Fisheries and Oceans Canada
Pêches et Océans Canada
Science
Sciences
National Capital Region
Canadian Science Advisory Secretariat
Science Advisory Report 2013/050

POTENTIAL EFFECTS SURROUNDING THE IMPORTATION OF EUROPEAN-ORIGIN CULTURED ATLANTIC SALMON TO ATLANTIC SALMON POPULATIONS AND HABITATS IN NEWFOUNDLAND

Net-pen aquaculture along the south coast of Newfoundland (photo credit: C. Hendry, DFO).

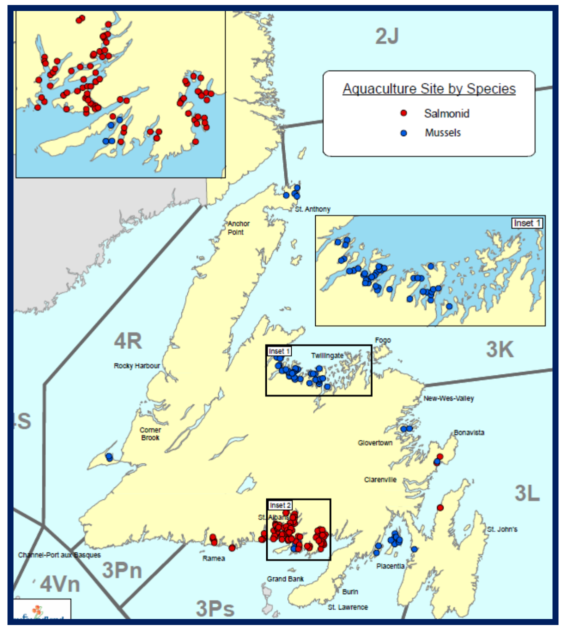

Figure 1: Location of marine Atlantic salmon aquaculture sites and adjacent watersheds along the south coast of Newfoundland (Insert 2).

Context:

Canada's finfish aquaculture industry have expressed interest in gaining access to alternative Atlantic salmon (Salmo salar) broodlines that could potentially increase Canadian aquaculture industry competitiveness. Two companies on the East Coast of Canada have sought approval from Fisheries and Oceans Canada (DFO) to import small numbers of Norwegian-origin Atlantic Salmon from an Icelandic facility for the purpose of conducting performance trials in net cages at sea. These companies would like to investigate whether this foreign strain has the potential for improved performance under Newfoundland conditions compared to that currently being realized from domestic-origin fish. These requests were previously denied, in part, due to the uncertainty surrounding the growth, survival, and reproduction of potential farm escapees in Newfoundland rivers. It was concluded that this high level of uncertainty precluded determination of the level of ecological and genetic risk that potential escapes from farms could pose to wild Atlantic Salmon and their habitat. An increased understanding and characterization of these risks is needed to help inform management on policy direction and/or decision-making and on possible mitigation measures that may alter risk profiles regarding advice on similar future requests.

Canada's National Code on Introductions and Transfers of Aquatic Organisms requires that a risk assessment be conducted in evaluating requests for introductions or transfers of fish. Aquaculture Operations Management Directorate is requesting science advice to inform the risk assessment and

Canada

subsequent risk management decisions regarding requests for importation and use of European-origin Atlantic Salmon broodlines in salmon aquaculture in Newfoundland.

This Science Advisory Report is from the March 26-28, 2013 meeting: Potential effects surrounding the importation of European-origin cultured Atlantic salmon to Atlantic salmon populations and habitats in Newfoundland. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

SUMMARY

- Atlantic salmon (Salmo salar) is a species with wide genetic diversity and variation in life history traits. North American and European salmon populations diverged about 500,000 years ago, and the resulting genetic divergence between these populations is significant, as illustrated by their different chromosome number and structure. There is also phenotypic and genetic divergence between Newfoundland and mainland North American salmon, including populations from the Saint John River, which is the primary source of strains used by the Newfoundland aquaculture industry. Because of intensive selection and domestication, farmed salmon are genetically distinct from wild populations.
- Native Newfoundland salmon populations are characterized by a large diversity of anadromous and non-anadromous phenotypes that have adapted to unique environmental conditions in fluvial (riverine) and lacustrine (lake) habitats and are often found in small population units. Recent reviews of the spawning escapement trends for south coast Newfoundland stocks have estimated population declines of an average of 40% over the last three generations (COSEWIC, 2010; DFO, 2012).
- Farmed European-origin Atlantic salmon strains can successfully breed with wild Atlantic salmon throughout the native species range and it is expected that potential fertile farmed European-origin Atlantic salmon escapees in Newfoundland waters would breed successfully with Newfoundland wild Atlantic salmon.
- There is a risk of substantive genetic and phenotypic consequences for native populations if they were to interbreed with escaped farmed European-origin Atlantic salmon (direct genetic effects). Although genetic and phenotypic consequences are difficult to predict, interbreeding would likely result in a subsequent reduction in genetic diversity among populations and reduced fitness within populations that would affect the character, abundance and viability of the native Newfoundland populations.
- These risks would be proportional to the frequency and number of escapees relative to the size and status of the native populations that would be exposed to potential interbreeding. The ability of escaped fish to survive and successfully interbreed with wild Atlantic salmon is influenced by the life-history stage (size) of escapees, their sex, the duration they remain in the culture environment, the time of year (season) they escape, timing of maturation and entry into freshwater.
- The fitness consequences of a given amount of interbreeding across multiple generations may vary depending on whether interbreeding is continuous or episodic.
- Indirect genetic effects (i.e., genetic changes that do not occur through interbreeding but because of changes in the environments that the organisms experience) have been documented in salmonids. Such environmental changes could occur through the presence of farmed European-origin Atlantic salmon in net-pens, whether or not the farmed fish escape. This effect may result in reduced adaptive genetic diversity and

altered survival and reproduction in native populations, but a better understanding of the nature and magnitude of indirect genetic effects is required.

- Escaped farmed European-origin Atlantic salmon might also pose ecological threats to native populations. Competition between native juvenile Atlantic salmon and juvenile farm strain origin Atlantic salmon in fresh water will occur due to space limitations, and due to traits associated with farm strains, such as fast growth, large size at age and aggressive behaviour. It is not expected that there would be significant competition in the marine environment. Competition between the two types of fish might also occur on the spawning ground. To the extent that these interactions occur, they are expected to result in reduced fitness in native populations.
- Through technological and operational improvements, a significant reduction in the number of reported escapees of farmed Atlantic salmon has been documented in several jurisdictions, such as Maine and Norway where operational standards and independent verification of sites and equipment have been required since 2006.
- While the reported number of escaped farmed fish has decreased in Norway over the last decade, the in-river proportion of escaped farmed fish to returning wild salmon has remained relatively constant (Norwegian Institute for Nature Research, 2011). The in-river proportion of escaped farmed Atlantic salmon to returning Atlantic salmon influences the scale of potential genetic and ecological consequences to wild Atlantic salmon populations.
- Despite improvements in technology and operational procedures, escapes of farmed salmon reared in marine net pens are inevitable, and based on current recapture methods, attempts to recover them are generally not successful.
- To assess the success of physical containment technologies and operational practices in mitigating escape events, information on the number and frequency of events is required. Challenges remain in detecting escapes from net-pens, particularly small-scale escapes and those involving smaller fish. Techniques used by the industry to estimate the number of fish in a net pen at a given point in time are not free of error, which may result in inventory discrepancies between number of fish stocked, reported deaths and harvesting. Improvements in tools and techniques to assess the number of fish within net pens during grow-out would allow for an increased ability to assess escape events involving small numbers of fish. Escapes tend to be linked primarily to structural damage of sea cages through weather events and operational errors. Examples of effective physical containment systems take into account site-specific information and include standards, auditing, and training.
- The only method currently available for effective reproductive containment of farmed fish on a commercial scale is the production of all-female triploids. The use of sterile female triploids in Atlantic salmon aquaculture would significantly reduce the proportion of escaped farm adults returning to rivers and the possibility of interbreeding with wild stocks. Although triploid Atlantic salmon can perform well in culture, further comparisons with diploids would be required to evaluate marine performance, pathogen resistance, disease transmission, ecological effects, costs of monitoring and husbandry techniques to optimize performance for use at a commercial scale.

INTRODUCTION

The Newfoundland and Labrador Atlantic salmon, *Salmo salar*, aquaculture industry originated in the Bay d'Espoir fjord of the south coast of Newfoundland in the early 1980s, utilizing local Newfoundland and Labrador wild stocks. These Newfoundland and Labrador stocks were determined to be unsuitable for aquaculture production and commercial activity began with the importation of Saint John River-origin (New Brunswick) strains in 1991. Production was modest with annual harvests increasing to just over 1,000 t until the industry expanded into Fortune Bay in 2002 and the fjords of the Connaigre Peninsula, thereafter. Salmon production subsequently increased to more than 15,000 t over the past decade involving about 90 sites. Aquaculture site production strategies in the south coast of Newfoundland involve one-year fallow periods between 18-24 month production cycles. All smolt production in Newfoundland and Labrador is from closed, recirculating aquaculture system (RAS) hatcheries.

Within a 30 km radius of the south coast of Newfoundland salmonid net-cage aquaculture industry are the mouths of 35 rivers, including 13 that are scheduled for recreational salmon fishing. The Newfoundland salmonid aquaculture industry would like to import European Atlantic salmon broodlines. Two previous industry requests for the importation were denied, in part, due to significant gaps in science knowledge with which to inform an estimate of the associated risk to wild salmon populations and their habitat. Aquaculture Operations Management Directorate requested CSAS advice to address the gap in science knowledge and to inform any future decisions regarding importation and use of European Atlantic salmon for aquaculture in Newfoundland and Labrador.

An interdisciplinary and cross-sectorial steering committee was formed in July 2012 to address this issue. The steering committee developed the terms of reference, timeframe, expertise, venue and participation. Four questions were addressed in five working papers at a peer review meeting in March 2013. The questions were as follows:

1. What is the likelihood that European-origin Atlantic salmon aquaculture escapees will mate successfully with native wild salmon? What risks could such interbreeding present to native populations? How might this risk scale with the size of the interaction?
2. What could be the direct and indirect genetic and phenotypic (e.g., growth, survival) consequences to native Atlantic salmon if European-origin cultured Atlantic salmon were to successfully breed and/or interbreed with native Atlantic salmon?
3. What ecological risks could European-origin cultured Atlantic salmon and their hybrids present to native Atlantic salmon populations in native river systems and marine habitats (i.e., changes in competition, disease transmission, reproduction, displacement, and predation)?
4. How might mitigation measures be used to prevent or reduce the likelihood of escape of European-origin Atlantic salmon from physical containment systems? Are there biocontainment measures that could operate subsequent to an escape event to reduce further the likelihood of interaction between the escaped and wild native salmon? How could these mitigation measures result in possible reductions in genetic, phenotypic and/or ecological risks to wild populations?

The scope of the peer-review was limited to assessing the potential genetic and ecological interactions between European-origin Atlantic salmon broodstock and wild Newfoundland and Labrador Atlantic salmon populations. While there is limited scientific data on the interactions between European-origin farmed Atlantic salmon strains and the wild Newfoundland and

Labrador Atlantic salmon populations, there is a more substantial body of knowledge on interactions between cultured and wild Atlantic salmon in both North America and Europe, upon which this analysis is based.

ANALYSIS

Potential direct and indirect genetic consequences

The general body of knowledge on indirect and direct genetic interactions (Figure 2) between genetically divergent conspecific populations has expanded over the last decade. This new information has strengthened the knowledge base to indicate that there is a significant risk of substantive phenotypic and genetic consequences for native populations when a non-native conspecific population is introduced. Although Atlantic salmon is one of the best characterised species from a demographic, phenotypic and genetic perspective, it is insufficiently well characterised to provide a robust prediction of the specific consequences for wild Newfoundland and Labrador populations of indirect and direct genetic interactions with European-origin salmon farm strains. Nevertheless, the two types of salmon are widely diverged and, in general, the greater the population divergence, the greater the expected negative impacts from hybridization. Though specific studies are lacking in relation to farmed European-origin Atlantic salmon strains and wild Newfoundland and Labrador Atlantic salmon populations, what is known strongly supports that the two types of fish are highly divergent.

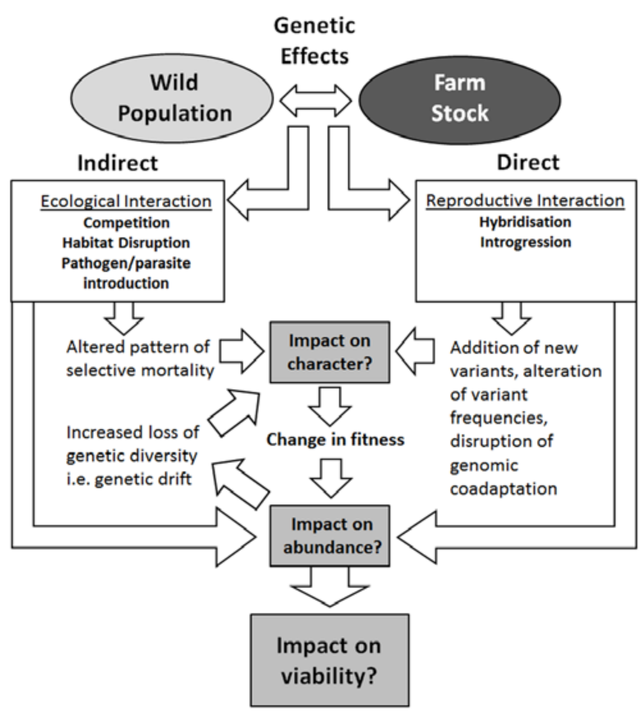

Figure 2: Diagrammatic overview of pathways of direct and indirect genetic effects arising from interactions between wild and farm populations.

Atlantic salmon genetic structure in Newfoundland and Labrador populations suggests significant diversity is present, particularly along the south coast, and it is associated with fine-scale local adaptation and habitat characteristics that appear to be stable over decades. There is considerable phenotypic variation among local populations. Non-anadromous salmon populations in Newfoundland show considerable behavioural variation in fresh water residence times and in migration patterns. Anadromous salmon populations in Newfoundland demonstrate phenotypic differentiation in life history traits (e.g., smolt length, smolt age, egg to smolt survival, size at maturity, etc.).

Direct genetic impacts from escaped farmed European-origin Atlantic salmon will occur when the escapees mature, enter rivers and reproduce successfully with wild fish. Interbreeding can be expected, though its precise extent is difficult to predict. Interbreeding can result in reductions in population size, non-specific loss of both adaptive and non-adaptive diversity, as well as introgression of new adaptively relevant gene variants, alteration of existing gene and genotype frequencies, or disruption of co-adaptive genomic structure. The performance of pure European-origin Atlantic salmon and hybrid offspring can be expected to be significantly depressed compared to wild populations but the extent of this fitness depression is unknown and cannot be predicted without additional information. It will also be dependent on the ecological circumstances, the amount of interbreeding and the demographic status (i.e., size and status) of the wild populations involved. The population-level consequences from direct genetic impacts will depend on the extent of reproductive interactions and the fitness of hybrid offspring.

Farmed fish kept in fresh or salt water net-pens have the biological potential for indirect genetic impacts associated with the release of strains of exotic pathogens or parasites or by increasing the incidence of native pathogens or parasites. When these situations lead to increased or selective mortality, they can alter gene frequencies in wild populations, and compromise a wild population's capacity to deal with environmental change in the long term. The risk associated with the release of exotic pathogen or parasite strains is currently mitigated through regulatory requirements associated with disease status for introduced strains; however, the lack of knowledge of local adaptation to pathogens and parasites in wild salmon populations, and variation in virulence of pathogens and parasites, precludes predicting the risk of using European-origin Atlantic salmon strains. The full extent of indirect genetic effects would require more study, but some level of indirect genetic impacts will almost certainly occur where farmed European-origin Atlantic salmon are reared in net-pens, either in fresh water (juveniles) or in salt water (post-smolts and adults).

While farmed European-origin Atlantic salmon can be expected to be relatively maladapted to Newfoundland and Labrador environmental conditions, a proportion of escaped fish from marine cages can be expected to survive, mature and enter rivers to spawn. These fish will have the potential to interfere with the reproduction of wild fish, reducing wild breeding success, and for those that breed successfully, to produce offspring that compete with wild juveniles. Both processes may alter selective pressures, change gene frequencies or depress wild abundance, increasing the loss of variation through genetic drift. The overall genetic effects from rare events of interbreeding of large number of escapees with a wild population compared to small numbers of escapees interbreeding on a continual (yearly) basis is the focus of modeling studies. These models suggest that the cumulative effects from constant, low level interbreeding, may have different fitness consequences than larger-scale interbreeding that affects one year class, and should not be discounted. More research is being undertaken to further elaborate these fitness consequences.

Potential ecological consequences from farmed European-origin Atlantic salmon or their hybrids

There is significant evidence that even with improved containment, escape events from aquaculture are inevitable and that wild populations at low abundance will be most vulnerable to negative impacts. The degree of ecological impact of escaped farmed European-origin Atlantic salmon will depend on the frequency of escapes, the scale of the escape compared with the size of the native wild populations, the survival and dispersal of escaped fish, and the ability to establish in wild environments. These factors each vary with life stage at escape, level of domestication, season and area of escape, and the presence of predators and competitors.

Predicting ecological impacts along the south coast of Newfoundland is difficult due to sparse information on the state of wild salmon populations. COSEWIC (2010) listed south coast salmon populations as "Threatened" and subsequent analysis suggests that under existing conditions, further declines are likely (DFO 2013). Within the marine environment, escaped Atlantic salmon behaviour will depend on the life stage and time of year that the escape event occurs. While studies indicate that initially escaped farmed Atlantic salmon are not adept at capturing wild prey, they are subsequently able to consume such prey in the marine environment. Escaped Atlantic salmon can also swim away from the point of release (hundreds of kilometres or more). Competitive and density-dependent effects in the marine environment are not well understood.

Based on information derived from lab, semi-natural and field studies, the greatest potential for escaped Atlantic salmon to have ecological impacts on wild conspecifics is during the juvenile stage in the freshwater environment. Domesticated juvenile Atlantic salmon use similar resources, have increased competitive ability, grow faster, are less risk averse, and are more aggressive than wild juveniles. As a result, farmed juvenile Atlantic salmon and hybrids show comparable survival to their wild counterparts. Although juvenile Atlantic salmon escapees will compete with wild juvenile conspecifics, this risk is mitigated through current husbandry practices in Newfoundland and Labrador, where freshwater stages are reared in closed RAS (recirculating aquaculture system) hatcheries. By contrast, escaped farmed adult Atlantic salmon have a less competitive spawning behaviour and a consistently lower reproductive success than their wild conspecifics.

Existing information suggests that escaped farmed European-origin Atlantic salmon will have three primary mechanisms of ecological effects that are mediated to some degree by the ability of these fish to hybridize with wild conspecifics. First, genetic introgression is almost certain to change adaptive traits associated with disease resistance, life history and ability of wild populations to adapt to change. Under poor recovery conditions, such as low numbers of wild fish and/or chronic escapes, these changes may persist. Second, assuming that freshwater escapes are limited through land-based RAS hatcheries, the competitive interactions associated with farmed European-origin Atlantic salmon juveniles and wild fish will occur primarily through hybrids. Intentional (e.g., growth) and unintentional (e.g., aggression) selection could result in a competitive advantage of European-origin Atlantic salmon juveniles over wild juveniles in the freshwater environment. Third, while reproductive interference can occur in the absence of successful mating (e.g., through unsuccessful hybridization, damage to existing reds, etc.), successful hybridization exacerbates other related types of interference by removing or hindering the opportunity for wild fish to successfully spawn with wild conspecifics, thus removing gametes from the wild fish population.

How might mitigation measures be used to prevent or reduce the likelihood of escape of farmed European-origin Atlantic salmon?

Escapes from aquaculture facilities can be broadly defined as either chronic losses of low numbers of fish, which are on-going or periodic during the grow-out cycle, or acute losses, which involve significant numbers of escapes that may occur quite suddenly. While the extent of farmed Atlantic salmon escapes globally is difficult to assess, official statistics, if available, are expected to underestimate the total number of escapes. This is because chronic losses or small numbers are undetected, unreported, or not required to be reported. Additionally, there are errors associated with the techniques used to assess the number of fish in a net-pen. Verification of actual stock numbers is not possible until date of harvest. Discrepancies in inventory between stocking and harvesting will also include losses due to undetected mortality during grow-out.

Based on official statistics from Norway and Scotland, the causes of Atlantic salmon escapes can be categorized as structural failures of the net pen and mooring system components, operational failures related to fish handling and farm management practices, and biological failures primarily associated with predatory attacks. In the marine environment, the majority of farmed Atlantic salmon escape events were due to structural failure, which is primarily due to wave and current interactions with farm infrastructure.

In addition to current containment codes and practices implemented by the aquaculture industry, in some jurisdictions (i.e., Norway) further mitigation measures to decrease the extent of escapes of farmed Atlantic salmon have included the development of technical standards that set requirements for site surveys, equipment design and certification, and engineering dimensioning and installation. Operational activities include structural and installation redundancies, operational procedures for the early identification of equipment deficiencies, accurate record keeping and training of staff on proper equipment and vessel use, standard operating procedures, and escape and Hazard Assessment Critical Control Point (HACCP) plans. While the reported number of escaped farmed Atlantic salmon has decreased in Norway over the last decade, the in-river proportion of escaped farmed Atlantic salmon to returning wild Atlantic salmon has remained relatively constant (Norwegian Institute for Nature Research, 2011). The in-river proportion of escaped farmed Atlantic salmon to returning Atlantic salmon influences the scale of potential genetic and ecological consequences to wild Atlantic salmon populations.

Biocontainment measures to reduce/mitigate potential post-escape interactions between cultured European-origin and wild native Atlantic salmon in Newfoundland

An effective way to reduce or mitigate potential post-escape interactions between cultured European-origin and wild native Atlantic salmon in Newfoundland is to ensure that the cultured fish cannot reproduce. Although this does not eliminate ecological risks, it at least assures that any ecological impacts will be limited to the lifetime of the escaped fish. The use of sterile fish eliminates the risk of genetic introgression by the escaped fish into the native population structure.

Induced triploidy is currently the only method available for rendering large populations of farmed Atlantic salmon sterile, and a great deal of research has been conducted on the basic biology and culture characteristics of triploid Atlantic salmon. Attaining 100% triploidy induction success is unlikely using current standard methods. However, with experience and adherence to good farm practice and standard operating procedures, it should be possible to routinely attain >98% induction success. By using all-female triploid populations, essentially complete elimination of gamete production can be achieved. Mixed-sex populations should be avoided because triploid males can show normal spawning behavior and produce dilute milt containing aneuploid sperm. Should such fish breed in nature, they will yield aneuploid offspring which survive early development but generally die before reaching the fry stage. Although this prevents genetic introgression, any wild eggs which are fertilized by triploid males will be lost from the population. Creating all-female populations, whether as diploids or triploids, is easily achieved.

Based on all the information currently available, it would appear that the use of triploid Atlantic salmon would have no impact on the rate of fish escapes from farms, but it may reduce their survival and dispersal in the receiving habitat. Triploid Atlantic salmon are less likely to survive in habitats that are relatively warm or low in dissolved oxygen. There is some indication that triploid Atlantic salmon are less resistant to pathogens and parasites, which would further limit their survival in the wild but would add the risk of becoming reservoirs for disease transmission to wild salmon populations. Triploid Atlantic salmon are likely to be effective competitors with wild diploids for food and space but, assuming all-female populations, they will show greatly reduced migration to fresh water if they escape from seawater sites.

No dramatic effects of triploidy on Atlantic salmon production-related traits in aquaculture, aside from their sterility, have been documented. Reports of reduced performance may reflect sub-optimal rearing conditions or the need to use different strains of fish. For all the research done evaluating triploid Atlantic salmon in Atlantic Canada, there is no information on how triploids of the best performing diploid strains compare to their diploid siblings. To evaluate the performance of Atlantic salmon triploids derived from the best performing production strains, to develop breeding programs specifically for enhanced performance of triploids and to define optimum husbandry conditions for Atlantic salmon triploids, additional research would be needed.

Sources of Uncertainty

- The full extent of adaptive population structuring in south-coast Newfoundland wild, anadromous and non-anadromous salmon populations is unknown.
- A major source of uncertainty is the extent of genetic divergence between farmed European-origin Atlantic salmon strains and wild Newfoundland Atlantic salmon populations. The specific differences in genomic architecture among European and North American Newfoundland salmon populations are unknown. In addition, specific studies are lacking in relation to hybridization between farmed European-origin Atlantic salmon strains and wild Newfoundland populations.
- There is a lack of information on the potential response of farmed European-origin salmon strains to endemic pathogens and parasites. There is also a lack of information on resistance and susceptibility of wild Newfoundland populations to endemic pathogens and parasites and their ability to respond to any changes in the pathways of exposure to them.
- There is a lack of information on phenotypic differences in reproductive behaviour of escaped farmed Atlantic salmon and their feral offspring and farm-wild hybrids, compared to their wild population counterparts.
- There is a lack of information on fitness differences among farm, wild and farm-wild hybrids in the wild; the extent of competitive interactions among farm and wild fish in the wild; their effect on the survival of wild fish; and, the impact of local population demographics on interaction outcomes.
- Precise information on the nature of structural failures in sea cages is lacking. Although there is a number of different modeling efforts related to net-pen structures, there is limited field-validation of these models.
- There is limited spatial and temporal monitoring of the wild populations in south coast Newfoundland, and the frequency and extent of escaped farmed Atlantic salmon in these populations is unknown in freshwater and marine environments.
- The cumulative effects of chronic, low-level escapes are unknown and difficult to assess because low-level escapes are difficult to identify and monitor at individual sites.

- The fitness consequences for natural Atlantic salmon populations from interbreeding with small, more-or-less steady numbers of escaped farmed Atlantic salmon year year after year (chronic), or in relatively large numbers (acute) in a single year, resulting from singular escape events, is difficult to measure, and has been the focus of recent modeling work. The modeling research indicates that given the same total number of escapes over a period of time, chronic escapes, which span multiple generations, may have greater fitness consequences than from acute escapes. While there is uncertainty and assumptions built into these models. The cumulative effects of constant, low level leakage should not be ignored, even if the magnitude of escapes is below the threshold that can reliably be detected through regular monitoring of inventory.
- There is uncertainty regarding the fate of escaped farm-origin fish in the marine and freshwater environment, including post-escape dispersal patterns, survival, feeding, and their movements into wild salmon rivers and maturation success.
- There is uncertainty regarding disease resistance of triploid salmon as well as their performance in aquaculture settings.

CONCLUSIONS AND ADVICE

1. There is a high likelihood that fertile farmed European-origin Atlantic salmon escapees would successfully interbreed with native Newfoundland salmon populations and that the resulting offspring would have a reduced ability to survive. This risk is elevated for small or declining salmon populations such as those found on the south coast of Newfoundland, that have also recently been designated as "Threatened" (COSEWIC, 2010).
2. There is a risk of substantive genetic and phenotypic consequences (direct genetic effects) should interbreeding between farmed European-origin Atlantic salmon escapees and native Newfoundland salmon populations occur frequently or on a large scale, likely resulting in a reduction in genetic diversity among populations and reduced fitness within populations, including the likely disruption of adaptive traits. There could also be indirect genetic effects such as reduced resistance to indigenous pathogens and parasites and increased susceptibility to novel pathogens, although a better understanding of the full extent of indirect genetic effects would require more study. It would not be necessary for salmon to escape from sea cages in order to cause the indirect effects described above.
3. Escaped farmed European-origin Atlantic salmon or their offspring might pose ecological risks to native Atlantic salmon populations, particularly in freshwater habitats. Competition may occur on spawning grounds between adult escaped European-origin Atlantic salmon and native adult Atlantic salmon. Competition between native juvenile Atlantic salmon and juvenile farm strain origin Atlantic salmon in fresh water will occur due to space limitations, and associated with farm strain traits such as faster growth, large size at age and aggressive behavior. Ecological effects are anticipated to be less pronounced in the marine environment, as significant competition in the marine environment is not expected.
4. Best management practices in conjunction with appropriate physical containment equipment designed for the specific site conditions could reduce the likelihood of farmed European-origin Atlantic salmon farmed fish escaping from sea cages, but these could never entirely remove this threat. The most successful containment programs in place for reducing escapes from physical containment include defined equipment standards for cage structures and moorings for site-specific conditions and best management protocols for fish husbandry practices (i.e., stocking, feeding, grading, harvesting) along with training, monitoring, auditing and timely reporting of losses.

Although mitigation measures can reduce the number of escapees entering the marine environment, the only biocontainment technology that could reduce the likelihood of direct genetic effects occurring between escaped aquaculture fish and native populations that is currently available for application in commercial aquaculture is all-female triploidy. All-female sterile triploids have a lower rate of fresh water migration compared to diploid farmed escapees, thus reducing the proportion of escaped farmed adults returning to spawning rivers, and decreasing the potential extent of reproductive interference. However, although Atlantic salmon triploids can perform well in culture, further comparisons with diploids would be required to evaluate marine performance, pathogen resistance, disease transmission, ecological effects, costs of monitoring and husbandry techniques to optimize performance for their use in an aquaculture setting.

SOURCES OF INFORMATION

This Science Advisory Report is from the March 26-28, 2013 advisory meeting on the potential effects surrounding the importation of European-origin cultured Atlantic salmon to Atlantic salmon populations and habitats in Newfoundland. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

COSEWIC. 2010. COSEWIC assessment and status report on the Atlantic Salmon *Salmo salar* (Nunavik population, Labrador population, Northeast Newfoundland population, South Newfoundland population, Southwest Newfoundland population, Northwest Newfoundland population, Quebec Eastern North Shore population, Quebec Western North Shore population, Anticosti Island population, Inner St. Lawrence population, Lake Ontario population, Gaspé-Southern Gulf of St. Lawrence population, Eastern Cape Breton population, Nova Scotia Southern Upland population, Inner Bay of Fundy population, Outer Bay of Fundy population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xlvii + 136 pp.

DFO 2013. Recovery Potential Assessment for the South Newfoundland Atlantic Salmon (*Salmo salar*) Designatable Unit. Fisheries and Oceans Canada Canadian Science Advisory Secretariat Science Advisory Report 2012/007.

Norwegian Institute for Nature Research. 2011. Status for norske laksebestander i 2011. (Editors E. B. Thorstad & T. Forseth.) Rapport fra Vitenskapelig råd for lakseforvaltning nr 3, 285 s. ISBN: 978-82-93038-05-4.

APPENDIX I: GLOSSARY

Aneuploid - An aneuploid is an individual organism whose chromosome number differs from the wild type by part of a chromosome set.

Biocontainment - Preventing organisms, or their genes, from spreading into the environment

Conspecific – individuals assigned to the same designated Linnaean species; as such in so far as species designations are working hypotheses, the assignment may be subject to change as biological knowledge changes and species designations are revised.

Fitness – a measure of an individual's ability to contribute to future generations

Genome – the sum of all DNA contained in the cell of an organism that is inherited from its parents and passed on to its offspring.

Genotype-environment interactions - interactions between the genome and the environment that underpin an organisms development and determines its character (phenotype) and fitness, including its capacity to leave viable offspring.

Hybridisation – the interbreeding of individuals from two evolutionarily distinct populations which may be from the same or a different designated Linnaean species.

Introgression - Infiltration of the genes of one species into the gene pool of another through repeated backcrossing of an interspecific hybrid with one of its parents.

Phenotype – the organismal manifestation of the interaction between a genome and the environment, either with respect to all traits or an individual trait (e.g., growth phenotype).

Population – a group of individuals and their offspring within which mating occurs, but where mating with other such groups is more or less absent; alternative terms: genetic population, deme.; not to be confused with the use of the term in a demographic or statistical sense; see Waples and Gaggiotti (2006) for discussion of differences in use of the word population in a biological context.

Salmon – *Salmo salar* L.; while commonly also used to refer to Pacific salmon, this use is excluded here.

Species – a set of one or more populations, which by virtue of their perceived sharing of a particular set of biological characteristics and an ability to inherently produce viable, fertile offspring, are deemed to be distinct from other populations, and given a common and unique Latin binomial e.g. *Salmo salar*.

Stock – an arbitrary group of individuals defined, usually for purposes of management, in respect of some characteristic such as sharing of being found in a particular area (e.g. a river or marine zone) or biological trait (e.g. age of maturity, time of return to freshwater); such a group will usually not be coincident with a genetic population but is more likely to correspond to part of a genetic population or to encompass all or part of a number of genetic populations.

Strain – a reproductively isolated breeding lineage of animals that have been maintained in culture for 2 or more generations and subject to the potential for domestication and may be artificially selected for particular traits.

Triploid – An organism possessing three complete sets of homologous chromosomes in its nuclear genome (as opposed to the more commonly observed two sets in diploids).

THIS REPORT IS AVAILABLE FROM THE:

Canadian Science Advisory Secretariat
National Capital Region
Fisheries and Oceans Canada
200 Kent Street
Ottawa, Ontario K1A 0E6

Telephone: 613-990-0293
E-Mail: csas-sccs@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2013. Potential Effects Surrounding the Importation of European-Origin Cultured Atlantic Salmon to Atlantic Salmon Populations and Habitats in Newfoundland. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/050.

Aussi disponible en français :

MPO. 2013. Effets potentiels entourant l'importation de saumons de l'Atlantique d'élevage d'origine européenne sur les populations et les habitats du saumon de l'Atlantique à Terre-Neuve. Secr. can. de consult. sci. du MPO, Avis sci. 2013/050.