASCO guidelines and is based on assessment of stock status relative to the two BRPs, the CL and the MT;
- the clearly specified BRP procedure and routinely reported outputs (e.g. Cefas/EA/NRW, 2018) give a common language for managers, fishermen, developers, politicians and scientists; although it has complexity for non-specialists and some inconsistencies that sometimes makes it difficult to explain. Nevertheless, assessment against CLs is now broadly accepted and common parlance even in the angling press;
- quantified BRP assessment offers objective evidence and advice on measures requiring regulatory change, policy revision and operational practice, or to improve monitoring. Over the last twenty years assessment of stock status against CLs has swung decisions that might otherwise have been avoided or gone the other way. Among many examples are: Net Limitation Orders, the regulators' means to control net exploitation, now rely on CLs as evidence to government Inspectors; the National Spring Salmon Byelaws (1998 and 2008) in part were justified because stocks were failing to meet their CLs; the

pressure to reduce the Irish drift net fisheries referred to rivers that were not achieving their CLs within Special Areas of Conservation in Southern England under EU legislation; and recent reviews of major water abstraction licenses in South Wales took attainment of CLs into account; and

- the analytical framework and algorithms show clearly where its sensitivities lie and what the priorities for improvement and related research are.

Challenges and some solutions

Many of these undoubted benefits also bring challenges, arising variously from weaknesses in communication and development of the scheme and the data (stochasticity of the system, gaps in process understanding and measurement errors).

Communications and inclusivity. The benefit of a single language is only fully realised if everyone understands it. There has been continuing difficulty in conveying simply the mechanisms of the CL derivation and assessment, the implications of the outputs, and particularly the need for critical, cautious interpretation, knowing the uncertainties and risks. There was misunderstanding of the aims with a mistaken perception that the CL BRP was intended to maximise harvest in the home water net fisheries (at the expense of rod fisheries) at a time when there were the beginnings of moves to reduce or eliminate harvest. Importantly, the scheme was never intended to promote killing up to the 'Spawning Target' (a term that was dropped early on). It was always strictly a lower limit reference point for conservation purposes and stock protection; but that has been a difficult point to convey. Sometimes even the notion of 'uncertainties' is taken as code for 'failure' of the scheme amongst the sceptics. The science needs to be scrupulous and clear if it is to be accepted and for credibility to be maintained. Some of the science, statistics and modelling are complicated, not readily accessible to non-specialists and there is only so much that can be done to help that; but it is nevertheless the scientists' role to take on that communication task. Improving trust, dialogue and genuine inclusivity is essential in the next stages of BRP development and application.

Development of BRPs, monitoring and assessment. The quality of the monitoring programmes, the statistical modelling and testing procedures has not developed as was initially envisaged and recommended in the 1990s, such that undoubted weaknesses remain. These shortfalls have given ammunition to the sceptics. The documentation of the original procedures repeatedly states that they were provisional, to be refined and developed as soon as possible and points to how this might be done. Resource limitations have partly constrained this, but what was a ground-breaking step has become outdated and leapfrogged by developments in other countries. The England and Wales draft Implementation Plan for 2019 undertakes to resolve this. A short list of priority topics includes:

- CL definition and setting: as population traits (age at first maturation, survival, growth rates) shift, so will the CLs and adjustment needs to be made for this. For example, declining marine survival reduces the CL. Complementary BRPs such as freshwater output have a place in a more comprehensive suite of BRPs, which should also include estimation of uncertainty to strengthen the probabilistic assessment;

- CL accuracy. Between 2008 and 2017 29% of the individual river/year assessments in England and Wales were at least 100% of the MT and 10% exceeded it by a factor of 2. The validity of these needs to be challenged because they seem unlikely at a time when the return rates of salmon are roughly half what they were 30 - 40 years ago. The errors, if they are so, could be due to incorrect CLs, or the egg deposition estimates, or both and the causes cannot be specified without digging into the analyses. However, the clear potential sources of error lie in the CL transfer mechanism which relies on very simple and not yet validated models of habitat quality (carrying capacity) and wetted stream width. While other issues are probably involved, the CL transfer model is highly likely to be a contributory factor in erroneous CLs and thus assessments;

- the major constraint on the transfer method is the lack of a National Channel Habitat Inventory, offering GIS-based quantification of channel types and salmonid carrying capacities for all rivers in England and Wales. The benefits of such a tool are clear from its usage in other countries in Europe, Scandinavia and in North America. Beneficial applications arise also for other aspects of aquatic ecosystem management and operational practice. Its absence may be due to the still prevailing 'pisci-centric' view that the aim of fisheries assessment is to monitor fish. That is only partly true: the most important task for any biologist facing a fisheries assessment question is to first evaluate the habitat that supports the fish, because habitat is the template for all fish production. This requires a shift in attitude, but the case is overwhelming. For example, terrestrial conservation or farming developments always start with questions such as how much land is there, what is its quality, how much stock can it hold, or what should be done to improve it? The same questions should apply to the aquatic environment as characterised by its hydro-morphology, connectivity, biodiversity and productivity. This recommendation is not new yet remains unfulfilled. It is a readily tractable matter, a major omission in England and Wales and probably the single most important improvement that could be made;

- poor assessment accuracy: assessment based on rod fisheries is vulnerable to sampling effort and efficiency changes over time. Exploitation rate on individual rivers needs to be routinely modelled with factors such as effort and river flow. Catch recording needs to be updated and could include selective log book sampling;

- reductionist approach to fish management. Three aspects occur. First, a misused BRP approach can lead to box ticking of simple metrics, oblivious to their caveats and the need for more penetrating, objective appraisal of the methods and the outputs. Second, it ignores population structuring within rivers (possible less of an issue in the smaller rivers), and between rivers. Multiple river groupings may be relevant in order to manage and protect the source-sink dynamics of meta-populations that may display beneficial portfolio properties. Third, it diverts attention and resources from other aspects of assessment such as habitat and juveniles that can be as equally informative as adult-based assessment; and

- it is symptomatic of utilitarianism. The criteria for judging the merits of salmon conservation have always been utilitarian; for many years simply as catch size or fisheries value, then in terms of ecosystem function: provisioning and cultural services through the notion of Ecosystem Services (Millennium Assessment, 2005) which was a major improvement, although still anthropocentric. There may be a further step. The idea that salmon and other fish have intrinsic worth in their own right has (re-)emerged in recent years, and while such notions may be contentious and difficult to convey. This is important to explore because environmental ethics are increasingly part of the conservation debate for the wider public.

Suggestions for NASCO's role

- NASCO plays an important and unique role as the guardian of consensus on best practice and through the Scientific Advisory Group and Working Group on North Atlantic Salmon (WGNAS) as an instigator of ground breaking research. Its role in scrutinising and constructively challenging countries' assessments and management through Implementation Plans and Annual Progress Reports is important because no other independent international body does it; so this process needs to be rigorous and penetrating;

- the derivation and usage of BRPs has evolved differently across countries and this may constrain the ability to present common stock assessments. NASCO could further promote and coordinate common practice. A precursor to this would be a systematic comparison and cross-validation of Management Objectives and supporting CLs. Priorities include: more uniform and comprehensive river habitat inventories, consideration of complementary freshwater-based BRPs, common approaches to incorporating probability into CL transfer between rivers, a methodology for sea-age component BRPs and improved quantification of marine survival. Incorporating these into a robust life cycle model, such as being developed by WGNAS, could form the core for national BRP harmonisation, as far this is appropriate and feasible; and

- in addition to technical aspects, a challenge for NASCO lies in expanding and promoting wider governmental and public awareness of salmon status as part of our wider global environmental state in freshwater and at sea, complemented by genuine inclusivity in the assessment process. In addition to conventional value systems, NASCO could usefully promote the notion of the intrinsic worth of salmon in nature. This recognises the role of environmental ethics which is increasingly part of the conservation debate and thus fully in keeping with the aims of The International Year of the Salmon and this Symposium.

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The challenge of reducing negative impacts of aquaculture activities

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The world´s leading seafood nation & the home of wild salmon and - a Norwegian dilemma?

Every year 10 million wild Atlantic salmon smolt migrate from more than 400 Norwegian rivers into the Atlantic Ocean and Barents Sea (Nilsen *et al*. 2017). In these oceans, they feed grow until they return to their native river. These 'Norwegian' Atlantic salmon constitute a considerable proportion of the world's total abundance of wild salmon.

Over the last five decades, farming of Atlantic salmon has grown to a multinational industry. When NASCO was established in 1984, production of farmed salmon in the North Atlantic was around 25,000 tonnes (NASCO 2016). In 2018, Norway alone sold 1.24 million tons of Atlantic salmon (Statistics Norway). Approximately 408 million farmed salmon (734 000 tons) are held at 587 active sea sites along the Norwegian coastline (Fiskehelserapporten 2018; Directorate of Fisheries in Aquaculture Statistics. 2019). Accordingly, each sea site harbour significantly more farmed salmon than the annual pre-fishery abundance of wild Atlantic salmon returning to Norway (530 000 in 2017 (Anonymous 2018)). The Norwegian Government's ambition is to become the world's leading seafood nation. A report predicting a five-fold increase in salmon production and six-fold increase in value creation between 2010 and 2050 is the driving force of this ambition (Olafsen *et al*. 2012). However, Norwegian salmon production has stagnated since 2012, due to unsolved 'biological issues'.

Large-scale intensive farming of Atlantic salmon in open net cages represents dramatic changes to the ecosystem by increasing the number of hosts and facilitating pathogen transmission and growth. This has resulted in the emergence of several infectious diseases within the industry (Rimstad 2011). Of the 53 million farmed salmon that were lost during the sea-phase in 2018, more than 87% died during production (Norwegian Directorate of Fisheries). Mortality is an indicator of the health status of farmed fish because it reflects the presence of infectious diseases and injuries (Fiskehelserapporten 2018). Variation in mortality across counties and production areas reflect differences in general health status and occurrence of diseases. Next to salmon louse *Lepeophtheirus salmonis* L, a number of viral diseases are considered the major health challenges in farmed Atlantic salmon in Norway (Fiskehelserapporten 2018). Horizontal transmission of pathogens between fish in open net cages and between sites is an important transmission route within the industry.

Pathogen transmission from farmed fish is also a threat to wild salmon, but an area in need of more knowledge. Infection pressure is a function of production volume and health status, and thus closely linked to industry structures and disease management. Accordingly, improving farmed fish health and reducing production are plausible alternatives to reduce infection pressure and impact on wild populations. Separating farmed fish from wild populations is also reasonable, but only partially feasible by implementation of National salmon fjords and salmon rivers and new technologies. Steps in the right directions will be to implement stricter disease control regimes (e.g. eradication of pancreas disease) and by including farm fish mortality in the Traffic Light system.

Climatic changes

Fish, vectors and pathogens each have a range of optimal climatic conditions, including temperature where they survive and reproduce. Climate change will thus affect infectious disease occurrence by altering patterns of host, pathogen and vector propagation, survival and distribution. Higher water temperatures may both lead to migration of species into new areas, but also ease the establishment of fish introduced by man. With new fish species comes new viruses, bacteria, protozoans and multicellular parasites. Atlantic salmon, both farmed and wild will experience temperatures that are outside the optimal range, which in turn may affect immunological and physiological functions necessary to combat diseases.

The role of NASCO

NASCO's role will be to exert influence such that Norwegian Authorities increase their attention to and prioritize the following areas.

- **The knowledge gap:** Infectious disease interaction and pathogen exchange between wild and farmed Atlantic salmon is an area where we lack knowledge. It is a methodologically challenging area, but also challenging due to lack of funding sources;

- **application of the precautionary principle:** Salmon louse is thus far the only sustainability concern that gain attention. Norwegian Authorities plan and facilitate expansion of farmed Atlantic salmon production but do not take the necessary precautions about other infectious diseases;

- **the traffic light system:** Mortality is an indicator of fish welfare, general health status and infectious disease occurrence in aquaculture. Accordingly, it is also an indicator of infection pressure generated by salmon farming. This indicator should therefore be included in the traffic light system; and

- **infectious disease eradication and control strategies:** The authorities (and the industry) seem more concerned with wild salmon as a source of infection for farmed fish than as a recipient of infection from the industry. The choice of eradication and control strategies thus take the presence of wild salmon reservoirs into account, but do not necessarily take the impact on wild salmon into account.

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The challenge of reducing negative impacts of aquaculture activities

Petter Arnesen, Federation of Norwegian Industries, Oslo, Norway

Further expansion of the Norwegian salmon farming industry cannot occur until challenges such as sea lice, viral diseases and escapes are effectively managed. The long-term potential of salmon production is more important than short-term results and one-sided focus on growth.

Our extensive sea and coastal areas, ideal temperatures and well-developed infrastructure give Norway a significant advantage in terms of efficient salmon production. Norwegian aquaculture can also build on well-established traditions, solutions and expertise from oil and gas and the maritime industries.

The production costs in Norwegian salmon farming need to be curbed to maintain competitiveness and can be achieved partly through increased industrialization. A proactive approach to solving industry challenges is required, rather than tackling problems after they have occurred. Collaboration between experts from different industries to develop 'crossover' solutions will be important and we are already seeing successful implementation of technology from the petroleum and maritime industries. Partly resulting from the development licenses program implemented by the government to spur technology concepts designed to solve industry challenges such as sea lice and escapes.

The Government's ambition is for Norway to become the world's leading seafood nation through a five-fold increase in salmon production and a six-fold increase in value creation between 2010 and 2050. However, mainly due to biological problems and scarcity of new production licenses, salmon production has stagnated since 2012. Going forward sea lice levels will be the key driver for growth in salmon production as it is the sole environmental indicator included in the new regulatory regime for industry growth, the so called 'traffic light' system.

Currently there are few salmon farmers who believe that the bulk of farmed salmon will be produced in land-based facilities in the foreseeable future. However, to comply with increasingly stricter environmental requirements salmon farmers will be forced to implement production practices and technology that reduce any negative impacts to levels regarded to be sustainable by regulators, consumers and society at large. Regarding wild salmon, the farming industry has both a self-interest and an obligation to ensure that stocks remain healthy.

Norsk Industri

THE CHALLENGE OF REDUCING NEGATIVE IMPACTS OF AQUACULTURE ACTIVITIES

Dr. Petter Arnesen, Federation of Norwegian Industries

Nasco Symposium
Tromsø, Norway Tuesday 4 June, 2019

The Federation of Norwegian Industries

Norsk Industri

- Represents more than 2,800 member companies
- Member companies' interests are the Federation's main focus
- Engages in the most important industrial and business policy issues of the day
- Works for framing conditions for businesses in sectors and industries such as:
  - Oil and gas contractors, onshore petroleum activities, aluminum, **aquaculture** and **aquaculture suppliers**, biotechnology and pharmaceuticals, cement, chemical industries, electro and energy equipment, furniture, glass and ceramics, machine and hardware industry, maritime industry, graphic arts and communication, metals, mining, paints and coatings, plastics, recycling and textiles

Norsk Industri

Norway = Salmon

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Photo: Mowi

Norsk Industri

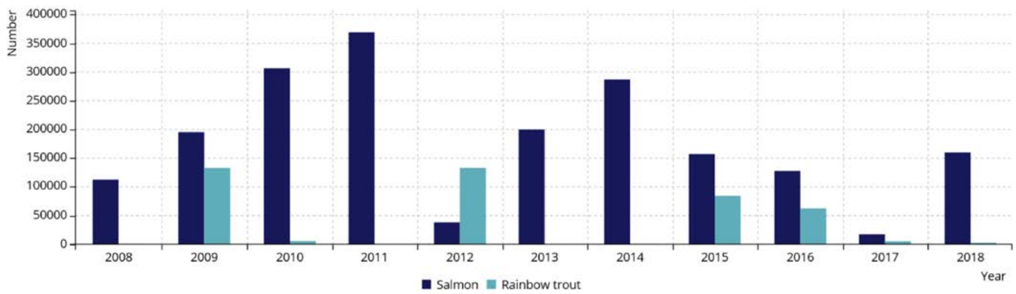
Salmon industry growth restricted by

- Sea lice

- Escapes

Norsk Industri

Escaped farmed fish 2008-2018

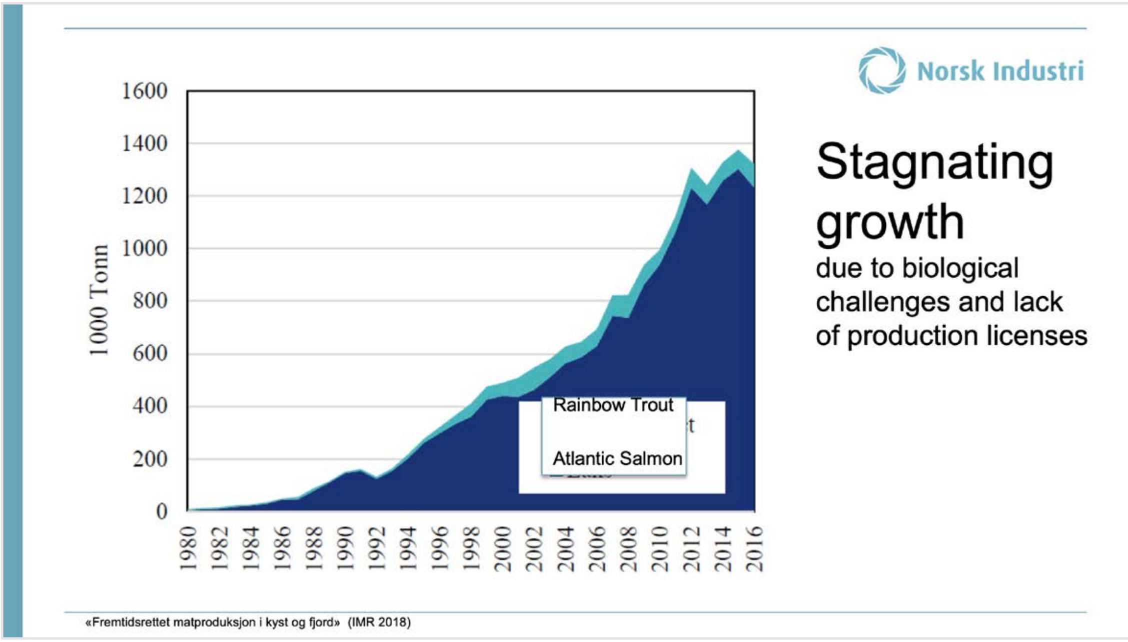


Barents Watch (https://www.barentswatch.no/en/havbruk/)

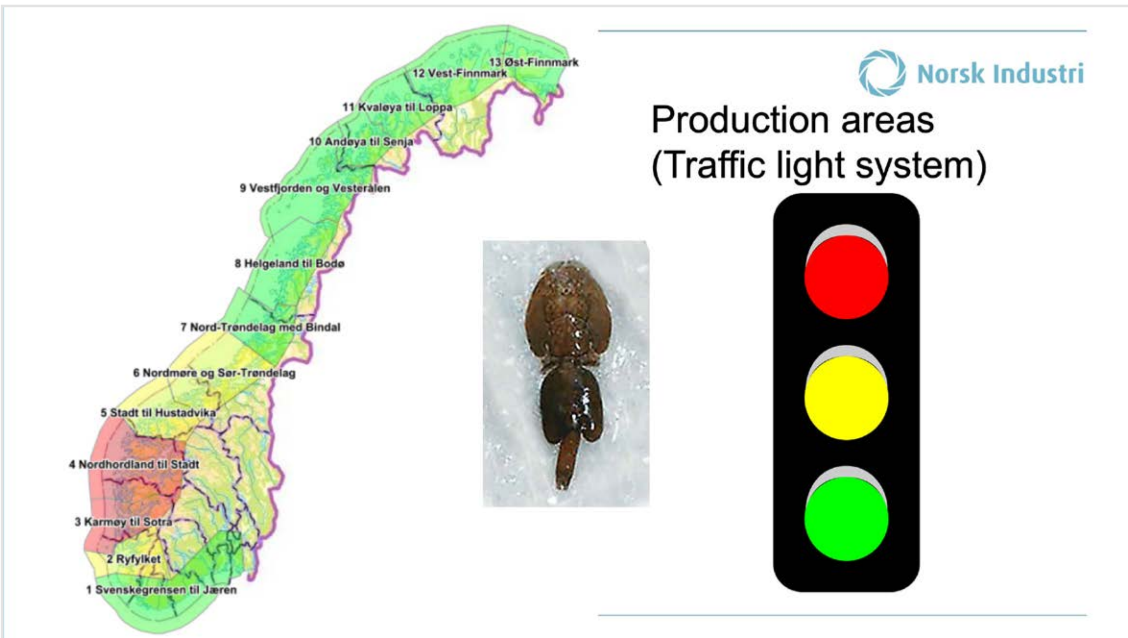
Norsk Industri

Tracing of escaped salmon

- Sporbarhet AS, a company established (2019) by Norway's biggest salmon farming companies (Mowi, Lerøy, Cermaq, Salmar)
- Mission is to establish and operate tracing systems for escaped salmon
- Tracing will be based on DNA and earth metals
- Important that all key stakeholders trust and are commited to the system


Norsk Industri
Stagnating growth
due to biological challenges and lack of production licenses
1000 Tonn
1600
1400
1200
1000
800
600
400
200
0
Rainbow Trout
Atlantic Salmon
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016
«Fremtidsrettet matproduksjon i kyst og fjord» (IMR 2018)

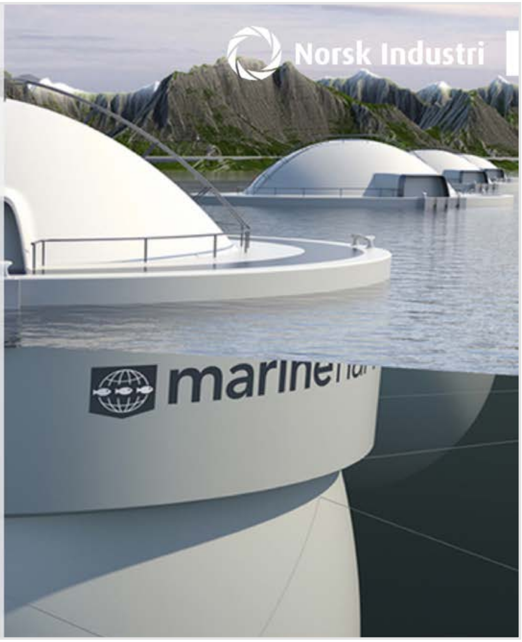

The "traffic light" for sustainable aquaculture development
Norsk Industri
DET KONGELIGE NÆRINGS- OG FISKERIDEPARTEMENT
Meld. St. 16
(2014–2015)
Melding til Stortinget
Forutsigbar og miljømessig bærekraftig vekst i norsk lakse- og ørretoppdrett
• Defining environmental goals and thresholds for impacts
• Divide the coast into 13 regions for assessment of regional environmental sustainability
• Salmon lice effects on wild salmonids currently the only parameter
• Farmed salmon production capacity in the region will be adjusted to "regional carrying capacity"
Parliament white paper (2015)
From presentation by Geir Lasse Taranger. IMR
8


Norsk Industri
Production areas (Traffic light system)
13 Øst-Finnmark
12 Vest-Finnmark
11 Kvaløya til Loppa
10 Andøya til Senja
9 Vestfjorden og Vesterålen
8 Helgeland til Bodø
7 Nord-Trøndelag med Bindal
6 Nordmøre og Sør-Trøndelag
5 Stadt til Hustadvika
4 Nordhordland til Stadt
3 Karmøy til Sotra
2 Ryfylket
1 Svenskegrensen til Jæren

Our vision:
Farmed Norwegian Salmon shall be the most effecient and eco-friendly production of protein in the world.

Increased production requires increased industrialization

- Growth cannot come at the expense of the environment
- Hence, the demand for an industrial roadmap
- Norway has potential to become the global leader in aquaculture technology



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Our zero vision

- No spreading of sea lice from farms
- No escapes
- No resources wasted

12

The sector needs a pro-active approach to emerging challenges, rather than spending resources on solving problems after they have occured.

Norsk Industri

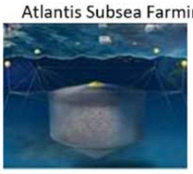
Road map

Norsk Industri

New technology opens up for use of new production areas

NRS/Aker

Atlantis Subsea Farming

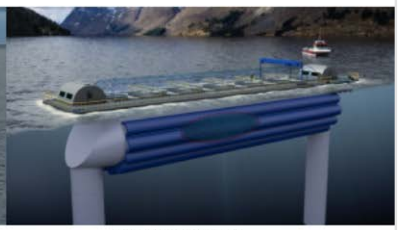


Aqualine

The Egg/Hauge Aqua/Mowi

Havfarm/Nordlaks

Ocean Farm I /Salmar



Pipe Farm/Lerøy

Norsk Industri

What about land-based?

Andfjord Salmon (Andøy, Norway) are planning to build the worlds biggest land based flow-through salmon farm. Capacity 10.000t with possibility to extend to 60.000t

BluehouseTM Miami - Coming in 2020

The MIAMI BLUEHOUSETM will bring production of Atlantic salmon close to the consumer in America, ensuring a fresher and better salmon than ever before. Moreover, it removes the need for airfreight that generates large carbon footprints. The Miami Bluehouse will also bring significant amounts of jobs for Americans and tax contribution

Source: Atlantic Sapphire/ iLaks

Norsk Industri

How can Nasco contribute?

- Engange in a dialogue with the farmed salmon industry in a way that benefits both wild and farmed salmon
- Invite the industry to meetings in order to ensure that discussions are informed
- See the farming industry as a partner and set common goals

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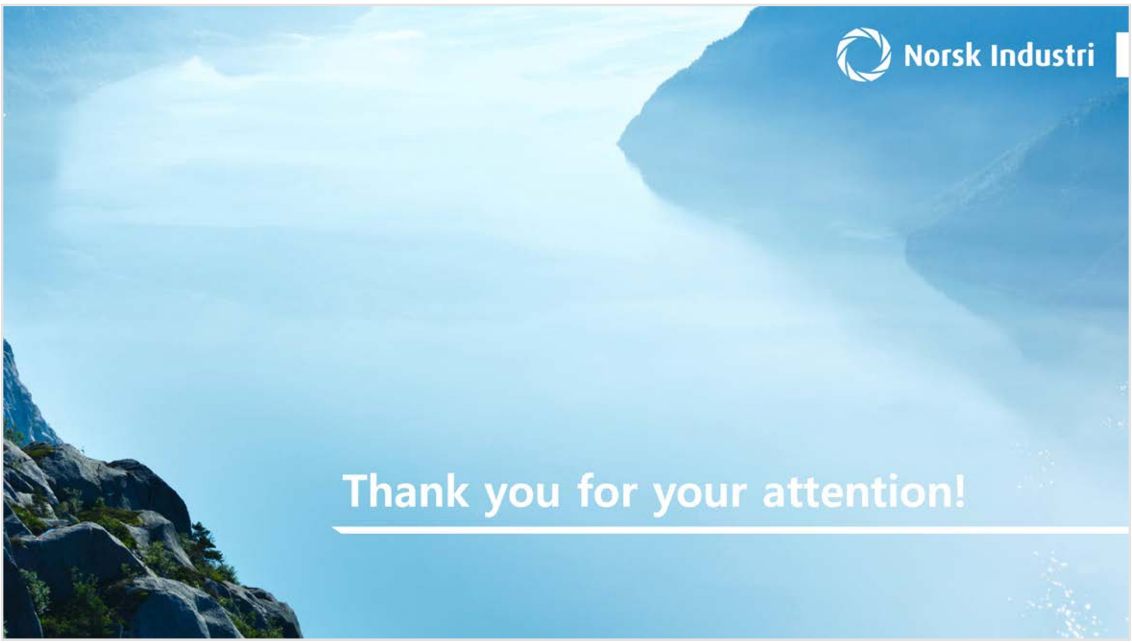

Atlantic salmon and non-native species: is there an issue?

Colin Bean, University of Glasgow, Scotland, U.K.

Introduction

The International Union for the Conservation of Nature (IUCN) assert that the spread of Invasive Alien Species (IAS) is, after habitats loss, the second most significant threat to global biodiversity. The most recent global assessment report on biodiversity and ecosystem services carried out by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz *et al.* 2019) concluded that nearly one fifth of the Earth's surface is at risk of plant and animal invasions, impacting native species, ecosystem functions and nature's contributions to people, as well as economies and human health.

Technically, any species which has been transplanted or introduced to an area outwith its native range (even within the same country), can be regarded as being an 'alien species'. However, the terms 'invasive nan-native species' (INNS) or 'invasive alien species' (IAS) are used interchangeably within the scientific literature to describe non-native (or alien) species which have become established and have negatively impacted native biodiversity, as well as ecosystem services on which humans depend. For clarity, the term IAS is used throughout to describe such species.

A number of international IAS databases are available to provide detail on the distribution, ecology and impact of many invasive species. Details of the best known, and most widely accessed, of these are provided in Table 1. Despite the volume of information available, it remains a difficult task to consolidate these data into a single, global, assessment of the number of IAS. Turbelin *et al.* (2017) attempted to map the global state of IAS using existing databases and concluded that, whilst evaluating the extent of such movements at a global level is problematic, it was clear that significant variation exists in the spatial patterns of invasion. This review also indicated that areas contained within the Global North (e.g. more developed countries), along with tropical islands, are the main recipients of IAS. The rise in establishment of IAS both internationally (Turbelin *et al.* 2017) and within Europe (Keller *et al.* 2011) is largely due to increased globalisation, which has led to the increased movement of people and goods to new areas.

Table 1. *Key IAS databases in use within Europe.*

IAS Database name	Access
Global Invasive Species Database (GISD)	http://www.invasivespecies.net/database/
Global Invasive Species Information Network (GISIN)	http://www.gisin.org/
CABI Invasive Species Compendium	https://www.cabi.org/isc/
European Alien Species Information Network (EASIN)	https://easin.jrc.ec.europa.eu/easin
The Regional Euro-Asian Biological Invasions Centre (REABIC)	https://www.reabic.net/
Delivering Alien Invasive Species Inventories for Europe (DAISIE)	http://www.europe-aliens.org/
The European Network on Invasive Alien Species (NOBANIS)	https://www.nobanis.org/

The role of globalisation in IAS spread

In a recent analysis of global introductions Seebens *et al.* (2017) and found that over one third of all introductions in the past 200 years occurred after 1970 and suggests that the rate of introductions is showing no sign of slowing down. Within Europe, Hulme (2009) showed that the highest rates of introductions have occurred over the last 25 years.

The expansion of new species into new areas can happen through natural means, however most invasions are associated with human activity. The pathways for aquatic organisms to enter new waterbodies either within, or into, Europe are many but Keller *et al.* (2017) break these down into three general themes: 1) transportation as a commodity; 2) arrival with a transport vector; and 3) self-dispersal by the species along infrastructure corridors. *Transportation as a commodity* is perhaps the most obvious of the three pathways described in that it includes the movement of fish or other taxa for sport (e.g. stocking and release of bait fish), aquaculture, biological control or aquarium (including pond) use. This also includes the transport of parasites (e.g *Gyrodactylus salaris*) and diseases which are not native to host species.

Arrival with a transport vector includes those species that may arrive as a passenger on transport (such as ships), but are not themselves a commodity. Some of the best examples of this include the transport of species in the ballast water of large transport ships, and include the introduction of Eurasian ruffe (*Gymnocephalus cernuus*), zebra mussel (*Dreissena polymorpha*) and round goby (*Neogobius melanostomus*) to the Great Lakes in 1986, 1988 and 1990 respectively (Pratt, 1988; Hebert *et al.* 1989; Corkum *et al.* 2004).

Self-dispersal of IAS along infrastructure corridors, such as roads and canals or via the movement of water between catchments for hydropower or drinking water is less commonly documented for aquatic species, and fish in particular (but see Panov *et al.* 2009). Perhaps the best known example of fish utilising waterways as an invasion route are the Asian carps (*Hypophthalmichthys nobilis* and *H. molitrix*) which have, since their release from aquaculture ponds in the 1970's, migrated northwards through the navigable waterways within the Mississippi River towards the North American Great Lakes (Ridgway and Bettoli 2017). Within Europe, examples include the movement of invasive fish species through the network of inland waterways within the River Rhine catchment (Leuven *et al.* 2009), and the transport of Arctic charr (*Salvelinus alpinus*) through a 1400m long tunnel used to transport water from Loch Awe to Cruachan Reservoir (Maitland and Adams 2019).

Other routes of invasion exist such as the deliberate release of unwanted plants, fish or invertebrates (such as crayfish), by aquarists and pond keepers who can obtain material from both retailers (West *et al*. 2019) and from a growing number of online suppliers (Lenda *et al.* 2014). Some pathways are less obvious, such as the deliberate release of animals for religious purposes (Liu *et al.* 2012).

Interactions with other stressors

Whilst invasive alien species (IAS) are considered one of the greatest threats to biodiversity, the magnitude of these impacts may be modified through their interactions with other drivers of change (Bellard *et al*. 2016; Didham *et al*. 2005; Early *et al*. 2016; Seebens *et al*. 2017). Other pressures, such as climate change and resource exploitation, may magnify the impact of IAS on native biota, meaning that when considering the impact of IAS one must also consider the role of other environmental stressors which may affect the fitness of native species.

Extreme climatic events resulting from climate change, such as floods can either transport IAS to new areas or allow fish to escape impoundments. This includes put-and-take fisheries or fish farms located in vulnerable floodplain areas. The increased frequency of storm events may also facilitate the escape of farmed fish into the wild, where they may establish new populations or interbreed with wild conspecifics (e.g. Jensen *et al*. 2010).

Climate change can also result in the opening up new pathways of introduction of IAS. For example, reduced shipping times facilitated by new or emerging Arctic shipping passages caused by melting ice caps may increase the risk of IAS surviving the journey, as well as increasing the potential for some species to greatly increase their global range naturally in response to these changing environmental conditions (Nong *et al*. 2018). Aquatic species at high latitudes may experience greater temperature-mediated pressure which may impact their ability to compete with new species, whether or not they have arrived there as a function of range expansion and natural colonisation. Greater environmental tolerances, a key feature of many successful IAS, may also mean that such animals may have the ability to expand more rapidly than native species to higher latitudes and be better adapted to future changes in climate than native species, thereby allowing them to dominate thermally modified habitats.

At a global scale, Arctic warming may also promote the interchange of fish, and other species, between the Pacific and Atlantic oceans (Wisz *et al*. 2015) and this may present new challenges for Atlantic salmon if such species present a predation risk for either themselves or other species on which they depend for food. Within the Atlantic and other marine regions, climate change is also promoting the shifting of marine species in a northerly direction (Perry *et al*. 2005; Lenoir *et al*. 2011), and this may already be affecting the production of Atlantic salmon at sea.

Changes to thermal and hydrological regimes of freshwaters due to climate change are already predicted to affect the distributions and prevalence of salmonids including Atlantic salmon (*Salmo salar*), brown trout (*Salmo trutta*), and Arctic charr (*Salvelinus alpinus*) (Elliott and Elliott 2010; Jonsson and Jonsson 2010; Finstad and Hein 2012; Svenning *et al*. 2016), suggesting that current habitats may be becoming less suitable than previously, and freshwater systems that currently have thermal barriers limiting the establishment of IAS may become more suitable for IAS as the climate changes (Ellender *et al.* 2016).

Impacts on species and ecosystems

Once introduced IAS can have significant direct and indirect impacts on individual species and aquatic ecosystems. In a review of the published literature Gallardo *et al*. (2016) concluded that IAS can reduce the overall abundance of species and, over time, alter the diversity of aquatic communities across a range of functional groups. However, the scale of any impact is likely to be context-dependent and may differ between species and habitats (Ricciardi *et al*. 2013). Invaders can impact individual species through competition for food and space, predation, disease and parasite transfer and genetic introgression. They can also impact ecosystem functioning, by disrupting foodwebs, modifying the physical environment (Ricciardi and MacIsaac 2011; Ricciardi *et al*. 2013; Gallardo *et al*. 2016). Along with the upward trend in the establishment of new species, the projected impacts on biodiversity are also expected to increase because of the growing number of species involved and the increasing vulnerability of ecosystems to invasions resulting from other pressures such as habitat loss, degradation, fragmentation, over-exploitation and climate change (Clavero and García-Berthou 2005; Didham *et al*. 2005; Bellard *et al*. 2016).

Examples of IAS impacts on Atlantic salmon

Little exists within the scientific literature with regard to the direct impact of exotic IAS on Atlantic salmon, however more information is available on the potential impact on 'Locally Absent Species' (LAS) (i.e. species which may be native to a nation state, but are not locally native to that waterbody). Short, non-exhaustive, examples of potential relationships between Atlantic salmon and predators, competitors, invertebrates and plants are provided to illustrate a range of interactions which may occur.

Introduced fish - predators

Whilst juvenile Atlantic salmon may have many natural predators, such as piscivorous birds, mammals and fish (Thorstad *et al*. 2012), there is little in the published scientific literature relating to the introduction of new piscivorous predators from outwith Europe. That is not to say, however, that native species, inappropriately introduced, do not present a potential threat. The introduction of pike (*Esox lucius*) to a waterbody from which it is naturally absent may constitute a significant risk to native fish species – including Atlantic salmon. Several studies (e.g. Kennedy *et al*. 2018) have demonstrated the impact that pike may have on Atlantic salmon smolts which migrate through natural lakes. It is logical to assume, therefore, that the introduction of this, or other locally non-native piscivorous fish species (including large trout), to new waterbodies where they may come into contact with Atlantic salmon will result in increased predation pressure.

Introduced fish - competitors

Whilst the introduction of a piscivorous predator may seem an obvious risk to Atlantic salmon (and other native fish species), the introduction and spread of species such as the Eurasian minnow (*Phoxinus phoxinus*) can also pose an unrealised risk. Museth *et al*. (2007), in a study of the impact of the expanding range of Eurasian minnow populations in Norway concluded that this species has the potential to impact brown trout (*Salmo trutta*) populations through increased competition for food resources. Whether this species has an impact on juvenile Atlantic salmon is not known, but given the nature of the competitive interaction with brown trout, potential for some ecological overlap exists. A similar situation exists in Scotland, were this species has been widely, and deliberately, spread by anglers by way of discarded live bait, and as a potential prey source for local trout.

Bullhead *Cottus gobio* are included in Annex II of the EU Habitats Directive and within the UK and they are a conservation feature in 17 Special Areas of Conservation. However, within the UK this species has a restricted, southerly distribution, and it is naturally absent from Scotland. Introduced populations exist in the Clyde, Forth and Tweed catchments and there is concern that competition, both for food and space, between bullheads and juvenile Atlantic salmon may result in an overall negative impact on Atlantic salmon production. Empirical evidence to support this is limited to basic inference, however Gabler *et al*. (2001) in one of the few studies to explore the interaction between Atlantic salmon parr and bullhead reported selective segregation in prey choice between species. It remains possible, however, that higher levels of dietary and spatial overlap exist between Atlantic salmon fry and bullhead at varying stages in their life history.

Introduced invertebrates

Introduced crayfish species can negatively impact salmonid fish (Holm *et al*. 1989; Savino and Miller 1991; Rubin *et al*. 1993; Griffiths *et al*. 2004; Fitzsimons *et al*. 2007; Peay *et al*. 2010). In Europe, most attention has in recent decades focussed on the impact of the signal crayfish *Pacifastacus leniusculus*, a North American species which has been widely introduced and has had significant adverse impacts on freshwater ecosystems and individual species (Holdich *et al*. 2009). Where introduced, crayfish can predate on fish and their eggs, compete for food and shelter and modify instream and bankside habitats (Everard *et al*. 2009; Reynolds 2014; Mathers *et al*. 2016; Turley *et al*. 2017). Whilst there is significant concern over the impact of introduced signal crayfish on native salmonid species, evidence of a significant impact through direct predation of juvenile Atlantic salmon is sparse. Fluvarium-based trials which have investigated whether signal crayfish have the potential to excavate and consume Atlantic salmon redds have been equivocal. One study demonstrated active excavation and predatory loss of eggs and fry (Edmonds *et al*. 2011), one showed no impact (Gladman *et al*. 2012) and another demonstrated that egg predation may only be carried out by larger animals (Findlay *et al*. 2014).

Introduced plants

Invasive riparian plants are now considered to be a significant issue for aquatic ecosystems, and species such as Japanese knotweed *Fallopia japonica* and Himalayan balsam *Impatiens glandulifera* are now widely established on river banks across the northern hemisphere (Seeney *et al*. 2019). Rapidly invading plant species such as these can negatively impact aquatic habitats through increased shading, reduced surface water temperatures and, as a consequence, may result in a reduced potential for autochthonous production. By outcompeting native riparian plant communities, winter dieback of large invasive monocultures can also result in increased flood risk and erosion. Changes to the composition and quantity of allochthonous leaf litter may also affect both the diversity and abundance of aquatic invertebrates (Claeson *et al*. 2013). Clear potential exists for riparian plant IAS to affect the distribution and abundance of Atlantic salmon in affected watercourses, although the scale of any impact will be site-specific and may be dependent on a range of other factors, such as the extent of plant growth, location within individual catchments and stream width.

Interactions between non-native in-stream plants and Atlantic salmon are absent from the peer-reviewed scientific literature, suggesting that this is a low risk. However, where the luxurious growth of riverine plants do become established, they can, in association with low flows, impact adult salmonids (House *et al*. 2016). In Scotland, the establishment of the River water-crowfoot *Ranunculus fluitans*, in the River Spey in 1979 is considered to be a problem for fishery managers. This species, which is native to other parts of the UK but not to the Spey catchment creates problems for anglers by choking pools and making it difficult for anglers to catch and land Atlantic salmon and other salmonids (Laughton *et al*. 2008). The ecological impact of this species on Atlantic salmon, particularly juvenile fish, is unquantified. Elsewhere in Scotland another water crowfoot species (*R. aquatilis*) has been present in the River Dee (Aberdeenshire) for almost 100 years, having first been recorded there in 1916. Where present, similar concerns in relation to plant abundance and impact on angling success exist.

Salmonids as invaders

Salmonids are successful invaders and new populations have been established across the globe over the course of the last century. Brown trout, for instance, is included in the list of the '100 worst invasive alien species' compiled by the IUCN Invasive Species Specialist Group (Lowe *et al*. 2000). Atlantic salmon are themselves, listed as IAS in several of the global IAS databases (IUCN Global Invasive Species database, CABI Invasive Species Compendium, and the NOBANIS European Network on Invasive Alien Species), but these listings relate specifically to the release of domestically reared fish into the wider environment. Farmed Atlantic salmon pose a particular risk to wild individuals because, despite domestication, likely to have similar physiological tolerances, can compete for food and space within rivers, may arrive in large numbers and can spawn with wild conspecifics. The importance of inherited adaptive variation in maintaining Atlantic salmon and other salmonid populations is well understood (Garcia de Leaniz *et al*. 2007; Fraser *et al.* 2011) and a substantial scientific literature exists to demonstrate that the stocking and transfer of Atlantic salmon (and other salmonids) could threaten the maintenance of wild populations (e.g. Karlsson *et al*. 2017). Over time, Bolstad *et al*. (2017) argues that the continued ingress of domesticated genes and the loss of locally adapted traits can alter the life history of wild Atlantic salmon populations. The same process may also affect Atlantic salmon populations which have been supplemented with wild fish from other catchments. Despite these impacts, stocking continues to be utilised as a tool to support declining numbers of returning fish (Aas *et al*. 2018). Instead of the term IAS to describe farmed Atlantic salmon in areas where they can cause damage to wild populations, a new term, Invasive Alien Conspecifics (IAC) could be used to differentiate between the impacts of other species to those caused by the same, but farmed or stocked, individuals. The term IAC could be used to describe the escape or deliberate release of any species into waters where wild conspecifics occur.

Beyond genetic impacts, the transfer of Atlantic salmon, and other salmonids, beyond national boundaries carries the risk of disease and parasite transfer. The introduction of the ectoparasite *G. salaris* to Norwegian rivers from infected Atlantic salmon from Sweden in 1975 (Sandodden *et al*. 2018) remains one of the greatest threats to Atlantic salmon in that country. It remains the best known example of how parasite transfer can have a catastrophic impact on individual Atlantic salmon populations. Whilst the parasite has been successfully removed from several river systems in Norway, the economic costs of this have been high, both in terms of the biological resource lost and the financial cost of eradication and post-treatment monitoring.

Salmonid introductions are often used to demonstrate the impact of biological invasions in aquatic ecosystems because they are among the most widely introduced fish taxa around the globe (Crawford and Muir 2008; Buoro *et al*. 2016). Within their native range salmonid introductions have been primarily driven by the desire to establish or maintain recreational fisheries, although introductions have also been carried out as conservation or compensatory/restoration measures. However the underlying policy instruments used to guide this activity vary between Nation States (Aas *et al*. 2018).

Pacific salmonids, and Rainbow trout *Oncorhynchus mykiss* in particular, have established self-sustaining populations around the globe, and proved to be a highly successful invaders in many cases (Crawford and Muir 2008). In terms of establishing self-sustaining populations in western Europe, the success of Rainbow trout has been limited, with only 130 confirmed or potential self-sustaining populations being recorded across 16 European countries (Stanković *et al*. 2015). Where present the potential for competition with, or predation of, juvenile Atlantic salmon cannot be discounted.

Despite being present in the White Sea and northern Scandinavia since the late 1950's the sudden expansion of odd-year Pink salmon *O. gorbuscha* into rivers in Finland, Norway, Iceland, Scotland, England, Ireland, Denmark, France and Germany in 2017 was unexpected (Armstrong *et al.* 2018; Mo *et al*. 2018; Sandlund *et al*. 2019). Time will tell whether this explosion of Pink salmon records around northwestern Europe was a single event, or whether this will become a more regular occurrence. The large numbers associated with returning Pacific salmonids within their native and introduced range suggest that propagule pressure may be high, but differences in run timing and overall life history may mean that their actual impact on Atlantic salmon is low. However, data to support this is currently lacking.

The Ponto-Caspian problem

IAS originating from the Ponto-Caspian region are considered to be a particular threat to freshwater habitats to which they are not native. The potential impact of species such as Killer shrimp (*Dikerogammarus villosus*), Demon shrimp (*D. haemobaphes*), Zebra mussel, Quagga mussel (*Dreissena r. bugensis*) and round goby on freshwater ecosystems is well documented (e.g. Gallardo and Aldridge 2015). Currently, over 100 species are known to be spreading outwards from the Ponto-Caspian region via a number of invasion pathways (Ketelaars 2004). The impact of Ponto-Caspian species on Atlantic salmon, their habitats and the ecological processes which support them is unquantified, and the potential for introduction remains a significant risk.

The cost of IAS

Approximately 12,000 non-native species have been registered in Europe (Keller *et al.* 2011; European Commission 2014) and many of the 10-15% of those species which have become IAS (Lockwood *et al*. 2013) were introduced intentionally because they have a high value to humans (Ehrenfeld 2010).

Where established, particularly within aquatic habitats, IAS are often difficult or contain, and in many cases, impossible to eradicate. Regardless as to whether an IAS can be controlled or eradicated, the economic cost of dealing with such species can be significant and long-term (Jardine and Sanchirico 2018). Direct management costs, such as those required to implement control measures or, where possible, eradicate can be expensive to implement and may require the allocation of research costs, as well as those required for equipment, monitoring and manpower. Lost benefits through a reduction in production, environmental damage (such as erosion, siltation) and impacts on environmental services (such as water supply or recreational fisheries) can escalate the cost of opportunity losses. The estimated annual costs attributable to the impact of IAS are as high as £1.7 billion in the UK, $1.4 trillion in the USA and $33.5 billion in SE Asia (Pimentel *et al*. 2005; Williams *et al*. 2010). Such evaluations are likely to be under-estimates of the true cost. In fact, Pimentel *et al.* (2001) suggests that losses in global production due to the impact of IAS could be as high as 5%.

Notwithstanding the fact that IAS can carry significant economic costs, biological invasions represent one of the greatest threats to freshwater ecosystems (Ehrenfeld 2010), and the ecosystem services that they provide (Pejchar and Mooney 2009).

Legislation and policy

International agreements

The IPBES Global Assessment Report on Biodiversity and Ecosystem Services published in May 2019 (Díaz *et al*. 2019) reaffirmed the role that IAS play in species extinctions worldwide. Whilst the scale of impact is of growing concern, the dangers posed by IAS at a global level have been recognised for some time. Article 8(h) of the Convention on Biological Diversity (CBD) states that, *'Each contracting Party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species'*, and as long ago as 1992, the CBD put forward a three-stage hierarchical approach to deal with the issue (Prevention, Early detection and rapid eradication; and Control and/or containment). In 2010 the majority of the world's governments adopted the CBD Strategic Plan for Biodiversity. This included the 20 headline objectives which now commonly referred to as the referred the 'Aichi Targets'. One of these, Aichi Target 9, is specifically related to the control of IAS and states that: *'By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment'.* This international commitment to addressing IAS was re-asserted in 2015 through the CBD's 2030 Agenda for Sustainable Development, which states that: *'By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species'.*

In response to global concerns, and driven by the fact that the number and extent of IAS were increasing within Europe, the European Union published two regulations of relevance to the issue of IAS and Atlantic salmon. The first of these was the Council Regulation (EC) No 708/2007 concerning use of alien and locally absent species in aquaculture. This regulation is intended to provide a framework to ensure adequate protection of aquatic habitats from the risks associated with the use of non-native species in aquaculture. The second is EU Regulation 1143/2014 on invasive alien (non-native) species, this is a commitment contained in Target 5 of the EU's Biodiversity Strategy to 2020 (European Commission, 2011). The Regulation establishes a coordinated EU-wide framework for action to prevent, minimise and mitigate the adverse impacts of IAS on biodiversity and ecosystem services, and limit their damage to the economy and human health. The Regulation also lists 49 species of Union Concern, many of which are aquatic. Examples include Chinese mittencrab *Eriocheir sinensis*, Spiny-cheek crayfish *Orconectes limosus*, Virile crayfish *O. virilis*, Signal crayfish, Red swamp crayfish *Procambarus clarkii*, Marbled crayfish P. *fallax f. virginalis* and Amur sleeper *Percottus glenii*. Riparian plant species, such as Himalayan balsam *Impatiens glandulifera* and Giant hogweed *Heracleum mantegazzianum* as well as a number of species which are commonly associated with large river and standing water habitats.

These new regulations augment existing commitments to control IAS within other international agreements (e.g. Bonn Convention on the Conservation of Migratory Species of Wild Animals and Bern Convention on the Conservation of European Wildlife and Natural Habitats), as well as existing European instruments for nature conservation (Article 22 of the EC Habitats Directive and Article 11 of the Birds Directive 79/409/EC). Whilst not explicitly mentioned in legislation, the EC Water Framework Directive requires member States to put in place national measures to achieve or maintain a good ecological status for European inland, transitional and coastal waters by 2015 and prevent their further deterioration. The control or eradication of IAS forms part of this work.

National measures

National controls on the spread on IAS at a national level vary significantly throughout Europe and, in the case of the UK, measures vary between national administrations. McGeoch *et al*. (2010) calculated that 55% of CBD signatories had domestic legislative measures in place to deal with IAS and many European countries have national regulations in place to regulate the import of species (e.g. McGeogh *et al*. 2016). However, the EU

IAS Regulation presents a new framework for coordinated action across all Member States, with prevention, eradication and control measures being applied at the national level, along with a commitment to identify invasion pathways and deal with new invaders rapidly. Information sharing between Member States and new reporting obligations should lead to greater consistency of approach when dealing with IAS in future.

An important, but less well appreciated, aspect of IAS introductions is the 'translocation' (including stocking) of species within a nation state, i.e. from waters in which a species occurs naturally to waters where it does not occur naturally (Bean and Copp 2016; Dodd *et al*. 2019). A long history of unregulated and unrecorded fish movements over past centuries makes it difficult to identify the true native range of some species. The deliberate introduction of 'locally absent' species may pose an equally high risk to native species and ecosystems as the introduction of alien species from other countries, and this is recognised internationally (ICES 2004; EIFAAC 2007). Three examples are provided in Section 5, namely pike, Eurasian minnow and bullhead.

Conclusion

Species which live in northerly latitudes are under significant threat from both climate change and IAS (Walther *et al*. 2009). The climate is warming faster at northern latitudes than elsewhere suggesting that the added pressure of IAS may be particularly significant in the temperate and Arctic waters which support vulnerable populations of Atlantic salmon.

The success or failure of IAS establishment depends on a number of factors, including the ecological tolerance of the invader and the environmental resistance of invaded systems (Ricciardi and Atkinson 2004), the frequency and intensity of propagule pressure (Lockwood *et al*. 2005), and the plasticity of invaders (Westley 2011). Although much more is known about the ecological consequences or impacts of biological invasions than in the past, such knowledge is only gained after AIS have become well established (Dunham *et al*. 2002). This points towards a need for greater surveillance, by Government, fishery managers and the general public to identify new arrivals as soon as possible. Once established, the ecological impacts of IAS are difficult to reverse (Vitule *et al*. 2009), particularly in freshwater habitats where eradication and control measures which do not, in themselves, cause significant environmental damage, are relatively few.

Introduced Atlantic salmon, either from fish farm escapes or planned stocking can have significant impacts of wild populations. These AIC (Aquatic Invasive Conspecifics), can pose a particular risk, and if the Atlantic salmon aquaculture industry moves northward in response to climate change, there is potential to affect populations which are currently not exposed to significant pressure.

Looking forward – horizon scanning and Risk Assessment

Horizon scanning is an approach used to prioritise the threat posed by potentially new IAS not yet established within a region, and has been seen as an essential component of IAS management with demonstrated net economic and ecological benefits (Roy *et al*. 2019). When used alongside risk analysis (Roy *et al*. 2017; Dodd *et al*. 2018), the impact of potential IAS on Atlantic salmon can be evaluated in a systematic and consistent way between nation states. The scientific literature suggests that risk analysis for Atlantic salmon across its native range would be a significant step forward in predicting the future impact of IAS on this species. National risk assessments exist for many of the most damaging and widely distributed IAS, as well as contingency plans to deal with parasites and notifiable diseases which may affect Atlantic salmon rivers. It is important that horizon scanning does not limit its focus to species which are 'exotic' to a locality, but also includes an assessment of the potential for Locally Absent Species (LAS) to impact Atlantic salmon directly, or the habitats and ecological processed that support them. Experience has shown, in the case of *G. salaris*, that 'local species' can act as reservoirs of disease and parasites and that their movement between catchments can pose a significant risk.

Monitoring and surveillance

A number of international agreements at both a global and European level provide clear direction with regard to the importance of the IAS issue and our collective responsibility to act. The EU Regulation 1143/2014 on invasive alien (non-native) species, requires greater surveillance for IAS and the identification of pathways of invasion. Whilst the cost of surveillance can be high, the adoption of new tools, such as eDNA for monitoring invasive fish (e.g. Gustavson *et al*. 2015), invertebrates (e.g. Harper *et al*. 2018) and even *G. salaris* (Rusch *et al*. 2018) can both reduce the costs and ease of sampling.

In summary, IAS, along with other stressors can have the potential to have a negative impact on Atlantic salmon, although direct empirical evidence is lacking in many areas. Whilst legislation to control the further movement and surveillance on IAS has improved significantly within Europe, promising better coordination between Member States, there remains a need to develop a strategy for Atlantic salmon, which sets out the risks posed by IAS, AIC and Locally Absent Species against a range of climate change scenarios and known pathways for invasion. The lack of published empirical evidence on the actual impact of AIS on Atlantic salmon remains a cause of concern, and any strategy should consider how this may be addressed in future years.

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The challenge of reducing the impacts of invasive pink salmon

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Pink salmon

Pink salmon (*Oncorhynchus gorbuscha*) are native to the northern Pacific (Figure 1). They typically have a two-year life cycle, which means that the offspring of spawning in the autumn of any particular year will return to spawn two years later. One consequence is that there are two broodlines of pink salmon; odd-year and even-year spawners. Eggs hatch in the spring, and the fry smoltify and leave the river after a few days or weeks, at a length of about 30-50 mm. After spending a little more than 12 months feeding at sea, the fish mature and return to rivers for spawning, at a body size of 0.5-4 kg.

Figure 1. *Pink salmon are native to the Pacific but introduced to Northwest Russia and are now spreading to other countries in the Northeast Atlantic. Photo: Eva. B. Thorstad*

How did they come to the Atlantic?

During the late 1950s, fertilised eggs of pink salmon from spawning stocks in Sakhalin Island (47 °N) on the Russian Pacific were transported to hatcheries on the White Sea in northwest Russia. After hatching, fry were released in rivers around the White Sea. The first return of spawners was in 1960, when pink salmon were recorded in relatively large numbers, also in Norwegian waters. During 1960-1980, returning adult pink salmon were recorded over a large area, from the Kara Sea in the east to Iceland, Scotland, England and Denmark on the western side of the Eurasian continent.

Despite frequent releases until 1979, the Russian aim of establishing self-sustaining pink salmon populations in White Sea rivers failed. It was assumed that the reason for not attaining natural reproduction was that the stocking material originated in rivers in a warmer climatic region. During these years, most returning adult pink salmon to both Russian and Norwegian waters were the result of the Russian stocking program, but there were also some cases of natural reproduction.

In 1985-1999, stocking activity was resumed, based on stocking material from further north on the Russian Pacific, in the Magadan area (59 °N, River Ola). These introductions resulted in successful natural reproduction by odd-year pink salmon in White Sea rivers, and pink salmon has been self-reproducing in this area at least since 2000. Russian catches of odd-year adult fish were usually below 100 tonnes before 2001 but has been increasing in recent years. In 2001-2017, mean annual catches of odd-year pink salmon in Russian waters was 220.5 tonnes (99.5-373.4 tonnes; the highest amount in 2017). According to ICES, the total catch of pink salmon in 2017 in the northwest of Russia was eight times higher than the total catch of Atlantic salmon in the area. Some pink salmon also return to the rivers in even years.

Spreading outside Russia and large invasion to several European countries in 2017

Pink salmon has spread to some rivers in Northern Norway, close to the Russian border, where they have spawned regularly in recent years (mainly odd years, but also some in even years). Occasionally, pink salmon have been caught in Norwegian rivers further south. This was the case in 2015, when 162 fish were reported from 21 Norwegian rivers, and in 2016, when 159 fish were reported from 30 Norwegian rivers. However, in 2017, there was a formidable invasion in rivers all along the Norwegian coast (Figure 2), with a minimum number of more than 11,000 pink salmon being caught or observed in 272 rivers. Spawning was observed in many rivers along the coast. During the winter of 2017-18, fertilised eggs, fry with partly absorbed yolk sac, and fry in the process of smoltification, have been collected as far south as around Bergen (60 °N). In 2017, a substantial number of pink salmon was also caught in Scotland, England, Ireland, Iceland and other countries in northwestern Europe (Figure 2). Some fish were also caught in rivers on the Atlantic coast of North America.

The reasons for the large increase in the number of pink salmon appearing in 2017 are not known. However, it is likely that there has been a combination of favourable conditions in spawning rivers in 2015-16 and favourable near-coastal and oceanic conditions in 2016-17. Some authors have suggested that warm years in the Barents Sea and North Norwegian Sea may favour pink salmon.

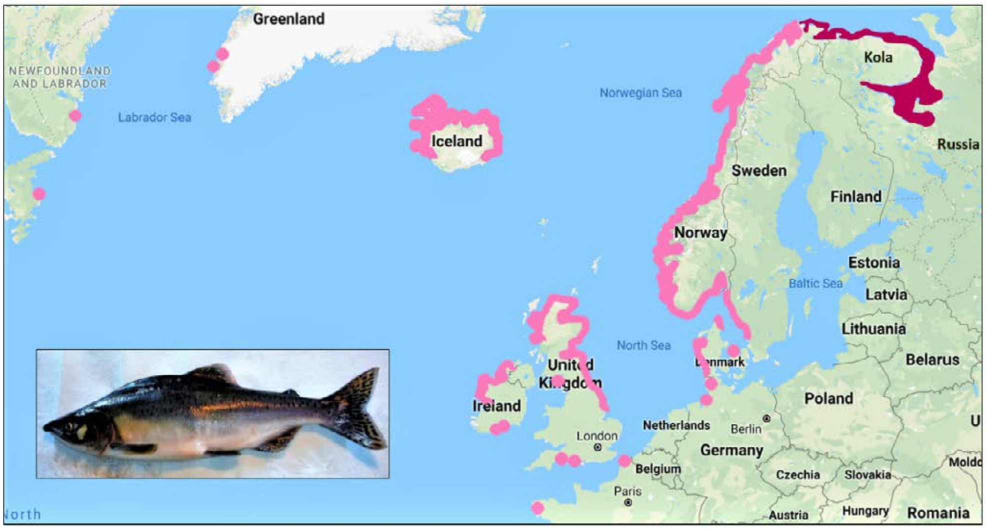

Figure 2. *Distribution of pink salmon catches in the North Atlantic and Barents region in 2017 shown in pink (areas shown in dark pink are areas in Russia and Northern Norway where pink salmon have been regularly captured also in earlier years). Based on Bean 2017; Armstrong et al .2018; Sandlund et al. 2019; and unpublished data gathered via google search and Twitter.*

How may pink salmon impact native salmonids and ecosystem services in the North Atlantic area?

Pink salmon normally enter the rivers and spawn before sea trout (*Salmo trutta*) and Atlantic salmon (S*almo salar*). They may, however, stress the native spawners, which are preparing for spawning, particularly when pink salmon occur in large numbers. When occurring in large numbers, pink salmon may also impact the angling catches of native species. Pink salmon caught in the rivers during the main angling season for native species are in a bad condition when close to their spawning and are not regarded as valuable food. All pink salmon die after spawning. The decaying carcasses may contribute to fertilise the river, which may alter entire ecosystems in unpredictable ways. The pink salmon eggs hatch before the native salmonids, and on emergence from the gravel, the fry already have the coloration and partly also the physiological status of smolts. They migrate downstream to estuaries and coastal waters the same spring but may also feed in the rivers for a few weeks and potentially be in competition with juveniles of native salmonids during this period. Their impact on native populations in this respect is unknown. Concerning parasites and diseases, little is known about the possible role of pink salmon as an agent or intermediate host for parasites and diseases that may affect the native salmonids.

Based on our present knowledge, it is difficult to predict the potential impact of invasive pink salmon on native salmonids, ecosystems and ecosystem services around the North Atlantic, but there is certainly a potential risk for negative impacts. The impact on native anadromous salmonids is likely related to the abundance of pink salmon. The high numbers of pink salmon occurring in 2017 indicate that there is a large potential for spreading and possible establishment under favourable conditions.

The challenge of reducing the impacts and advice for management

The sudden increase in the occurrence of pink salmon in rivers along the entire Norwegian coast and in other countries around the Northeast Atlantic in 2017 most likely stems from spawning in Russian rivers, and possibly in some Norwegian rivers close to the Russian border in Finnmark. As long as there is successful reproduction of pink salmon in rivers in northwest Russia and Northern Norway every year there will be a pool of potential invaders in the Barents Sea and the Northeast Atlantic, with a risk of spreading and establishment in new areas.

The management measures available to reduce this pressure are to hinder pink salmon in entering the rivers, to catch as many pink salmon as possible before they can spawn or try to destroy spawning redds before hatching. All possible management measures involve a huge effort and possible negative consequences for native fauna.

Pink salmon apparently spread widely among rivers and across national borders when they return for spawning. Although mainly homing to the area where they were born, they do not have the same precise homing as for instance Atlantic salmon. The migration pattern and potential for spreading show that eradication of pink salmon from single rivers at best would have a short-term effect. To achieve any long-term effect, mitigation measures must be implemented through coordinated efforts over larger areas. Hence, mitigation efforts to reduce the risk of establishment and negative impacts of pink salmon in the Northeast Atlantic and Barents area, may only be efficient if regional and international collaboration and co-ordination to reduce pink salmon abundance can be achieved.

Knowledge gaps are linked to predicting the likelihood of spreading to larger areas in the North Atlantic, and the possible impacts on native species, ecosystems and ecosystem services. Climate change may influence the likelihood of pink salmon being established in Northern Europe, particularly if they are currently restricted by cold years in the sea and rivers, but this is not well known. Climate change may already put native salmonids under pressure. This may render them vulnerable to other negative impacts, such as introduced pink salmon. Ensuring strong populations of local salmonids will likely also help to minimise the possible negative impacts of pink salmon and other pressures caused by anthropogenic activities.

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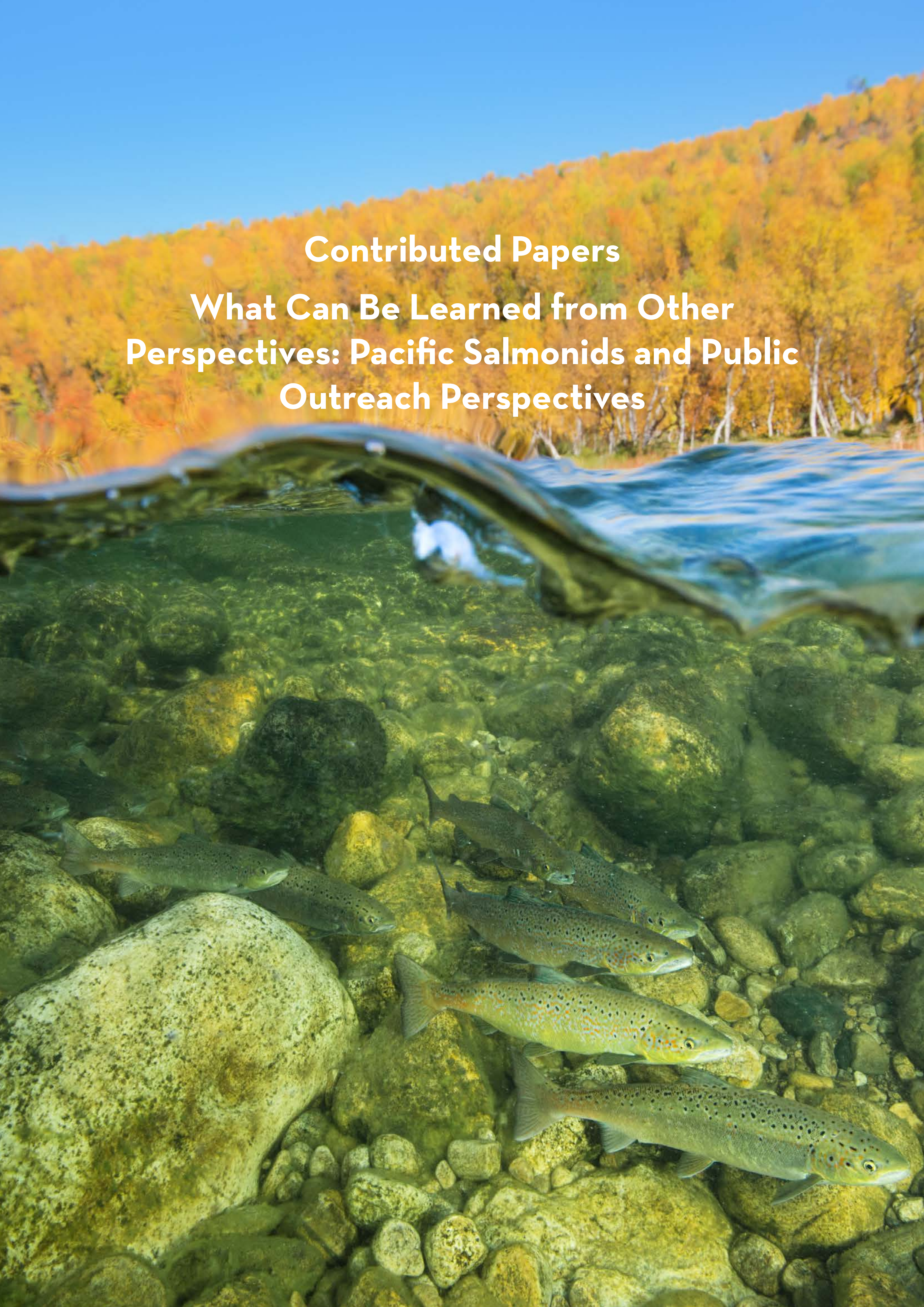
Contributed Papers

What Can Be Learned from Other Perspectives: Pacific Salmonids and Public Outreach Perspectives



Challenges of Managing Pacific Salmonids: What can the Atlantic side learn from the Pacific side?

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Introduction

Pacific salmon are an important element of ecosystems throughout much of British Columbia (BC) (Figure 1), with inland migrations extending as far as 1,000 km. There are six species of anadromous salmon in BC: Chinook (*Oncorhynchus tshawytscha*), Sockeye (*O. nerka*), Coho (*O. tshawytscha)*, Chum (*O. keta*), Pink salmon (*O. gorbuscha*), and Steelhead (*O. mykiss*). These species rely on a broad set of freshwater and Northeast Pacific Ocean ecosystems, and can also be key elements of freshwater ecosystems through their contributions of nutrients to aquatic and terrestrial systems (Darimont *et al.* 2010). Pacific salmon life-histories vary by species and population and can include different ages, time spent on freshwater and marine ecosystems, distributions, and migration timing. Some species have relatively small populations (hundreds or thousands) while others such as Fraser River Sockeye can have returns of up to tens of millions in some years. Many salmon populations have been in decline or at reduced levels of abundance over recent decades, resulting in implications for people who rely on these populations, and also for ecosystems more broadly.

Background

In BC, salmon are managed in accordance with provisions of the Pacific Salmon Treaty (PST), first established between Canada and the United States (US) in 1985. The PST clearly identifies conservation as the highest priority in salmon management, and also sets out harvest sharing arrangements between the two countries.

Both a regulatory framework and a strong framework of conservation policies guide fisheries management decisions in BC. Key is *Canada's Policy for Conservation of Wild Pacific Salmon* (known as Wild Salmon Policy (WSP)) (DFO 2005) which sets out a framework for maintaining genetic diversity and supporting ecosystems. Indigenous fisheries for food, social and ceremonial (FSC) purposes have the highest priority, second only to conservation. Commercial and recreational fisheries are next in priority, with their relative priority differing by species. Commercial and recreational fisheries are significant contributors to the economy of BC and are especially important to coastal communities.

Figure 1. *Major BC Salmon Rivers.*

In general, the majority of BC salmon production is from wild populations. Hatchery production is largely focused on Chinook and Coho, to support fisheries and conservation objectives.

There are strong and diverse interests in the conservation and harvest of BC salmon. An annual planning process involving formalised arrangements for obtaining input from Indigenous groups, the Province of BC, and commercial, recreational, and environmental stakeholder organizations, informs development of the Integrated Fisheries Management Plans for Northern and Southern BC salmon – setting out the fisheries management approaches and harvest rules for each year. For species like Chinook and Coho salmon there is limited information available to guide in-season management decisions, whereas others such as Fraser River sockeye are very actively managed based on a wealth of data collected through the spawning migration period.

Declines in Pacific Salmon

Many BC salmon stocks have declined in recent decades including Southern BC Coho, Fraser Sockeye, and Chinook salmon, while Chum and Pink salmon have experienced more variable returns. During the 1990s the productivity of Southern BC Coho populations declined markedly (Figure 2), resulting in complete closure of targeted fisheries and constraints on fisheries with bycatch impacts. While some southern Coho stocks have shown signs of recovery, many, including Interior Fraser River Coho have not recovered despite maintaining total fishery–related mortality (Canada and US) at a range of 13-15% for the past 20 years.

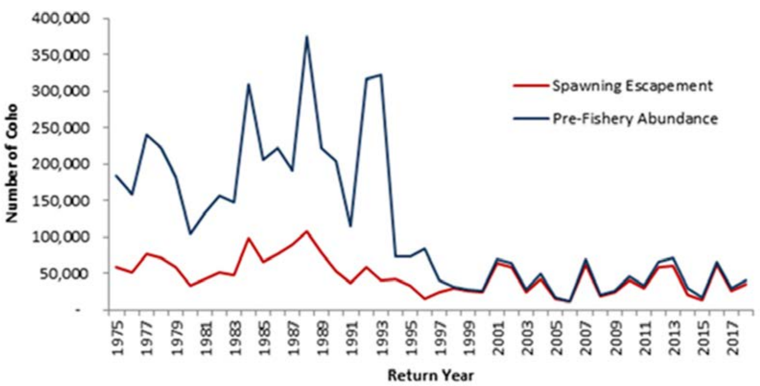

Figure 2. *Total Abundance and Spawning Escapement of Interior Fraser River Coho 1975-2018. Credit: Lynda Ritchie, DFO*

Fraser Sockeye declines began in the mid-1990s and were attributed to factors acting in their freshwater and marine ecosystems. In recent years, warmer ocean and freshwater conditions have contributed to lower Fraser Sockeye survival (MacDonald *et al.* 2018). In 13 of the past 14 years, Fraser sockeye returns have been below the median forecast level (Table 5 in DFO 2018; MacDonald *et al*. 2018), reflecting an overall decline in productivity from earlier years. Returns have also become more variable, with years of extremely high returns (~28 million in 2014), now followed by 3 years of extremely low returns (Figure 3).

Many BC Chinook salmon stocks have also declined in the past two decades. Recent PST re-negotiations in 2018 resulted in lowered maximum harvest levels for both Canada and the US due to a trend of population declines between California and Alaska. In addition to fewer numbers of Chinook salmon, there has also been a pattern of reduced body size, reduced size-at-age, with fewer older fish returning to spawn, and decreased fecundity (Ohlberger *et al*. 2018).

What is driving salmon declines?

Concerns about Fraser River Sockeye, which have supported important First Nations FSC fisheries and large commercial as well as recreational fisheries in the past, have resulted in multiple inquiries and reviews since the 1990s. The Commission of Enquiry into the Decline of Sockeye Salmon in the Fraser River (Cohen 2012) is the most recent and extensive review. The key finding based on available science, and testimony from many expert witnesses, was as follows:

> *'I concluded that the evidence led before this Commission has identified numerous stressors that may have negatively affected Fraser River sockeye salmon over the past 20 years. At the same time, there are patterns of declining productivity at a regional scale which suggest that mechanisms operating on larger, regional spatial scales, and/or in places where a large number of correlated sockeye stocks overlap should be seriously examined. I also concluded that it is not a matter of choosing one potential cause over the other. The available evidence shows that both Fraser River–specific stressors (such as development along the river or contaminants in the water) and region-wide influences (such as marine conditions in the Strait of Georgia or Queen Charlotte Sound) may have contributed to the long-term decline.'*

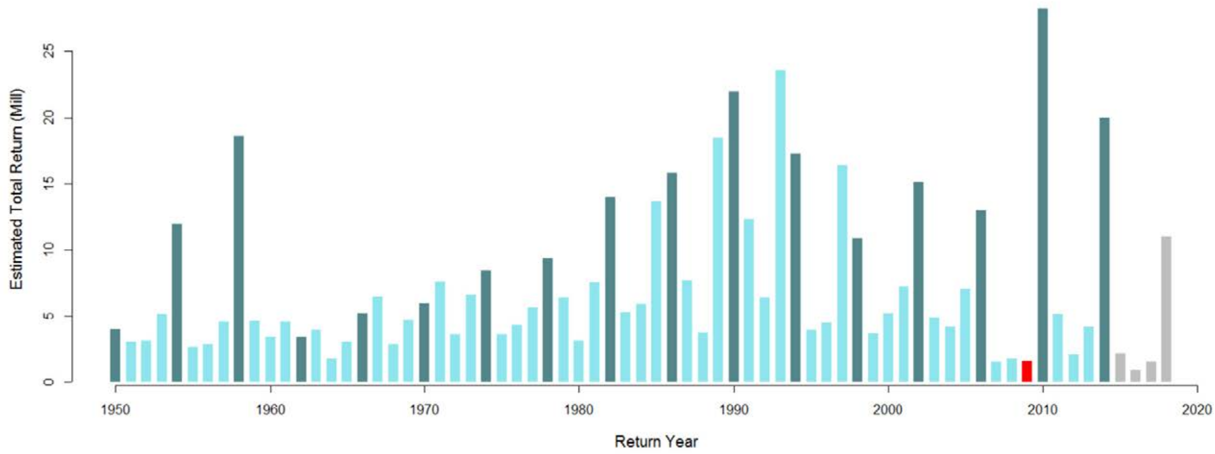

Figure 3. *Estimated Total returns of Fraser River Sockeye from 1950-2018. Red bar indicates low return that prompted Cohen Commission inquiry. Grey bars indicate the last 4-year cycle.*

While the Cohen Commission was focused on Fraser River Sockeye, it is likely that declines in other Pacific salmon species and Sockeye populations are caused by similar factors, and that the cumulative effect of numerous stressors in both freshwater and marine environments need to be considered and acted upon to address declines.

Climate change is an increasingly important threat for salmon, with documented warming trends in freshwater and marine ecosystems linked to salmon declines (Sue Grant, DFO, pers. comm.). A recent significant marine heatwave known as 'the blob' in the Northeast Pacific Ocean persisted from the spring of 2013 through to 2016 and extended from Alaska to California at its peak (Bond *et al*. 2015; Ross *et al*. 2017). During this event, temperatures in the Northeast Pacific Ocean were 3-5˚C above seasonal average and extended down to 100 m depth (Bond *et al*. 2015). These warmer temperatures can affect salmon directly, and also indirectly through their effect on marine food webs. Decreases in nutritious cold-water zooplankton species and increases in southern warm water zooplankton species occurred with this warming event (Galbraith and Young 2018). Salmon returns were generally lower than average during the marine heatwave, and in some cases, body sizes were below average.

The Pacific Climate Impacts Consortium (PCIC) reported warmer than average air temperatures in British Columbia in recent years, which coincided with the warm conditions observed in the Northeast Pacific Ocean (D. Patterson, DFO, pers. comm.). Warm temperatures in rivers and lakes can affect all life history stages of Pacific salmon, through impacts to adults migrating upstream, egg incubation, juvenile rearing, and smolt downstream migration

Annual monitoring of Fraser River discharge and temperatures shows a clear trend of earlier freshet (Figure 4), followed by significantly warmer summer water temperatures during key times when salmon are migrating up-river to spawning areas. The frequency and duration of water temperatures in excess of 18˚C has increased over the past 30 years (Figure 5) (D. Patterson, DFO, pers. comm.; MacDonald *et al.* 2018).

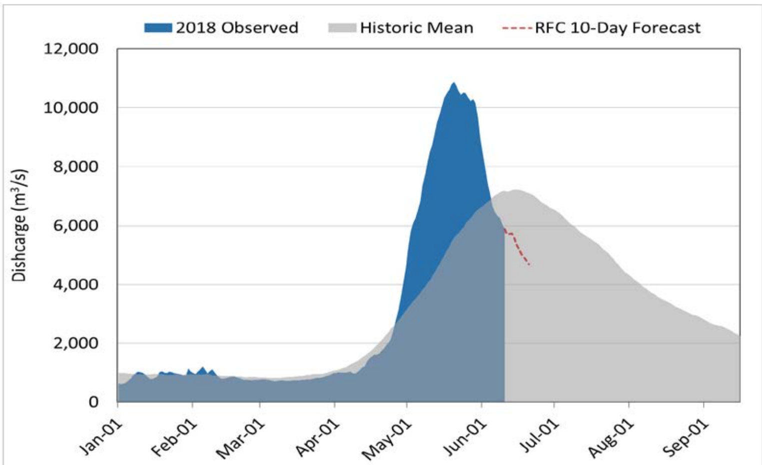

Figure 4. *2018 Fraser River Discharge at Hope BC showing recent early freshet versus historic mean. Approximately 40% of the May-September total volume is estimated to have run off in May compared to 20% in normal years. Credit: David Patterson, Environmental Watch Program, DFO.*

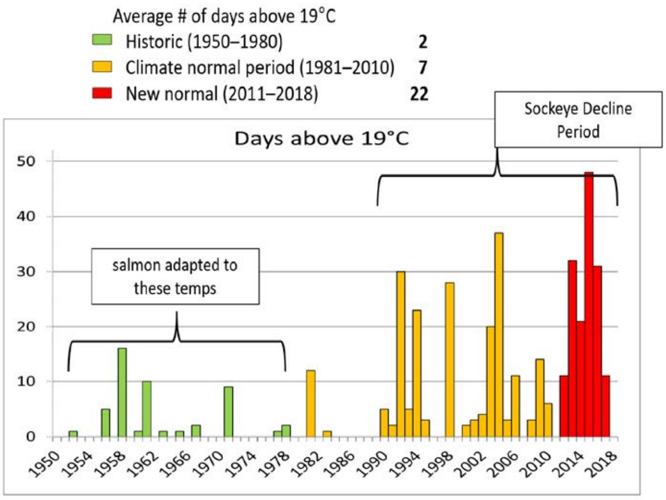

Figure 5. *Fraser River Sockeye Migration Temperatures. The number of days the Fraser River is above 19˚C in a given year, indicating a higher 'new normal' for adult upstream migration. Credit: David Patterson, Environmental Watch Program, DFO.*

Temperatures above 18˚C can result in decreased adult salmon swimming performance, and above 20˚C can increase adult mortality, adult disease, egg viability, and have legacy effects with negative impacts on juvenile condition (Burt *et al*. 2011; Patterson & Robinson 2019; Sopinka *et al*. 2016; Tierney *et al*. 2009). Recent science indicates that direct human impacts on watersheds, combined with climate change effects, are resulting in synergistic effects for salmon, with widespread and in some cases severe impacts for freshwater habitats (R. Bailey, DFO, pers. comm.). Warmer winters have resulted in losses of forest canopies in BC from the expanding range of Mountain Pine Beetle, which attack and kill Pine trees. As well, warmer and drier summers over the past decade have led to a large increase in the number and extent of forest fires occurring, resulting in further deforestation. Combined with logging activity, this loss of forest cover (Figure 6) has contributed to disruption of hydrology and severe erosion events that reduce the quality of salmon spawning and juvenile rearing habitats (R. Bailey, DFO, pers. comm.).

Effects of warming temperatures exacerbating impacts of nutrient loading in Cultus Lake provides another example of ecosystem responses to synergies between climate change and human caused habitat changes that are negatively effecting salmon populations in these ecosystems (D. Selbie, DFO, pers. comm.).

Figure 6. *Comparison of forest cover in the Thompson-Nicola area (a key salmon producing area) of the Fraser River Watershed, 1984 (left) and 2018 (right). Reference: https://earthengine.google.com/timelapse/*

Steps Taken to Protect Pacific Salmon

As salmon populations decline, harvest is typically reduced in an effort to achieve adequate numbers of spawners. Each year brings a series of harvest measures to protect weak stocks, including closure of fisheries that target stocks of concern, and measures to minimise their interception in fisheries targeting healthy stocks. As well, for Fraser River Sockeye, river temperature and discharge are monitored throughout the spawning migration period, and models are used to inform managers of appropriate 'management adjustments' required to off-set anticipated en-route losses in order to achieve spawning escapement goals. Other initiatives include habitat restoration work and a range of stewardship initiatives.

Unfortunately, reducing fisheries impacts and a range of restoration initiatives have not always result in recovery of populations as the pace of restoration and stewardship work is limited. Where productivity levels are so low that populations are not replacing themselves, declines will continue even in the absence of harvesting. This points to the need to implement additional actions to additional actions to support recovery of BC salmon populations.

Success Stories

There are examples of successes with rebuilding of salmon populations in various systems in BC. The Cowichan River, a rain-dominated system on Vancouver Island, faced a range of issues including very low water flows and high water temperatures during summer months, significant sedimentation issues due to erosion, and water quality issues. The Cowichan River had supported numerous freshwater fish species as well as Chinook, Coho and Chum salmon. The Cowichan Stewardship Roundtable was formed in 2002, with a focus on protecting the watershed (www.cowichanstewardship.com). There are now 30 member organizations in the process, which brings together Indigenous groups, multiple levels of government, corporations, environmental organizations, and private citizens to address watershed issues and maximise effective use of resources. The Cowichan Stewardship Roundtable has been instrumental in addressing watershed issues and restoring salmon populations. In 2009, just 900 Chinook salmon returned to the river. Following collaborative efforts to address instream flow, water quality issues, erosion, and other factors, Chinook returns of 10,000-12,000 fish were documented in 2017 and 2018, while many other nearby populations continued to decline. The involvement of all levels of government (including Indigenous organizations) and stakeholder groups working together in an integrated approach to prevent further damage and address impacts has been key to the successes achieved.

Where to from here?

Integrated and collaborative efforts to protect and restore fish habitat

While all levels of government, and the public at large, express great concern about declining salmon stocks, it remains very challenging to address the range of factors affecting salmon on a large geographic scale. There are regulatory gaps that result in continuation of damage to fish habitat (Cohen 2012), and restoration efforts cannot keep pace with the rate of loss. There may also be a lack of understanding among various levels of government and the public regarding the sources of impacts, and the roles they could play in implementing solutions.

Protection and restoration of riparian areas is especially critical given continued warming trends in BC, and the role of shade in mitigating warming effects, in addition to many other well-documented benefits. One recent modelling study found that restoring riparian vegetation could result in water temperatures up to 7.6oC cooler (Wondzell *et al.* 2019). Despite clear benefits for fish and riparian land owners (due to stabilised stream banks), protecting and restoring riparian areas remains an ongoing challenge on both private and publicly owned lands.

The current plight of salmon is an outcome of many decisions and actions taken by multiple jurisdictions and individuals over time – the same range of management agencies, and the public more broadly will need to be involved in reversing salmon population decline. This points to the need for a broader and more integrated approach to fish and ecosystem management (i.e. extending beyond fisheries management) to achieve recovery of salmon populations. Current salmon management and assessment frameworks (Figure 7a) are relatively simple. An integrated framework that aligns harvest with protection and rebuilding of salmon populations is provided for comparison (Figure 7b).

Effective communication of scientific information to other levels of government and the public:

Achieving the collaboration necessary to protect and restore salmon populations will require communicating scientific information in a way that can be readily understood to promote a broader understanding of the challenges facing salmon populations – and the solutions. The Cowichan Stewardship Roundtable provides an example of what can be achieved through an integrated approach when information and expertise is shared in a partnership arrangement.

Shifting the dialogue

Continued effort is needed to shift dialogue from 'Somebody else needs to change' to 'How can I contribute to solutions?'. Stronger linkages between science, fisheries managers, and managers of the land and water resources may help effect a shift in dialogue needed to arrive at integrated and collaborative management approaches as achieved with the Cowichan Stewardship Roundtable, and as set out in Figure 7b.

Assessment Framework	Management Procedure		
	Harvest	Hatchery	Habitat / Ecosystem
Status Assessment	Current Emphasis		
Inform Management Procedure / Response			
Research and Development			

Figure 7a. *Schematic of Current BC Salmon Management & Assessment Framework.*

Life History Stage	Status / Limiting Factors/ Interactions	Inform Management Procedure			Research and Development
		Harvest	Hatchery	Habitat / Ecosystem	
Spawning					
Egg					
FW Rearing					
FW Smolt Migration					
Early Marine					
Marine Rearing					
Marine Migration					
FW Adult Migration					
	What, why	How to adapt and respond			Key knowledge gaps

Figure 7b. *Schematic of an Integrated Stock Assessment and Management Matrix. This integrated approach is consistent with WSP implementation. Credits: Diana Dobson, DFO.*

How can NASCO support?

NASCO has an important role in bringing together countries, as well as environmental organizations, to work collaboratively in support of salmon. There appears to be many common issues affecting Atlantic and Pacific salmon, and further development of linkages now being advanced between NASCO and Pacific organizations such as the North Pacific Anadromous Fish Commission, through the International Year of the Salmon, could enable broader sharing of science, management issues and strategies, educational tools, success stories, and more. NASCO and other international organizations could also take on a leadership role in encouraging countries to adopt more integrated and collaborative management approaches to support protection and restoration of salmon. Strengthened Atlantic-Pacific collaboration with respect to salmon could also help to foster a strengthened understanding of the importance of addressing local issues as part of global solutions, and inspire further action in support of salmon.

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Addressing the challenge of stakeholder engagement to achieve positive outcomes for people and nature

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This paper focuses on the challenge of stakeholder engagement – an issue increasingly recognised in policy and practice. I run through a number of questions that need reflection ahead of engagement processes, and call for more pro-active approaches to conservation challenges, specifically on understanding conflicts and the conditions required for multi-stakeholder processes.

Over the last few decades, there has been an increase recognition of the importance of engaging stakeholders and local communities for achieving more sustainable, long-term and inclusive decision-making processes. Due to the complex and often irreversible nature of conservation problems, governments and other institutions are increasingly implementing approaches that aim at engaging stakeholders and local communities. This move towards broader engagement is also reflected in policy. The United Nations, for example, has propelled engagement at the most relevant level of decision-making in regard to sustainable development through Agenda 21. As a consequence, public engagement is now firmly rooted in public policy and a requirement under legislation such as the Aarhus Conventions and associated EU Directive. The need for engagement with local communities in the context of conservation is embedded in the 2020 Aichi biodiversity targets and is widely thought to be critical to the long-term success of conservation efforts.

There remain, however, a number of challenges associated with effective and sustainable stakeholder engagement. These challenges include the need for much greater reflection ahead of any stakeholder process on the following questions:

Why engage – or in other words what is the purpose of engagement?

Whilst this may seem like a basic question, it requires reflection on one's basic rationale for engagement, and the specific purpose of engagement in relation to the issue.

There are a number of rationales put forward for broader engagement. These include the normative rationale (because it is the right thing to do in a democratic society); the instrumental rationale (where engagement is a means to some pre-defined end); and the substantive rationale (like the instrumental rationale there is a focus on outcomes rather than process, but under this rationale, what counts as a positive outcome is determined according to deliberated (and different) values).

In the context of conservation, a number of purposes can then be put forward for broader engagement, including the need or desire to: Develop a common understanding and shared solutions; Increase learning and trust; Foster more 'ownership' of solutions; Make decision-making more collaborative, thereby increasing the legitimacy and credibility of decisions; and to help ensure the effectiveness and long-term sustainability of efforts to conserve wildlife. The key aspects here is to reflect on, clarify and then communicate the purpose of engagement, in order to manage expectations, and then develop tailored approaches.

Who should be engaged?

This question depends in large part on the selected purpose of engagement (see above). In conservation contexts, who to engage could include local communities; NGOs, funding agencies, experts, statutory organizations; farming, forestry, transport representatives; businesses; the general public; government representatives, etc. Not all stakeholders will necessarily need to be involved at the same time or indeed in the same way (see below). A first step might be to carry out mapping to explore the range of stakeholders involved. Another key issue here is the question of who should or could lead the process. Questions of credibility, trust and mandate will be apparent here.

When to engage?

Not all stakeholders will necessarily be engaged at the same time in the process. Developing a project timeline can help planning when to engage different stakeholders as well as the frequency and the duration of their engagement. There are a number of papers and toolboxes that can help with developing timelines and planning effective timing for engagement (e.g. Dovers *et al.* 2015; Durham *et al.* 2014; Reed 2008).

How to engage?

This issue is key, as poorly developed or implemented engagement processes can be harmful for the relationships of stakeholders, the people involved, and the success of conservation initiatives. Many initiatives have, however, learned from past processes, in order to develop engagement processes that are ethical, effective and sustainable. A helpful approach to devising principles of engagement (PARTNERS principles) has been developed by the Snow Leopard Trust (Mishra 2016; Mishra *et al.* 2017) and builds on ideas developed in diverse fields such as applied ecology, community health, social psychology, rural development, negotiation theory, and ethics. The PARTNERS principles outline some of the elements that need to be considered when engaging with communities to effect conservation.

In this talk, based on guidelines developed as part of the IUCN Task Force on human-wildlife conflicts, I run through these different dimensions in more detail, illustrating each with case studies from around the world.

In particular, I focus on research from a stakeholder process in Scotland, that aimed to address the conflict between salmon fishing and seal conservation. The Moray Firth in north-east Scotland has Special Areas of Conservation (SACs) established for three protected species (bottlenose dolphin *Tursiops truncates*, harbour seal *Phoca vitulina*, and Atlantic salmon *Salmo salar*). In addition, there is a wide range of local stakeholders, with wildlife tourism and conservation groups supporting seal conservation, and rod and net fisheries viewing seal predation as having an impact on their livelihoods (Butler *et al.* 2011).

The Scottish Government issued a Conservation Order in 2002 that prohibited the killing, injuring or taking of harbour seals. This was due to declining numbers of harbour seals and the potential risk of a Phocine Distemper Virus outbreak. With declining catches of salmon, and the imperative to protect salmon SACs, a bottom-up process triggered by salmon fishery stakeholders emerged which aimed to balance seal and salmon conservation. The District Salmon Fishery Boards collaborated with the Scottish Government, the Government's Fisheries Research Services, Scottish Natural Heritage, the Sea Mammal Research Unit (SMRU) and the Moray Firth Partnership (a forum representing local wildlife tourism operators, conservation groups and marine fishery interests) to develop the Moray Firth Seal Management Plan (MFSMP). The MFSMP allowed for annual licence applications to shoot a limited number of seals most likely to be impacting on fisheries (Butler 2005; Butler *et al.* 2008; Graham *et al.* 2011).

A number of conditions enabled the successful negotiation and implementation of the resulting management plan initiated by local stakeholders (Young *et al.* 2012). The first was the emergence of a local 'champion' – a scientist employed by the Spey DSFB, with a background in wildlife conflict resolution and salmon management experience. A combination of a window of opportunity, his scientific background and sense of empathy for all interests made him the lynchpin of the process and trusted by the key stakeholders (Young *et al.* 2016). His facilitation enabled the integration of all relevant stakeholders on an equal footing and resulted in the MFSMP being endorsed by all stakeholders involved. The second condition was the involvement of the Scottish Government, both in terms of creating a crisis point (in the forms of a Conservation Order) and in the process of developing the MFSMP by ensuring that the scope of the plan was realistically bounded by the specific issues defining the seal-salmon fishery conflict, and that agreements reached could and would be implemented with government endorsement and facilitation. The last condition, and one that has not yet been resolved by the MFSMP, is the provision of financial and institutional local scale support to ensure long-term implementation of the plan.

The MFSMP has been monitored since 2004 and has evolved from a community-led cooperative system to one which is increasingly government-led and instructive (Butler *et al.* 2015): the system is 'ticking along' with annual licence applications being put to and approved by the Scottish Government. The emergence of a new animal welfare stakeholder in the area may cause a further shift in the system – potentially acting as another crisis point engendering a more collaborative governance approach.

To conclude, the challenge of stakeholder engagement is apparent in all conservation challenges, including the specific case of salmon. In the above example, salmon fishing and conservation was at the root of a process that bought stakeholders together around a common challenge. However, as the process has evolved, this cooperation has diminished, opening the door to potential future conflicts. A key issue around stakeholder engagement and conservation conflicts is therefore the need to better pre-empt and evaluate conflicts and their management (including the engagement of stakeholders in these processes) (Young *et al.* 2016).

This requires a greater understanding from institutions dealing with conflicts on what these conflicts are about (including the evidence base informing future management) and whether a multi-stakeholder is necessary – and if so what kind of processes, and for what purposes. Without this reflection, there is a risk that engagement processes are poorly thought-through, with potential negative repercussions on people and nature.

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Collaborative Governance – Lessons Learned from Pacific Salmon Management

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On the West Coast of Vancouver Island (WCVI), British Columbia, Canada, the Indigenous people (Nuu-chah-nulth)[4] hold the principle of *hishuk ish tsawalk*; everything is connected, everything is one. This concept is representative of the ecological and social complexity not just on the west coast, but around the world. Indigenous people, fishers, and others have historically expressed concern though that fisheries management in Canada has not been reflective of this principle. Instead, management has been characterised by government authorities acting in silos, government conducting consultations on a sector by sector basis, decisions being based on limited information sources, and top down processes that have left those locally impacted feeling disconnected from decision making. Faced with continually declining salmon stocks, growing conflict between fishing groups, and lost stewardship opportunities due to a lack of coordination between relevant parties, the need for a new governance mechanism was identified; one that acknowledged the 'whole of society' effort needed to address the full range of challenges that salmon are facing. What emerged was a pilot approach to governance that was more reflective of *hishuk ish tsawalk*. This paper provides a summary of 14 years of learning from the growth and evolution of the West Coast of Vancouver Island Salmon Roundtables[5].

The Salmon Roundtables are geographically structured according to Fisheries and Oceans Canada (DFO) Management Areas[6]. These Management Areas (also known as Statistical Areas) are smaller scale areas where multiple rivers and streams flow into a common marine environment. The Salmon Roundtables started in Area 23 Barkley Sound in 2005, and then expanded to Area 24 Clayoquot Sound, Area 25 Nootka Sound, Area 26 Kyuquot Sound, and Area 22 Cheewaht Watershed, which together cover two-thirds of the west coast of Vancouver Island. These consensus-based[7] Roundtables are considered to be 'collaborative governance' or 'co-management' where decision making, within the bounds of government regulation, is shared amongst the participants. The Roundtables do not deal with allocation: what portion of the fishery each sector receives. This is determined in government policy, which is developed through a separate consultation process, and is guided by Indigenous treaties and legal decisions. After allocation is determined, the Roundtables review fishing forecasts, develop coordinated fishing plans that aim to maximise catch value and minimise gear conflict, determine areas of closure for conservation, and set out monitoring for stock assessment.

A further description of the composition and operation of the Roundtables can be described through a series of principles that have been witnessed in the practices of each Roundtable.

Principle 1: Integration

The Roundtables are integrated on three fronts; activities, people and knowledge.

Activities:

Conventionally, fisheries management may be thought of as including the allocation of the resource to different fishing sectors, and the harvest of that allocation. However, harvest is intimately interrelated to stewardship, which includes protection, enhancement (e.g. hatchery production), and habitat restoration. The Roundtables are taking a systems approach by looking at all of these components together, which is expressed in their current work of developing comprehensive strategic plans; if *x* fish are needed for the ecological health of a stock and system, and *y* fish are desired for harvest, how will hatcheries be used to increase production, and what habitat work is needed in support of those goals? Considering activities together is also about respecting that there are multiple values associated with the resource. 'Integrated management establishes decision making structures that consider both the conservation and protection of ecosystems, while at the same time providing opportunities for creating wealth in oceans related economies and communities.'[8]

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[4] https://nuuchahnulth.org/

[5] https://www.roundtables.westcoastaquatic.ca/

[6] http://www.pac.dfo-mpo.gc.ca/fm-gp/maps-cartes/areas-secteurs/index-eng.html

[7] The Roundtables have defined consensus to mean that no action is taken is unless all members of the group can support the action or agree not to obstruct it. Consensus does not require that everyone be in complete agreement, but only that all will be willing to accept a decision.

[8] Fisheries and Oceans Canada. 2002. *Canada's Oceans Strategy.* Retrieved from http://waves- vagues.dfompo.gc.ca/Library/264675.pdf

People:

The diversity of activities informs who attends the Roundtables. When harvest issues are being discussed at the Roundtables, all fishing groups (Indigenous, sport/recreational, and commercial) are present along with DFO. When discussions turn to habitat restoration, the participants expand to non-profit stewardship groups, additional government authorities, and industry such as forestry, mining, aquaculture, agriculture, and industrial water users. The importance of Indigenous, stakeholder and public involvement in fisheries management has been cited in core government documents:

'Oceans governance in particular, is much more than a federal responsibility…(it) is a collective responsibility shared by all.' 'Accordingly, (there is a core commitment to) engage Canadians in oceans-related decisions in which they have a stake.'[9]

'The province's approach is based on the belief that all British Columbians affected by fishery-management decisions should have a say in how those decisions are made.'[10]

The shared belief that use of a common resource requires managing that resource collectively[11] is found in Canadian federal and provincial sources respectively, such as Canada's Oceans Strategy and the BC Fisheries Strategy.

Some observers of the Roundtables have commented that certain groups should not be participants because of the belief that their values are fundamentally different from the majority. However, the approach is that if you have the potential to impact the fishery resource or the associated habitat, or you are impacted by fisheries management, you need to be at the table. A further criticism voiced about this inclusivity is that those who are viewed as negatively impacting the resource can use the Roundtable process to 'greenwash' their activities. However, the consensus-based nature of the process provides an equal voice to all participants, with everyone contributing to commonly supported solutions.

Knowledge:

Often, disputes around a decision are rooted in a disagreement about the validity of the data that the decision was made upon. Typically, in these situations data has come from a single source and has been analysed by the same source. The Roundtables have acknowledged the value of multiple knowledge systems: scientific, Indigenous, and local. These knowledge systems capture, for example, generational data held by Indigenous people and detailed observations from local people about changes in environmental condition, species abundance, and species behaviour. Given limits to government resources for data collection and monitoring, these additional knowledge systems and citizen science make significant contributions to management discussions. An example of integrating knowledge in this way is the Risk Assessment Methodology for Salmon[12] that evaluates the key limiting factors to salmon abundance based on input from all participants at the Roundtable. From the Risk Assessments, priority areas of research are identified. One of the next goals of the Roundtables is for multiple knowledge systems to be applied to all aspects of research: the research methods are co-designed, the data collected is jointly analysed and interpreted, and the research results are collaboratively implemented.

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[9] Fisheries and Oceans Canada. 2002. *Canada's Oceans Strategy*. Retrieved from http://waves- vagues.dfo-mpo.gc.ca/Library/264675.pdf

[10] Ministry of Agriculture, Fisheries and Food. 1997. The BC Fisheries Strategy: towards a 'made- in-BC' vision to renew the Pacific salmon fishery. Retrieved from https://www.for.gov.bc.ca/hfd/library/documents/bib75137.pdf

[11] O'Connell, Ryan. 2012. *Reconciling Participants Values in the BC Pacific Halibut Allocation Dispute*. (Master's thesis). Retrieved from https://skemman.is/bitstream/1946/12800/4/Ryan%20O%27Connell%20-%20Reconciling%20participants%20values%20in%20the%20BC%20Pacific%20halibut%20allocation%20dispute%20%28Skemman%29.pdf

[12] "The Risk Assessment Method for Salmon (RAMS) process helps identify management interventions to conserve, restore or enhance salmon Conservation Units of interest within a broader ecosystem or applied Management Unit (MU) context (Hyatt, Pearsall and Luedke, 2017). This methodology has been adapted from a framework on Ecological Risk Assessment for the Effects of Fishing initially developed to inform an ecosystem-based approach to fisheries management in Australia (Hobday *et al.*, 2011). Pilot testing of RAMS in several workshops has allowed DFO to provide an evidence-based diagnosis of factors driving state changes for populations or CUs of interest, as well as to identify management intervention actions that may be effective in avoiding, stabilizing or (less commonly), reversing a decline." Fisheries and Oceans Canada. *2018 Wild Salmon Policy 2018* to *2022 Implementation Plan*. Retrieved from http://www.pac.dfo-mpo.gc.ca/fm-gp/species-especes/salmon-saumon/wsp- pss/ip-pmo/assess-eval-eng.html

Principle 2: Start where you can, to get to where you need

Interest in collaborative governance often stems from harvest related conflicts. However, it is extremely difficult to bring diverse groups together for a true dialogue when those groups may have never worked together before, and often hold feelings of animosity and distrust for each other. In these instances, parties may come to a Roundtable with strongly held assumptions and positions, which impede the ability for any real progress. Windows of opportunity have been found by encouraging groups to start with values-based discussions. Groups may not agree on the 'how' – e.g. the types of gear that should be used, or the ways to access key fishing grounds, or even if fishing should take place given conservation concerns. However, when assisted to explore the 'why' – e.g. what they care about - seemingly disparate groups may find their commonalities, such as that they share a sense of responsibility towards contributing to the long-term health of the resource. Within fisheries resource management, stewardship values often become the starting point around which groups can build a working relationship that can extend to harvest and other issues over time.

Geographic extent is another consideration for the starting point. The need for collaboration may be identified due to an issue that affects a whole coast, e.g. declining abundance of a migratory species. However, the complexity of collaboration and integration increases with geographic extent. The WCVI Salmon Roundtables have started at a community-based, watershed or sub-regional level where relationships already exist and/or are more easily formed, and where existing knowledge can more readily be mobilised. As the Roundtables have evolved, the issues they deal with have naturally grown and 'bumped up' against jurisdictions beyond their initial scope. The Roundtables are now considering what governance mechanism is needed to advance their Management Area efforts up to a regional scale, and similarly, how to effectively connect multiple regions together.

Implicit in this principle is the ability to identify and leverage 'bright spots'. This can begin at the most basic scale of an individual who has the energy and willingness to champion advancement of an issue. It can simply be two people who already have experience working together, or two organizations that have cultivated a relationship. Or it can be 'gathering around where people already are' and expanding the scope of an already existing initiative. As daunting as it may seem to begin a collaborative process, especially in an environment of conflict, there is almost always a bright spot that can be harnessed and built upon.

Principle 3: Relationships First

When parties first start to work together, a proposal made by a sector may immediately be dismissed by another as being unreasonable or untenable. This may not come from a factual disagreement with the merits of the proposal. Instead, it may come from a lack of understanding of the other sector's worldview, values, interests, incentives, and stressors. Developing an understanding and respect for multiple perspectives only comes through the development of relationships. In some cases, parties may take months or even years to build relationships before they ever sit down to work together. In other cases, relationships may grow concurrent to the work at hand. In this latter case, allowing work to proceed at a conducive pace instead of pressing for an expedient agenda is critical. In practical terms, putting relationships first may mean withholding decisions – even those agreed to be positive for the resource – if such a decision would damage or set back the status of the relationship. The adage of 'being hard on issues and soft on people' is regularly cited as a ground rule at the Roundtables. This is increasingly encouraged as participants divulge that there is a level of stress that comes from trying to balance the mandate given by their constituents with the compromises sometimes needed to come to a consensus that works for the group as a whole. Relationships, while difficult to tangibly measure, are considered one of the greatest outcomes of the Roundtables, as they benefit the broader communities well beyond their purpose for fisheries management.

Principle 4: Neutral Facilitation

Typically, fisheries management processes have been defined and led by government. However, there are challenges associated with trying to manage process and, at the same time, participate in a technical and regulatory capacity. Further, where relationships have not yet been established, suspicion about government process can derail an initiative before it even starts. The Salmon Roundtables foresaw the need for co-developed and jointly implemented Terms of References that were guided by a third party, neutral facilitator. This provides members of the Roundtables with a 'container' in which they are freed up to solely concentrate on the substantive issues.

As a non-profit organization, West Coast Aquatic's mandate is to increase collaboration in natural resource management. To that end, the organization designs and facilitates co-management and collaborative governance processes. West Coast Aquatic facilitates all of the WCVI Salmon Roundtables. Common facilitation of all Roundtables across the region has provided the opportunity to see trends between the sub-regions, which will be particularly important when defining the scope of issues that the Roundtables may work on when governance is applied at a regional scale.

While the Salmon Roundtables represent a form of governance that can address the challenges of managing a complex resource such as a salmon, the Roundtables should not be thought of as a 'model' per se that can be lifted and simply replicated in another area. Indeed, other areas around the world can develop collaborative governance by learning from the Salmon Roundtables but should approach this task by considering how the principles presented here can be expressed within an area's own unique environmental, cultural and social conditions.

Contributed Papers

Introduction to Symposium Discussion

Managing Atlantic Salmon in a Changing Environment – Management Challenges and Possible Responses

Scene-setter for the General Discussion

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Salmon and the Impacts of Climate Change

We are by now all too familiar with climate mediated ecosystem change, both in freshwater and in the oceans. Not surprisingly therefore, the overall theme of climate change permeated every aspect of the Symposium. The essence of the challenges facing us was captured for me by the revelation that the Barents Sea ice may well have disappeared by 2100! Some of the scenarios presented over the course of the Symposium and some of the timescales mentioned may seem to us reasonably far into the future, but the reality of the situation facing salmon clearly indicates that we have already entered a crisis phase in protecting and conserving our Atlantic salmon populations.

In freshwater, in particular, this crisis is all too apparent and those of us attending the Symposium, who work in freshwater ecosystems, see on a daily basis increasingly serious impacts from:

- more intense flood events;
- fewer snowmelt related floods;
- increases in annual precipitation;
- larger and more stark differences between seasons;
- climate related impacts on the juvenile stages of salmon; and
- the occurrence of younger and smaller salmon smolts.

Challenges relating to adaptation and to the speed of adaptation were constantly referred to throughout the presentations. Adaptation is nothing new to populations of Atlantic salmon but the burning question is whether or not they can adapt quickly enough to keep pace with the fast moving changes in climate outlined to us over the course of the Symposium. Adaptation was also a key theme during the course of presentations on invasive species and their ability to quickly adapt and take advantage of new and fast evolving opportunities within an ever-changing aquatic environment. This ability to adapt and change is to be seen even more clearly in the case of diseases and parasites, which, given the appropriate environment, can mutate quickly and proliferate into a wide range of virulent forms.

Assessing and interpreting such fast moving changes will require the use of ever more sophisticated modelling systems and the downscaling of climate models to a catchment scale. Witnessing the predicted impacts of climate change on an individual catchment has in many ways a far greater impact than examining the results from wider and more dispersed modelling systems. Communicating and demonstrating climate change impacts with a view to changing behaviour are far more impactful when delivered on a catchment / watershed scale.

Recent work in the context of the International Year of the Salmon on cooperative programmes with our colleagues in the Pacific has greatly emphasised the importance of the unique Atlantic Salmon Index Systems which we have scattered across the North Atlantic. Such Index Systems may well prove of even greater importance as we link more closely biological and climate / modelling research.

The Ocean and Big Data Modelling

The papers on salmon in the ocean showed that the North Atlantic is not now capable of supporting salmon populations at historical levels. Temperatures are beginning to increase and we are facing into a very challenging and increasingly uncertain future. There is the potential for a northerly expansion of wild salmon populations into colder sea areas and a southerly retraction of stocks from warmer zones.

Again the themes of closer cooperation and big data modelling came to the fore. Joint work across both the Atlantic and the Pacific is urgently required to see what we can learn about ocean wide, climate mediated changes when these two great bodies of water are studied on a hemispherical basis. To achieve this will require cooperative programmes that will attract a wide range of new, non-traditional partners and the use of innovative, quantitative tools that will more accurately elucidate the key drivers in terms of mortality and survival of Atlantic salmon stocks in the ocean.

Initiatives are under way to incorporate such data into the fast evolving Likely Suspects Framework and ultimately into a series of nested Likely Suspects Framework models. Based on the work of the data modellers within the ICES Working Group on North Atlantic Salmon, their fledgling life cycle model is being expanded to incorporate novel aspects such as: energetics (the way in which energy is distributed across biological processes), gender components and the addition of virtual mortality domains.

The Pelagic Family of Fishes

It was also clear from the presentations that we must redouble our efforts to ensure that Atlantic salmon is seen as a legitimate member of the Pelagic Family of Fishes. The annual research investment in the assessment of other pelagic species is very significant, and there is a compelling argument for Atlantic salmon to be included on a regular basis in such programmes. The overlap in time and space between these stocks is clear and it must be mutually beneficial for all concerned to trade off regular biological assessment of all of these sister stocks of pelagic fishes.

Hopefully progress can be made at the planned ICES / NASCO Workshop, when we will, for the first time, meet with marine colleagues who are actively involved in researching the ecosystem within which this whole community of fish lives.

Other related programmes which may help in forging a far closer working relationship includes the use of PIT tags in tracking pelagic fish and eDNA research geared towards tracking populations of pelagic fish across the surface layers of the ocean.

Mention was also made of the ongoing Norwegian SeaSalar Programme, which will tackle the question of salmon by-catch in the commercial pelagic fisheries, using a new eDNA Atlantic Salmon probe, developed jointly by University College Dublin and the Atlantic Salmon Trust.

Genetic Impacts

Introgression between farmed and wild salmon has been a cause of major concern for many years. It is clear from data presented at the Symposium that such introgression may have far longer term and more serious impacts than was suggested by previous research. It is also clear that we must be acutely aware of the risk of genetic change arising from introgression, at a regional scale. There is no doubt that the salmon farming industry is looking for cooler locations in the far north. This may pose new risks to salmon stocks in such areas. For example along the coasts of Norway and Russia some of the unique northern populations of wild salmon inhabiting these areas may not have the robustness and the resilience that stocks in the southern portion of the salmon's range possess.

It is clear that we need to be proactive in protecting these unique northerly stocks from such long-lasting and profound impacts. We need to be arguing robustly for a precautionary approach in protecting such areas from aquaculture development and the expansion of existing aquaculture operations.

The Role of Stocking

Following on from proactive protection of ‘at risk’ wild stocks of salmon, we also need to be planning for the doomsday scenario to guard against the loss of unique populations of fish. Perhaps we need to be re-examining how our hatcheries and rearing stations might provide us with an insurance policy in situations where our stocks are in danger of plummeting to a dangerously low level. Perhaps we need to be planning for the establishment of gene banks, as has been done, so successfully here in Norway to counteract the effects of *Gyrodactylus* and its devastating impact on wild Atlantic salmon juveniles. We also need to be considering innovative ideas, such as those outlined to us at a previous NASCO Annual Meeting when it was suggested that the physical re-distribution of wild fry might lead to the survival of additional parr and smolts, in a situation where spawning stocks were at a critically low level.

Management Challenges and Solutions

The sections of the Symposium covering the role of the social sciences in salmon conservation provided us with a new and refreshing approach to managing the resource. The key message was that the real challenge in managing salmon is managing people! We are constantly worried about whether or not the salmon will adapt quick enough to deal with our changing climate. Perhaps the real question is can we adapt quickly enough? Can we adapt our management regimes so that we can manage and conserve the remaining stocks of salmon?

There was great emphasis on the importance of understanding the cause(s) of conflict and understanding the power dynamic that underlies the political space in which negotiations take place. It was also emphasised that we need to be aware that decisions can and do have unintended consequences. Adaptation is also a key aspect of fisheries management and people management. Adaptation is a social skill and we need to have the skills of the social scientist to actually navigate our way through the very stormy and often seemingly impenetrable problems that may face us as fisheries managers and scientists. We also need to acquire the skills of adaptive capacity and of critical self-assessment. Emphasis was also placed on shifting the focus towards those who can achieve the desired change.

We heard from various representatives of indigenous peoples and their request for more involvement in the decision making processes. They are seeking more acknowledgment of the cultural importance of the salmon in traditional communities and the salmon's intrinsic worth. The real challenge is how to bring such communities with us in a way whereby a cultural icon, such as the Atlantic salmon, is more honoured by its conservation rather than its harvest.

We will forget at our peril that salmon fishing and traditions of salmon fishing have been extant for thousands of years. We may be looking, for legitimate and urgent conservation reasons, to change these ways of life over the space of just one generation. No matter how urgent the perceived conservation and management needs we may try to make these changes too quickly at our peril; lose the communities and you may lose the fish! We do not need tokenism but real and sincere engagement with those closely linked with such a core, cultural icon and cultural heritage.

We urgently require harvest rules which are in harmony with the subsistence needs of the native people or in line with the conservation needs of individual rivers. How to achieve this balance is a fascinating challenge and one which is faced in several locations. The two examples provided to the Symposium may seem a world apart. However, in these, the west coast of Greenland and the west coast of Norway, the approaches that are being taken towards managing a limited salmon resource within local communities are very similar in terms of the underlying philosophy and the practical arrangements that are being put in place. The key would appear to be adaptation, communication and the introduction of novel management structures in combination with the building of real trust between the various communities.

When Science is Not Enough!

How do you get support for prioritising the environment over development? In Europe, we are currently in a very good place, since we are told that we are on the crest of the so called *green wave*. However, waves have an uncomfortable habit of running out of energy and crashing to the sea floor. We can only make serious progress while the waves are cresting and we need to make that progress as quickly as possible.

We urgently need to find common ground with our fellow environmentalists so that they too are in support of arguments in relation to the protection and conservation of wild Atlantic salmon. Areas of common concern which suggest themselves include: water quality; impacts of toxic chemicals; invasive species; water abstraction; water resource management and managing flood relief programmes.

This is a challenging area. How can we best integrate our needs, the salmon's needs, the needs of the wider fisheries community and the wider aquatic community? How do we devise messages that clearly define the key areas to be tackled, the key objectives and hopefully key successes which we aiming to achieve?

Faced with a series of very difficult and seemingly intractable problems, in areas such as climate change impacts, fish farming impacts and habitat / environmental change, the social scientists advised us to develop a common understanding and shared solutions; increase learning and trust; foster more 'ownership' of solutions and make decision-making more collaborative, thereby increasing the legitimacy and credibility of decisions. They encouraged us to work together across perceived demarcation lines, making firm, rational decisions so as to achieve together what we couldn't do alone.

Poster Abstracts

Acoustic Monitoring of Juvenile Atlantic Salmon: from Migration Analysis to Species Management

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Atlantic salmon are anadromous species, where the juveniles spend 1-4 years in freshwater before migrating to sea, where they will spend 1-3 years before returning to their natal river to reproduce. While the freshwater part of their life cycle is well documented, the marine phase stays mysterious and poorly understood. Greater understanding of this marine phase is especially needed as for several years, marine mortality has been increasing, indicating that the conditions encountered in the marine environment may be changing. SAMARCH (SAlmonid MAnagement Round the CHannel) www.samarch.org, which is an English-France Interreg VA Channel Programme funded project, aims to fill some of these knowledge gaps and further management measures to protect Atlantic salmon in estuaries and inshore waters. As part of SAMARCH, 233 Atlantic salmon smolts, so far, have been acoustically tagged before their marine migration through four estuaries: the Bresle and Scorff in France and the Tamar and Frome in England. Data from 58 Vemco 180 kHz acoustic receivers has been gathered to identify their use of estuaries and inshore waters in terms of timing, habitat use and mortality rate in key zones. The results will be used to influence management practices to protect Atlantic salmon in estuaries and inshore waters.

Co-inheritance of Sea Age at Maturity and Iteroparity in the Atlantic Salmon *vgll3* genomic Region

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Co-inheritance in life history traits may result in unpredictable evolutionary trajectories if not accounted for in life-history models. Iteroparity (the reproductive strategy of reproducing more than once) in Atlantic salmon (*Salmo salar*) is a fitness trait with substantial variation within and among populations. In the Teno River in northern Europe, iteroparous individuals constitute an important component of many populations and have experienced a sharp increase in abundance in the last 20 years, partly overlapping with a general decrease in age structure. The physiological basis of iteroparity bears similarities to that of age at first maturity, another life history trait with substantial fitness effects in salmon. Sea age at maturity in Atlantic salmon is controlled by a major locus around the vgll3 gene, and we used this opportunity demonstrate that these two traits are co-inherited around this genome region. The odds ratio of survival until second reproduction was up to 2.4 (1.8-3.5 90% CI) times higher for fish with the early-maturing *vgll3* genotype (*EE*) compared to fish with the late-maturing genotype (*LL*). Post hoc analysis indicated that iteroparous fish with the *EE* genotype had accelerated growth prior to first reproduction compared to first-time spawners of the same genotype, across all age groups, while this effect was not detected in fish with the *LL* genotype. These results broaden the functional link around the *vgll3* genome region and help us understand constraints in the evolution of life history variation in salmon. Our results further highlight the need to account for genetic correlations between fitness traits when predicting demographic changes in changing environments, and for improved improve future conservation and management efforts.

Genetic Variation in *six6* gene is Linked to the Diet Specialisation of Atlantic Salmon at Sea

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An ecological consequence of climate change is the alteration of food-web structures. Species with ontogenetic (age-dependent) diet variation, such as Atlantic salmon, exhibit age-dependent variation in the diet composition, thus food-web perturbations may result age-dependent changes in survival hence the demographic composition. Age-at-maturity in Atlantic salmon is controlled by major effect loci. However, how these regions are linked to diet is not known. We conducted targeted genotyping of Atlantic salmon sampled at the sea on their return migration to freshwater and quantified their diet via stomach content analysis. We present evidence that prey composition in Atlantic salmon is linked to genomic regions controlling the age at maturity. Our result suggests Atlantic salmon are not as generalist as previously thought and that genetic variation underlies the diet scope of individuals. Providing that this genomic region is spatially divergent across populations, we hypothesise that the populations might have diverse evolutionary responses to changes in marine food-web structures.

Investigating the Demogenetic Responses of Exploited Atlantic Salmon Populations to Climate Change

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Atlantic salmon *Salmo salar* is the subject of many management actions aiming at their conservation. There is a strong demand, expressed by a diversity of local to international bodies, for assessing the consequences of climate change for this species relative to the conflicting objectives of both conservation and exploitation. This issue is especially pressing for populations at the southern limit of their area distribution like Atlantic salmon in France. However, our predictive ability is still limited by the complexity of environments, complexity of the life cycle and especially by the challenges of teasing apart evolutionary change from more 'plastic' responses to environmental perturbation. Simulation studies provide a powerful tool for disentangling eco-evolutionary processes and investigating interactive, synergistic effects among multiple factors in order to fully understand the resilience of populations in the face of various scenarios of climate change. Using an Individual-based model, we investigate the demogenetic consequences of environmental change scenarios on an exploited population of Atlantic salmon. Our results show that increasing flow amplitude and water temperature in freshwater, and poor oceanic growth conditions resulting from environmental change drove mainly demographic consequences and phenotypic responses, such as a shift towards a multiple-sea-winter life history accompanied by a decline in population size. Effects of environmental change was also contrasted with fisheries strategies impacts to investigate whether fisheries induced evolution and how selective fisheries can promote adaptation to climate change. We show that increased selective fishing against multiple-sea-winter fish mainly induced an evolutionary effect in the form of a lower maturation threshold in females, increasing the proportion of one sea-winter fish. These results reinforce the need to explore the potential of management strategies that would be unselective and that would increase intra-population biodiversity promoting stability and resilience of populations.

Revisiting Conservation Limits for Atlantic Salmon: A New Risk Based Definition

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The North Atlantic Salmon Conservation Organization precautionary approach is essentially based on a fixed escapement strategy for the management of salmon populations and the regulation of their associated fisheries. It is based on a benchmark reference point, i.e. a conservation limit (CL), defined as the spawning stock size that maximises the long term average of potential catch. This widely applied international recommendation implicitly considers that ensuring conservation is equivalent to maximising exploitation potential. Under this premise, CLs should be revised downward when the generation renewal of populations weakens. Maximising exploitation and conservation are not necessarily incompatible, but they must be separated because maximising catches can be conflicting with conservation.

Following NASCO's clear priority for conservation over exploitation, we propose a new CL definition based on the premise that conservation should aim at avoiding, i.e. controlling the risk of, low recruitment. We demonstrate its implementation on the salmon populations (18) of Brittany (France). For each population, the CL is derived from river-specific stock-recruitment (SR) relationships, relating the number of eggs produced by pre-spawning females (stock) to the abundance of the resulting young-of-the-year juveniles (recruitment). Stock estimates are derived by combining rod catch statistics, partial adult counts on 3 rivers, and precise return estimates from an index river, the Scorff. Recruitment estimates are derived from a comprehensive regional survey by electrofishing. A hierarchical SR model, based on a Beverton-Holt type relationship with a mixture of lognormal process errors, is used for the joint analysis of all populations. Relying on the Bayesian framework for statistical inference, the risk associated to the CLs fully integrates the major sources of uncertainty: recruitment stochasticity, measurement errors of the stock and the recruitment, estimation of the SR relationship. This development of new CLs is conducted in close dialogue with management agencies and user groups.

Diagnosing and Mitigating the Adverse Effects of Extreme Climate on Salmonid Spawning and Recruitment

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The freshwater environment is a vastly diverse ecosystem that faces unparalleled pressures, pressures that have caused increasing global declines in freshwater biodiversity over the last few decades. Of particular trepidation is the impact climate change will have on this vulnerable system, with predictions indicating that anthropogenic global warming will threaten ~50% of global freshwater fish species alone. Atlantic salmon (Salmo salar) are particularly vulnerable to the impact that global warming will have on river hydrology and thermal regimes, both of which can exacerbate existing stressors known to increase fatalities in freshwater fishes. As such, there are many challenges that will threaten salmonid species in the coming years, with climatic changes posing pressures that are potentially beyond the limits of evolutionary adaptation, and that are perpetuated by anthropogenic appropriation of freshwater.

To protect salmonids and their freshwater habitats, global cooperation is required, incorporating experts from multitudes of fields, that can work together to inform policy, integrate legislation, and impose accountability. River systems and freshwater ecosystems will vary in response regionally, and it is important that management is adaptive to the fluctuations that occur between catchments and climates, with the development of models that can be interchangeable between river systems an important consideration. As such, the poster addresses main management challenges in dealing with the thermal regimes and hydrology of salmonid rivers, and potential ways in which these may be mitigated. A main area of focus is in predicting temperature anomalies and areas most at risk, through the implementation of computer and GIS based models. These models can then be used to target vulnerable areas for insolation reduction, through the adding of shade and appropriate land management. This is particularly important for incubating salmonids, who are highly vulnerable to changes in their environment.

Creation of River Specific Fisheries Management in a Baltic River, Råneå Sweden

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The Råneå River in the Bothnian Bay Sweden has for over 40 years had extremely weak salmon stocks and a splintered local management system without data input. We conclude that with financial aid (European Union funding) and a clear objective from the local fisheries management organization a robust total management system for a River system can be created within a three-year period. A total local management system shall include, fish counters, electro fishing surveys, smolt counting, daily and yearly catch bags based on tags and a digitalised catch reporting system. Our local management inputs have included the buying up of traditional trap-net fishing rights within the estuary, leasing fisheries areas within river and systemised consultation of local citizens, sport fishermen and other end users. Results are that salmon returns have increased from 1000 fish 2015 to over 4700 salmon in River 2018. This has resulted in a once marginalised river regaining salmon stocks and now being recognised as a competitive destination for sports fishermen.

The Atlantic Salmon Research Joint Venture

‘Shaping the Future of Wild Atlantic Salmon Science and Conservation’

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The formation of the Atlantic Salmon Research Joint Venture (ASRJV) was initiated by the Canadian Federal Department of Fisheries and Oceans as a direct response to the catastrophic declines in wild Atlantic salmon populations witnessed in 2014. The Ministerial Advisory Committee on Atlantic Salmon (MACAS) Report released in July 2015 provided recommendations to protect, conserve, and rebuild Atlantic salmon stocks across eastern Canada included having the Atlantic Salmon science community better connected. From this the idea to form a research Joint Venture was born. Modelled after the successful Joint Ventures of the North American Waterfowl Management Plan, the partnership represents a collaboration between scientists from Canadian and U.S. Federal Government agencies, Provincial and Territorial fisheries and natural resource departments, Indigenous research groups, non-governmental conservation organizations, and academia.

The Joint Venture’s mission is for scientists to work together to advance knowledge of Atlantic salmon with the following objectives: coordinating cooperative and collaborative data collection; encouraging and improving data and information sharing; and joint design and execute research activities to address urgent knowledge gaps affecting wild Atlantic salmon throughout their life stages and geographic range. Guided by the research priorities identified within the ASRJV Science Plan, the ASRJV partnership has thus facilitated the funding of 16 studies representing a combined $3.5M investment in wild Atlantic salmon research since inception in 2016. The Joint Venture has also hosted three science workshops and most recently, the Atlantic Salmon Ecosystems Forum in Québec City, Canada. Like the International Year of the Salmon, the Joint Venture is endeavouring to advance Atlantic salmon science in North America by ‘connecting people-through sound science-at the rivers to ocean level-using a partnership approach’.

The Joint Venture’s activities are being guided by Atlantic Salmon Research Joint Venture Science Plan 2018 – 2023 [available at www.asrjv_pcrsa.ca]. You can also follow the ASRJV on Facebook: @ASRJVPCRSA and Twitter: @ASRJV_PCRSA.

Restoring a Salmon Population Against the Background of a Rapidly Changing Marine Environment: Lessons Learned from the River Lagan in Northern Ireland

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The River Lagan in UK (Northern Ireland) was one of the first rivers in Europe where Atlantic salmon was extirpated by man. In 1988 a restoration programme for salmon was started on the river with the aim to re-establish a self-sustaining population. Connectivity in the catchment was somewhat improved and a large stocking programme using a local donor stock was initiated. Initially the project produced good numbers of returning adults from the stocked hatchery fry. However, the regime shifts in marine survival as a result of changing oceanic conditions in the early 1990's and 2000's not only had an effect on the number of returning adults in wild Northern Irish stocks, but crucially also on the Lagan restoration programme. Returning adults declined from several hundred in the beginning of the programme, to below 50 around 2010. It was however noted that after a few years of no stocking the number of returning adults from those spawning years did not differ from years when there was stocking. A small self-sustaining population had established itself in the Lagan. This had gone unnoticed due to the annual stocking of hatchery fish.

Management lessons learned from the Lagan restoration project:

- Restoration programmes against a background of low marine survival/changing environmental conditions might struggle attaining initial goals;
- Under such circumstances projects should refocus on removing other stressors;
- Synergistic effects can be severe in a situation with multiple stressors acting on a stock, limiting success;
- Partial success can be an acceptable outcome under changing environmental conditions;
- Stocking should be reviewed regularly; and
- NASCO could advise on salmon restoration in a changing climate.

Managing the Large Atlantic Salmon Population Complex of the River Teno / Tana: Population-Specific Monitoring, Targets and Regulations

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The River Teno (Tana in Norwegian, Deatnu in Sami) is a border river system between northernmost Finland and Norway that supports a large population complex of Atlantic salmon. Fisheries are managed by a bilateral agreement between Finland and Norway and salmon are exploited in mixed-stock fisheries in the Teno main stem and various tributaries.

A recent (2017) bilateral agreement on the Teno fisheries has implemented an adaptive knowledge-based stock-specific management regime based on NASCO principles. Stock-specific status assessments and mixed-stock fisheries evaluations are carried out annually by the joint Teno Monitoring and Research Group, consisting of four scientists from Norway and Finland. Spawning targets (=conservation limits) have recently been established for most populations in tributaries and the main stem of the river. Target attainment is estimated based on a combination of a spatially designed monitoring program which counts ascending salmon (video, sonar) and spawners (snorkeling) in various parts of the river and detailed catch statistics. Poor target attainment (>40% probability of reaching the spawning target over the last 4 years) should trigger the implementation of stock-specific recovery plans with specific management actions reducing the stock-specific exploitation down to a level specified in the plan.

In order to evaluate the stock-specific effects of the mixed-stock fishery, the composition of the mixed-stock catch in the main stem of the river has been analysed by genetic methods for stock assignment. Around 30 genetically distinct populations were defined as a baseline. Based on catch statistics, stock-identified catch samples, population-specific exploitation in the main stem can be estimated in time and space, for different fishing gears and user groups and for different life histories (sea-ages, previous spawners). Thus, stock-specific regulatory measures can be selected as part of the recovery plans in order to restore the weakest populations while allowing for the continuation of a diverse salmon fishery.

Stocking Accentuates Genetic Introgression of Farmed Escaped Salmon in a Wild Salmon Population

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Supplementary stocking is an important conservation strategy to mitigate population declines in Atlantic salmon (*Salmo salar*). However, stocking can have unwanted population genetic effects on the recipient population, particularly in systems where a mixture between domesticated and wild conspecifics occurs and where broodstock may be introgressed with farmed escapees. We used a comprehensive data set comprising 2,914 individuals of returning adult salmon from 20 run years over a 30-year period in River Eira in Norway to investigate how stocking affects farmed genetic introgression in a wild recipient population.

Our results show that severely introgressed hatchery broodstock produce four times the number of adult offspring compared to hatchery broodstock with wild ancestry, and that returning adult spawners of hatchery origin are more introgressed than adult spawners of wild-born origin. Supplementary stocking has therefore increased farmed genetic introgression in River Eira. This study is the first to show that supplementary stocking may amplify domesticated genotypes in the offspring of hatchery broodstock and cause accentuated genetic introgression of escaped farmed salmon in wild salmon populations.

We advise that 1) conservation programmes where broodstock is held in captivity for several generations are particularly cautious not to select for domesticated genotypes, 2) the selection pressure that favours domesticated genotypes in the hatchery is reduced by minimising mortality, creating a less artificial environment and that individuals are released at an early life history stage, 3) the use of previously released hatchery fish as broodstock is avoided, and 4) introgressed broodstock are identified and removed from the captive breeding population.

The Application of a Modern Detection Method for the Salmon Killer *Gyrodactylus salaris* and its Two Main Hosts

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The ectoparasite *Gyrodactylus salaris* is one of the major threats to Atlantic salmon in freshwater. Therefore, costly surveillance programs have been implemented to detect new infections and avoid spreading to unaffected areas. Conventional surveillance using electrofishing and manual inspection of fish under a stereomicroscope is both time consuming and expensive. Development and application of new detection techniques and surveillance methods that are both cost effective, fast and more animal welfare friendly than current monitoring methods is therefore important. This will make it possible to get a better overview of the distribution of this salmon killer in all areas with less effort.

All organism leaves traces of its presence within the environment it inhabits even if it is not directly observable. These traces can comprise of shed cells, either from epithelial cells in faeces and urine or mucus or gametes or other propagules or even entire specimens of microscopic organisms. Environmental DNA (eDNA) methodology utilises genetic material obtained from environmental samples, very often water filter samples, and enables detection through molecular biological techniques without the necessity for any apparent sign of the biological source. This eDNA methodology is now being used on a wide variety of target species in several countries and holds promise to complement or replace conventional monitoring.

At the Norwegian Veterinary Institute we have developed a method that can be used to detect not only the parasite *G. salaris*, but also its two main hosts: Atlantic salmon and rainbow trout. This is important in order to track spreading of potentially infected hosts to new areas and drainages and to assess their infection status. Here we present the eDNA method for *G. salaris* and its application in field studies in both North western Russia and on the Swedish west coast.

Spreading of *Gyrodactylus salaris* in the Russian North – a Threat to Vulnerable Salmon Stocks

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Wild populations of Atlantic salmon, *Salmo salar*, have experienced a dramatic decline in recent years and one of the major threats to stocks of Atlantic salmon is the parasite *Gyrodactylus salaris*. This parasite has caused enormous ecological and economic damage in Norway after its introduction in the 1970s and 1980s and has had a negative impact on populations of Atlantic salmon in one Russian river and possibly also in rivers on the Swedish west coast. The parasite has been successfully eradicated from many rivers in Norway during recent years and salmon in only seven out of the previously 50 infected rivers are still infected. However, spreading of the parasite continues in Russia and on the Swedish west coast and this is of great concern to management authorities in the respective countries. Recently, the Norwegian Veterinary Institute (NVI), which is the reference laboratory for *G. salaris* in the World Organisation for Animal Health (OIE), diagnosed *G. salaris* from both salmon and rainbow trout in Northwest Russia, close to the Norwegian and Finnish border. There is generally little knowledge of the presence of *G. salaris* in the Northern part of Russia and thus, Russian and Norwegian researchers collaborate on studying the natural distribution of the parasite in this area in order to contribute to stopping further spreading of the parasite to new vulnerable salmon populations. Here we present updated data on the distribution of *G. salaris* in Russia with focus on North western areas and we discuss both possible routes of introduction and possible control measures.

Inferring Marine Migration of Wild Atlantic Salmon from Otoliths

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Atlantic salmon (*Salmo salar*) are subject to diverse anthropogenic and ecological pressures as a consequence of their movement across broad spatial scales. Identification of the spatial and temporal limits of those pressures is contingent on knowledge of migratory behaviour and space-use. Long term declines in marine survivorship have focused concerns on the least well-known aspect of Atlantic salmon ecology – the marine migration. Conventional capture-mark-recapture and, more recently, archival data storage tag (DST) studies have greatly increased our understanding of salmon movement in coastal and open-ocean environments, but are limited in scope due to tag cost and the challenges of fish retrieval. Recent advances in the interrogation of time-series information stored in biological structures such as scales and otoliths has enabled their use to infer likely migration patterns. Changes in oxygen stable isotope values derived from measurements across otolith sections for individual fish are related to ambient water temperature at the time of otolith carbonate deposition. We use these serial estimates of the temperature regime experienced by individual salmon, together with gridded sea surface temperature archives, to infer the ocean migration of return adult Scottish one sea-winter (1SW) and two sea-winter (2SW) salmon. The distributions of geolocations from smolt emigration to adult return to freshwater are compared with information from tag recaptures to demonstrate that this novel method produces plausible outputs. The method places 1SW salmon migration within the Norwegian Sea, and 2SW salmon migration either within the Norwegian Sea or as far as West Greenland. Solving the challenge of understanding and ameliorating marine mortality requires targeted management actions informed by responses of salmon to a changing marine environment. With further development, ocean space-use inferred from otolith analyses can provide a cost-effective means of better understanding the seasonal timing and location of zones that are critical for salmon at sea.

Mitigating the Effects of Climate Change on Local Fish Populations of the River Tweed, Scotland, using the Results from The Scotland River Temperature Monitoring Network (SRTMN)

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River temperature is important to the health of cold water adapted fish like trout and salmon. Under climate change, we expect rising river temperatures will affect fish populations, either through lethal temperatures being reached more frequently or changes in the ecology of the river. Bankside woodlands offer a potential mitigation option through increased shading from sunlight. To plan where planting of trees may need to take place, information is required on where temperatures are going to get hottest and which rivers and regions will change the most. To answer these questions, a strategically designed national temperature monitoring network of 223 calibrated Tinytag loggers across 13 different catchments in Scotland was deployed in 2014, including 31 sites in the Tweed catchment. A large scale spatio-temporal statistical model was then applied to the data to predict river temperatures in unmonitored locations. The results showed that 1) the spatial patterns in water temperature reflect air temperature, landscape covariates and location and 2) warmest temperatures are in low altitude, unshaded rivers, particularly in the north of Scotland. The two key map outputs from the modelling exercise that are being used on the Tweed show areas that need the most protection from either high water temperatures or the largest changes in temperature. The Tweed maps can now be assessed to identify locations with the most 'shade-able' characteristics. Combined with local knowledge, contacts with landowners and utilisation of existing grant schemes in the forestry and farming sector, bankside tree planting is now being carried out on a strategic basis in the Tweed catchment to help mitigate any temperature changes in the future. The application of this research and the associated management outputs that are being applied on the Tweed are applicable to other small and medium sized rivers in the NASCO area.

Using Environmental DNA Analyses to Detect Atlantic Salmon

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The Atlantic salmon (*Salmo salar*) has worldwide ecological, cultural, and economic importance. The species has undergone extensive decline across its native range, yet concerns have been raised about its invasive potential in the Pacific. Knowledge on the distribution of this species is vital for addressing conservation goals. This study presents an environmental DNA assay to detect Atlantic salmon in water samples, using quantitative polymerase chain reaction technology. Species specific primers and a minor groove binding probe were designed for the assay, based on the mitochondrial cytochrome oxidase I gene. The results of this study indicate that environmental DNA is a highly effective tool for detecting Atlantic salmon *in situ*, and could provide an alternative, non-invasive method for determining the distribution of this species. Examples of deployments of the assay range from distribution of Atlantic salmon in small streams, commercial fisheries by-catch and paleo lake cores. Further, 2017 saw an unprecedented large invasion of pink salmon (*Oncorhynchus gorbuscha*) in several rivers in Northern Europe. Due to the pink salmon's strict 2-year life cycle 2019 might show an increased number of pink salmon invading European rivers. In an effort to monitor the potential invasion we have developed (in collaboration with the Norwegian Institute for Nature Research) an environmental DNA assay that could be used to detect the presence of pink salmon in rivers.

Home Ground Advantage: Local Atlantic Salmon Have Higher Reproductive Fitness than Dispersers in the Wild

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Knowledge of the extent and scale of local adaptation in wild populations can help managers make better plans to preserve biodiversity of local salmon stocks. A long-held, but poorly tested, assumption in natural populations is that individuals that disperse into new areas for reproduction are at a disadvantage compared to individuals that reproduce in their natal habitat, underpinning the eco-evolutionary processes of local adaptation and ecological speciation. Here, we capitalise on fine-scale population structure and natural dispersal events to compare the reproductive success of local and dispersing individuals captured on the same spawning ground in four consecutive parent-offspring cohorts of wild Atlantic salmon (*Salmo salar*). Parentage analysis conducted on adults and juvenile fish showed that local females and males had 9.6 and 2.9 times higher reproductive success than dispersers, respectively. Our results reveal how higher reproductive success in local spawners compared to dispersers may act in natural populations to drive population divergence and promote local adaptation over microgeographic spatial scales without clear morphological differences between populations. The home ground advantage in reproduction uncovered here may benefit wild salmon by being more resilient to invasion by escapees from salmon farms. However, stocking fish from non-local (i.e. brood stocks from neighbouring spawning grounds) would likely have a negative impact on local reproductive fitness.

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Investigating the Drivers of Atlantic Salmon Populations Decline at the North Atlantic Basin Scale through a Bayesian Life Cycle Modelling Approach

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We investigated the drivers of the widespread decline of Atlantic salmon (*Salmo salar*) populations in the north Atlantic ocean over the last four decades. A hierarchical Bayesian life cycle model was developed that allows for a collective analysis of the dynamics of 24 stock units (SUs) from three continental stock groups (CSGs) in North America, Northern Europe and Southern Europe in a single hierarchical model over the period 1971–2014. It provides a framework to investigate the drivers of changes in salmon population dynamics in a hierarchy of spatial scales.

The results provide evidence of a decline in the marine post-smolts survival together with an increase in the proportion of fish that mature after the first winter at sea, common to all SUs. The spatial covariation in the temporal variations also shows that the spatial coherence in the response increases for geographically close populations that likely share similar migration routes. Temporal variations in the post-smolts survival are best explained by variations of Sea Surface Temperature (negative correlation) and Primary Production (positive correlation) encountered by salmon in space-time domains corresponding to late summer/early autumn foraging areas. Finally, our findings support the hypothesis of a common response of salmon populations to large scale bottom-up environmentally driven changes in the north Atlantic, but also that drivers and/or mechanisms could be different between CSGs in relation to different migration routes.

The new life cycle model is also a benchmark for Atlantic salmon stock assessment in the north Atlantic. We illustrate its potential as a tool for management strategy evaluation by evaluating the probability that returns of spawners in all SUs fulfil management objectives for different catch options in both the Western Greenland and Faroes mixed stock fisheries.

Multidisciplinary Research Informs the Conservation of an Important Subarctic Atlantic Salmon Stock.

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Atlantic salmon is an ecologically, economically, and culturally important species, yet it continues to decline. Further, many extant populations show recent changes in life-history parameters such as age-at-maturity. Human impacts, including fishing, climate change, and hybridization with domesticated salmon, have been implicated in these changes. One contemporary challenge is to manage salmon populations to conserve their ecological and evolutionary integrity while also maintaining the livelihoods and traditions of people for whom salmon have economic and cultural significance.

The important Atlantic salmon stock of the subarctic Deatnu (Teno / Tana) River of Finland and Norway is both biologically diverse and culturally important to the local Sámi. The stock, one of the largest in the world, comprises multiple, genetically distinct, subpopulations and exhibits extraordinary life-history diversity. Here, we present multidisciplinary work that combines ecological and evolutionary genetics, Traditional Ecological Knowledge (TEK), and population modelling, to guide management of Deatnu salmon.

Our results show that a long-term decline in the proportion of large, multi sea-winter salmon returning to the river is underlain by change at a genomic region that strongly influences age-at-maturity. This genetic change appears to be driven both directly by selective fishing of salmon, and indirectly by fishing of a prey species (capelin). We also find evidence that this age-at-maturity gene, and other genes involved in reproductive timing, energy homeostasis and immune defense, have been selected in different ways in different subpopulations. This indicates that salmon spawning in different parts of the river are genetically adapted to local conditions, and therefore not ecologically interchangeable. The features and transmission of TEK were studied by structured interviews of Sámi fishers. Finally, we developed a new Bayesian population model framework, which enables us to better assess the dynamics of individual cohorts and subpopulations, and to incorporate genetics and TEK to inform Deatnu salmon management.

50 Years of Sampling Atlantic Salmon at Greenland

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A mixed-stock Atlantic salmon (Salmo salar) fishery that harvests fish from North America and Europe has existed off the west coast of Greenland since the early 1960's. Reported harvest peaked at ~2700 t in 1971, but has been reduced to an average of 37 t over the past ten years due to a downturn in salmon abundance and the adoption of increasingly stringent management measures. Effective management of the resource requires data on annual landings and information on the biological characteristics of the harvest (i.e. length, weight, and scale / tissue samples) to assess the impact of the fishery on contributing stocks. Information on fish age and growth are interpreted from the scale samples and region of origin determined by further analysis of scale or tissue samples. Annual sampling of the Greenland Atlantic salmon harvest has occurred since 1969 (excluding 1993-1994) through international collaborative efforts, latterly coordinated through NASCO. However, the sampling methodology varied by time period as follows: (1) 1969-1981 random samples from research vessels using commercial gill nets, (2) 1982-1997 and 2001 non-random samples from commercial factory landings and (3) 1998-2000 and 2002-2018 random samples from local markets, vendors, and commercial factories when landings were permitted. The West Greenland database currently contains over 60,000 individual records of sampled salmon. The sampling program and resulting dataset are a rare and unique resource supporting science and management. The program offers a cost efficient platform to support a wide variety of marine salmon studies and the spatial and temporal coverage of these data and samples provide an opportunity to investigate the factors affecting marine survival of this highly migratory species in a variable and rapidly changing environment. To continually meet the challenges of Atlantic salmon conservation, restoration, and science-based management, long-term monitoring programs like this one must be maintained and supported into the future.

From Newcastle-on-Tyne to New England

Technology Transfer Using Naturalised Conservation Hatchery Methods to Recover Endangered Atlantic Salmon.

Promising Results Tested During 7 Years of Extreme Climatic Conditions and Warming of the Gulf of Maine.

Zachariah Sheller, Rachel Gorich and Dwayne Shaw

Downeast Salmon Federation (DSF), United States

In recent decades the stocking program in Maine has focused on the use of unfed fry, smolt stocking and captive reared adults, but success has been limited with these approaches. Downeast Salmon Federation (DSF), in collaboration with federal, state, and fellow NASCO NGO partners, implemented the Peter Gray Parr Project to grow and assess the effectiveness of rearing 0+ fall parr in an on-river hatchery. The methods being used were developed on the River Tyne, where they contributed to one of the biggest salmon recovery success stories in Europe. Utilising unfiltered river water from the natal river, substrate incubators, darkened tanks, some natural feed, and water velocity manipulation; our goal is to produce more naturalised salmon. Parr are stocked during the fall at densities significantly higher than historic stocking rates. Results are assessed using electrofishing, rotary screw traps, and redd surveys. Key goals are to maintain and increase genetic diversity of the river specific strain and increase the overall numbers at all life stages in the population.

Since 2012, over 1 million parr have been stocked into the East Machias River. During this period the watershed experienced record setting: drought, cold, precipitation, flooding, and extreme warming of the Gulf of Maine. Despite these climate stressors, results are encouraging. The decadal median large parr density from fall parr stocking (2012-present) is more than double that of unfed fry stocking (2000-2011). Densities of large parr in the river have reached levels not seen since the 1970's and in most habitats, fall parr stocking has outperformed unfed fry, fed fry, and captive reared adult stocking strategies. The number of smolt has more than quadrupled and the adults returning from those smolts have done so at rates higher than naturally-reared smolts on the nearby Narraguagus River and age 1 smolts stocked in Maine's Penobscot River.

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