Atlantic salmon

Salmo salar

Image © Monterey Bay Aquarium

Atlantic North America

USA (Maine) and Atlantic Canada (New Brunswick, Newfoundland, Nova Scotia)

Marine Net Pens

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About Seafood Watch®

Monterey Bay Aquarium's Seafood Watch program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from www.seafoodwatch.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Watch Assessment. Each assessment synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices," "Good Alternatives" or "Avoid." This ethic is operationalized in the Seafood Watch standards, available on our website here. In producing the assessments, Seafood Watch seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch's sustainability recommendations and the underlying assessments will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Watch assessments in any way they find useful.

Guiding Principles

Seafood Watch® defines "sustainable seafood" as seafood from sources, whether fished or farmed, that can maintain or increase production without jeopardizing the structure and function of affected ecosystems.

Sustainable aquaculture farms and collective industries, by design, management and/or regulation, address the impacts of individual farms and the cumulative impacts of multiple farms at the local or regional scale by:

1. **Having robust and up-to-date information on production practices and their impacts available for analysis;**
   Poor data quality or availability limits the ability to understand and assess the environmental impacts of aquaculture production and subsequently for seafood purchasers to make informed choices. Robust and up-to-date information on production practices and their impacts should be available for analysis.
2. **Not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level;**
   Aquaculture farms minimize or avoid the production and discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges.
3. **Being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats;**
   The siting of aquaculture farms does not result in the loss of critical ecosystem services at the local, regional, or ecosystem level.
4. **Limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms;**
   Aquaculture farms avoid the discharge of chemicals toxic to aquatic life or limit the type, frequency or total volume of use to ensure a low risk of impact to non-target organisms.
5. **Sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains;**
   Producing feeds and their constituent ingredients has complex global ecological impacts, and the efficiency of conversion can result in net food gains or dramatic net losses of nutrients. Aquaculture operations source only sustainable feed ingredients or those of low value for human consumption (e.g., by-products of other food production), and convert them efficiently and responsibly.
6. **Preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes;**
   Aquaculture farms, by limiting escapes or the nature of escapees, prevent competition, reductions in genetic fitness, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems that may result from the escape of native, non-native and/or genetically distinct farmed species.
7. **Preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites;**
   Aquaculture farms pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites, or the increased virulence of naturally occurring pathogens.

8. **Using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture;**
   Aquaculture farms use eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture, or where farm-raised broodstocks are not yet available, ensure that the harvest of wild broodstock does not have population-level impacts on affected species. Wild-caught juveniles may be used from passive inflow, or natural settlement.
9. **Preventing population-level impacts to predators or other species of wildlife attracted to farm sites;**
   Aquaculture operations use non-lethal exclusion devices or deterrents, prevent accidental mortality of wildlife, and use lethal control only as a last resort, thereby ensuring any mortalities do not have population-level impacts on affected species.
10. **Avoiding the potential for the accidental introduction of secondary species or pathogens resulting from the shipment of animals;**
    Aquaculture farms avoid the international or trans-waterbody movements of live animals, or ensure that either the source or destination of movements is biosecure in order to avoid the introduction of unintended pathogens, parasites and invasive species to the natural environment.

Once a score and rating has been assigned to each criterion, an overall seafood recommendation is developed on additional evaluation guidelines. Criteria ratings and the overall recommendation are color-coded to correspond to the categories on the Seafood Watch pocket guide:

Best Choices/Green: Are well managed and caught or farmed in environmentally friendly ways.

Good Alternatives/Yellow: Buy, but be aware there are concerns with how they're caught or farmed.

Avoid/Red: Take a pass on these. These items are overfished or caught or farmed in ways that harm other marine life or the environment.

Final Seafood Recommendation

Atlantic salmon

Salmo salar
Maine (United States)
New Brunswick, Newfoundland, Nova Scotia (Canada)
Marine net pens

Criterion	Maine	New Brunswick	Newfoundland	Nova Scotia
C1 Data	5.91	5.91	5.91	5.91
C2 Effluent	4.00	4.00	4.00	4.00
C3 Habitat	6.93	6.93	6.93	6.93
C4 Chemical Use	8	2	2	8
C5 Feed	5.25	5.25	5.25	5.25
C6 Escapes	4	3	3	4
C7 Disease	4	0	2	4
C8X Source of stock	0	0	0	0
C9X Wildlife mortalities	-2.00	-2.00	-2.00	-2.00
C10X Introductions	-0.8	-0.4	-0.6	-1.4
Total	35.29	24.69	26.49	34.69
Final score (0-10)	**5.04**	**3.53**	**3.78**	**4.96**

OVERALL RATING

	Maine	New Brunswick	Newfoundland	Nova Scotia
Final Score	5.04	3.53	3.78	4.96
Initial rating	Y	Y	Y	Y
Red criteria	0	3	3	0
Interim rating	Y	R	R	Y
Critical Criteria?	0	0	0	0
Final Rating	**Yellow**	**Red**	**Red**	**Yellow**

Scoring note – scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of -10 reflects a very significant impact. Two or more Red criteria result in a Red final result.

Summary

- The final numerical score for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Maine (US) is 5.04 out of 10. With no red criteria, the final rating is yellow and a recommendation of Good Alternative.
- The final numerical score for Atlantic salmon (*Salmo salar*) farmed in marine net pens in New Brunswick (Canada) is 3.53 out of 10. With three red criteria (Chemical Use, Escapes and Disease), the final rating is red and a recommendation of Avoid.

- The final numerical score for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Newfoundland (Canada) is 3.78 out of 10. With three red criteria (Chemical Use, Escapes and Disease), the final rating is red and a recommendation of Avoid.
- The final numerical score for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Nova Scotia (Canada) is 4.96 out of 10. With no red criteria, the final rating is yellow and a recommendation of Good Alternative.

Executive Summary

Annual farmed salmon production in Atlantic North America has fluctuated around 70,000 mt in recent years and was estimated to be 67,741 mt in 2018 (the latest FAO data available). Of this 2018 total, approximately 51,634 mt (76%) was produced in Atlantic Canada, and the remaining 16,107 mt was produced in the US (Maine, 24%). In Atlantic Canada, the industry is concentrated in New Brunswick (28,289 mt in 2018), with a smaller scale of production in Newfoundland and Labrador (14,167 mt in 2018), and Nova Scotia (7,361 mt in 2018). Salmon harvested in Maine are largely considered to remain in the US, and approximately 23,000 mt was exported to the US from the three East Canadian provinces in 2019.

This Seafood Watch assessment involves criteria covering impacts associated with effluent, habitats, wildlife mortalities, chemical use, feed production, escapes, introduction of secondary species (other than the farmed species), disease, the source stock, and general data availability[1]. As noted below, the overall data availability in Atlantic North America allows each of the four production regions to be assessed separately here (see Figure 1 for a map).

Atlantic North America does not have the comprehensive publicly available databases for aquaculture data that are available in Norway and Scotland, and within Canada, relevant data are much more readily available for British Columbia compared to the Atlantic provinces. Recent publicly available data are also limited from the industry associations or the government in Maine. Nevertheless, there are many useful sources of data and information, including industry datasets (e.g., sea lice reports for New Brunswick from the Atlantic Canada Fish Farmers Association), Canadian Food Inspection Agency (CFIA) and DFO data (e.g., antimicrobial and pesticide use), provincial data such as seabed monitoring reports (including those provided on request for this assessment), personal communications with industry representatives, and from NGOs. Data relevant to many aspects of this assessment were provided by the region's dominant producer (representing approximately 80% of production) and acknowledged here.

The availability of academic studies relevant to this assessment are variable across subject areas; for example, information on the interactions of escaping farmed salmon with endangered wild salmon populations is much more readily available than the interactions of pathogens or parasites with the same wild fish. Examples from other countries were used with caution when relevant. The regulatory requirements and their differences across federal, provincial, and state organizations are publicly available, but often challenging to interpret in a practical context, particularly as they continue to evolve over time. While there are differences in data availability across different topics between the US and Canada, and between the Canadian provinces, the overall data availability is considered to be moderate to good across all regions and the final numerical score for Criterion 1 – Data is 5.91 out of 10 for Atlantic North America.

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[1] The full Seafood Watch Aquaculture Standard is available at: http://www.seafoodwatch.org/seafood-recommendations/our-standards

Salmon farms discharge large quantities of waste nutrients and depend on coastal waterbodies to assimilate them. While small nutrient increases can be detected at considerable distances from the farm and at the waterbody scale, the potential for soluble nutrients to exceed the local or waterbody carrying capacity is low. Data from benthic monitoring for all regions show high compliance with provincial and federal thresholds, but with significant declines in performance in recent years (e.g., from close to 100% in 2019 to 70% in 2020 – noting that farms not meeting the thresholds, in addition to fallowing, must subsequently demonstrate a return to compliance before receiving approval for continued operation). There is some indication that the monitoring parameters and sampling methods used are not optimal, and comprehensive research from these and other salmon farming regions show farms have a substantial cyclical impact in the immediate farm area during the production-fallow cycle. In Atlantic North America, there continues to be the potential for poorly understood impacts to commercially important lobster that may occur in the immediate area. The proximity of sites indicates a potential for cumulative impacts at the waterbody or regional scale in densely farmed areas such as the Bay of Fundy (which are largely managed collectively in Bay Management Areas), but there is currently no evidence of such cumulative impacts. Given the available body of research and monitoring data, the Evidence-Based Assessment method was used, and overall, there are considered to be frequent yet temporary impacts within the immediate vicinity of the farm, and the final score for the Criterion 2 - Effluent is 4 out of 10 for all regions.

Salmon farm net pens and their supporting infrastructures contribute much physical structure to nearshore habitats and are known to modify the physical environment at the farm location by modifying light penetration, currents, and wave action as well as providing surfaces for the development of rich assemblages that may further increase the complexity of the habitat. An average salmon farm comprises approximately 50,000 m^2 of submerged artificial substrates that can be colonized by a large suite of hard-bottom associated species that may not otherwise find suitable habitat in a given area (e.g., muddy bottoms or in the water column). These additional species may have a variety of direct and cascading effects on the surrounding ecosystem, including inadvertently supporting the persistence and distribution of non-native species. Salmon farms also attract a variety of wild animals as fish aggregation devices or artificial reefs (including predators such as seals that may prey on wild salmon smolts migrating past farms) or may repel other wild animals through disturbance such as noise, lights or increased boat traffic. Changes in behavior of wild fish around fish farms and even of their flesh quality due to the consumption of waste feed have been reported. A key aspect of these potential impacts is their circumstantial variability, their limited study, and the challenge of their quantification, particularly in the context of the more obvious impacts of soluble and particulate effluent wastes (assessed in Criterion 2 - Effluent).

The regulatory systems and their enforcement for siting and licensing are available, including requirements for baseline studies or assessments, but they are often challenging to interpret in a practical context as they evolve across multiple provincial and federal agencies. Their application to impacts other than effluent wastes on the seabed is typically unclear, but the site licensing process and its enforcement are considered to be largely effective. Further, the literature indicates that the realization of any or all of these potential impacts does not significantly impact the functionality of the ecosystems in which farms are sited. More basically, the siting of net pen arrays does not result in habitat conversion in the same way that, for example, pond construction does, and the removal of farm infrastructure would immediately restore all baseline biophysical processes. Overall, (noting that soluble and particulate wastes are addressed in Criterion 2 – Effluent) the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management effectiveness regarding the known impacts of the floating net pens appears moderate. The final score for Criterion 3 – Habitat is of 6.93 out of 10.

Antimicrobial use in Atlantic North America has declined since at least 2012. Data from the dominant producer that operates approximately 80% of active sites in the region (and is the only operator in Nova Scotia and Maine) show the average treatment frequency has been less than 0.5 treatments per site per year since at least 2014. In 2020, with only eight treatments across the four regions, antimicrobial use was 0.12 treatments per site. There have been no antimicrobial treatments in Maine since 2017 and there were none in Nova Scotia in 2020. The highest antimicrobial use has been in New Brunswick, with an average number of treatments per site per year between 2017 and 2020 of 0.33. While the performance of the secondary producer (in New Brunswick and Newfoundland) may differ from these data, it is considered highly likely that the frequency of antimicrobial use is still less than one treatment per site per year in these two regions. The dominant treatments (oxytetracycline and florfenicol) are listed as highly important for human medicine by the World Health Organization, highlighting the importance of continued prudent use.

Accurately describing pesticide use in Atlantic North America is challenged by variable data availability in the most recent years, combined with rapid changes in production practices and pesticide use over the same period. Data from the only producer in two regions show there has been no pesticide use in Maine since 2018 and none in Nova Scotia since at least 2016. In the other two Canadian provinces, New Brunswick and Newfoundland, pesticide use has been high prior to 2018 with multiple treatments per site per year on average. In New Brunswick, pesticide use has been high with multiple treatments per year on average. The dominant producer (operating approximately 80% of active sites in New Brunswick) still uses in-feed treatments at a frequency of <0.7 treatments per year but has almost eliminated bath treatments. Data from DFO indicate there is likely some ongoing use of in-feed and bath treatments by the secondary producer in New Brunswick. In Newfoundland, pesticide use has also been high (half of Newfoundland’s active sites received 10 or more pesticide treatments in 2018). The dominant producer (operating just over half of the sites) has almost eliminated bath treatments and also eliminated in-feed treatments, but the available data indicate there is likely some ongoing use of in-feed and bath treatments by the secondary producer in Newfoundland, although the exact frequency is uncertain.

The impacts on non-target organisms (including commercially important species such as lobster) of in-feed and bath pesticide treatments continue to be challenging to quantify in the field, but are likely to have been considerable, at least in the immediate farm area during periods of high pesticide use. In addition, the known cases of illegal pesticide use and the detections of residues of chemicals not approved for use in Canada remain a concern although they are considered to represent exceptional cases at the typical farm level. The recent rapid decrease in pesticide use limits these concerns (particularly in areas where pesticide use has been minimal or has largely been eliminated in recent years). The previous high levels of pesticide use have also contributed to the resistance to some treatments observed in the region, but while such genetic changes to sea lice populations may linger, the recent decline in chemical use limits further development.

Overall, the data demonstrate that chemical treatments have been consistently used less than once per site per year in both Maine and Nova Scotia; for both of these regions, the final score for Criterion 4 – Chemical Use is 8 out of 10. For New Brunswick and Newfoundland, with minor antimicrobial use, the uncertainly with the ongoing pesticide use by the secondary producer necessitates some precaution. Although the most recent data implies low use by the primary producer, the relatively recent (e.g., 2018) high frequency of use, combined with the data uncertainty particularly for the secondary producer results in a final score for Criterion 4 – Chemical Use of 2 out of 10 for New Brunswick and Newfoundland on a precautionary basis. While the recent rapid decline in chemical use is recognized here, additional data (particularly from DFO and ideally reinstating the publication of frequency values) to confirm the ongoing reduction would be needed to allocate a trend adjustment (see the Seafood Watch Aquaculture Standard for details).

Feed data were provided by the primary producer representing approximately 80% of feed use in the region. Additional data points, where needed, were obtained from reference feeds in the academic literature and salmon farming company reports. While the formulation generated may not be specifically accurate, the key aspects relating to this assessment were considered to be sufficiently robust and representative of the broader region. Using total fishmeal and fish oil inclusions of 7.2% and 11.1% respectively, an eFCR of 1.3, and yield values modified according to the dominant use of Gulf Menhaden, from first principles, 1.13 mt of wild fish must be caught to produce the fish oil needed to grow 1.0 mt of farmed salmon. With 70% of marine feed ingredients sourced from Gulf Menhaden and with an unspecified remainder, the overall sustainability was moderate, and resulted in a Wild Fish Use score of 5.50 out of 10. There is a substantial net loss of 63.8% of feed protein (score 3 out of 10) and a low feed ingredient footprint of 13.13 kg CO_2-eq. per kg of harvested protein (score of 7 out of 10). Overall, the three factors combine to result in a final feed score for Criterion 5 – Feed of 5.25 out of 10.

Best management practices to prevent escapes, such as Codes of Containment, are in place in every region in Atlantic North America and they have been effective in reducing the number of escapes over time. However, net pen systems are inherently vulnerable to both large-scale and small-scale fish escapes, and data show that escapes do still occur in the Atlantic North American industry, albeit with regional variation. Farms in Maine have not reported an escape since 2003, and farms in Nova Scotia have reported only 44 escaped fish in the past ten years. New Brunswick and Newfoundland have each reported many thousands of escaped fish over this time period. Escapees have been shown to disperse rapidly and recapture at sea is unlikely, but a second recapture opportunity occurs in rivers. The number of escaped fish entering rivers in the four regions is highly variable by river and by year, and while fish traps in some rivers allow the recapture and removal of (potentially all) escapees, the extent of their presence and operation across all rivers in the region is not known.

Although the industry in Atlantic North America has largely relied on local broodstocks, farmed Atlantic salmon are genetically distinct from their wild counterparts. Hybridization between escaped and wild salmon and genetic introgression have been demonstrated, particularly after a large escape of mature fish in Newfoundland. While the presence of hybrid offspring declines rapidly, determining the longevity of the introgression and quantifying the impact to affected populations remain challenging. Wild salmon populations in the North Atlantic have been in long-term decline (for many decades prior to salmon farming's introduction) and continue to decline in areas with and without salmon farms; nevertheless, several wild salmon populations in the vicinity of the salmon farming industry are of special concern, threatened, or endangered, and any contributions to their further decline or inhibitions of their recovery are a concern.

In Maine, there have been no reported escapes since 2003, very few escaped fish have been detected in rivers, and capture devices in important rivers allow their removal. The production system remains vulnerable, and escapees could potentially enter rivers in areas without recapture devices. The final score for Criterion 6 – Escapes for Maine is 4 out of 10. In New Brunswick, escape numbers have been high and escapees are detected in rivers, and though capture devices in important rivers allow their removal, escapees could enter rivers in areas with vulnerable populations in the Inner Bay of Fundy. The final score for Criterion 6 – Escapes for New Brunswick is 3 out of 10. In Newfoundland, escape numbers have been high and while typical numbers of escapees in rivers are moderate, there are fewer opportunities for recapture and studies of specific escape events have demonstrated genetic introgression in many rivers. The final score for Criterion 6 – Escapes for Newfoundland is 3 out of 10. In Nova Scotia, the number of reported escapes is very low and there have been few escaped fish detected in rivers, but recent and ongoing monitoring appear limited. There are fewer opportunities for recapture in rivers in Nova Scotia and escapees could potentially enter rivers in areas without recapture devices. The final score for Criterion 6 – Escapes for Nova Scotia is 4 out of 10.

Large amounts of research and publicly available fish health and mortality data in other areas (particularly British Columbia and Norway) note the concern regarding the potential transfer of pathogens and parasites from salmon farms to wild salmonids, but there is very little information available in Atlantic North America. While many disease-related management and monitoring measures are in place, few data are available, and the open net pen system remains vulnerable. The ongoing occurrence of mortality events in Atlantic North American farms (as reported by industry media) highlights the likelihood that some diseases occur or are secondary factors in these events. Nevertheless, the potential for salmon farms to act as a reservoir for transmission of pathogens to wild fish (i.e., of types and numbers of pathogens that they wouldn't naturally encounter) remains uncertain. While recent research, particularly in British

Columbia, continues to develop rapidly on many fronts and is making many associations between farm viruses and wild salmon, there have been few robust conclusions on demonstrable impacts.

A similar situation exists for sea lice. Large publicly available datasets from routine monitoring and research in the eastern Atlantic (Norway) and western Canada (British Columbia) demonstrate it is likely that there will be substantial mortality of wild salmon in some areas in some years. The limited available data in Atlantic North America indicate sea lice levels on farms are high in New Brunswick, including in some areas each year during the juvenile salmon outmigration period, but are likely low in Maine and Nova Scotia. Despite the welcome start of (minimal) data publication in Newfoundland, lice levels here remain largely unknown. Atlantic salmon are one of the most susceptible salmonid species to sea lice and sub-lethal impacts and increased risk of predation may also be important.

The analysis here has been limited to a simplistic overview, particularly given the limited data in the region. It highlights the ongoing uncertainty in the potential for wild Atlantic salmon to be infected with pathogens and parasites that they would not naturally experience, the uncertainty in the impact of any such infections, and in the potential cumulative impacts of pathogens and parasites from farms. The applicability of the research in other regions to Atlantic North America is also uncertain. Given the status of wild salmon populations in the Atlantic (see Criterion 6 – Escapes), the uncertainties driven by the lack of data largely define the need for a precautionary approach. For all regions, the potential impacts of viral or bacterial pathogens remains unknown, but in New Brunswick, lice levels on average are often high in at least one BMA each year during out-migration, with likely very high levels in individual farms, and the final score for Criterion 7 – Disease is 0 out of 10. In Newfoundland, lice levels remain largely uncertain and given the established pathogen and parasite transfer risk, the final score for Criterion 7 – Disease is 2 out of 10. For Nova Scotia and Maine, sea lice count data availability is also limited, but when combined with the pesticide use data, they indicate lice levels are low and the simple open nature of the production systems results in a final score for Criterion 7 – Disease of 4 out of 10 (all scores are allocated using the Seafood Watch risk assessment).

All Atlantic salmon raised in the US and Canada are sourced from hatchery-raised broodstock; the industry’s production is considered to be independent of wild fisheries for both broodstock and juveniles. The industry has increasingly used cleaner fish as an alternative to chemical pesticide treatments, which requires a minor use of eggs from wild caught lumpfish (*Cyclopterus lumpus).* This species is listed as threatened by COSEWIC, but the quantities used represent less than 0.15% of the commercial catch and are intended to result in the development of domesticated. In addition, wild-caught wrasse have been used on a small number of sites, but this use is not currently considered to reach the scoring threshold in the Seafood Watch standard (i.e., the reliance of 10% of the region’s farmed salmon production on their capture). Due to the small amounts of wild caught cleaner fish, the final numerical score for Criterion 8X – Source of Stock for all of Atlantic North America is a deduction of 0 out of -10 for all regions.

Regulations and management practices for non-harmful exclusion of wildlife are in place and Canada is amending the Marine Mammal Regulations (effective January 2022) to match those of the US Marine Mammal Protection Act, which prohibits lethal control of marine mammals with the exception of incidences where human safety is endangered (i.e., Nuisance Seal Licenses will no longer be issued in Canada). Although there are no publicly available data with which to confirm the mortality numbers, lethal control is considered to only be used in exceptional cases that would not affect the population status of the affected species (noting that Atlantic Canada continues to have an annual commercial hunt of grey and harp seals). Accidental mortalities (e.g., entanglement) of seals, birds, and large fish (sharks or tuna) cannot be eliminated in the net pen system and without robust data, mortality numbers are unknown. However, with effective deterrents (primarily above- and below-water predator nets), mortality of these species is also considered limited to exceptional circumstances and highly unlikely to affect population health. Without a robust dataset to determine the impact of farm-wildlife interactions, the Risk-Based Assessment method was used, and the final score for Criterion 9X – Wildlife Mortalities for all of Atlantic North America is -2 out of -10.

Data on introductions and transfers from DFO shows there are considerable movements of aquatic organisms, including farmed salmon and cleaner fish, occurring into all Canadian provinces from elsewhere (typically other provinces, but also internationally). There are no data to understand movements into Maine from other regions, so the average of Canadian movements is used as a proxy. Regulations regarding live fish movements in the US and Canada are available, particularly through the US Animal and Plant Health Inspection Service and following the Canadian Code on Introductions and Transfers of Aquatic Organisms (which includes a “parasite or fellow traveler” risk assessment process). The combination of the tank-based hatchery systems (considered the dominant source of live animal movements during the salmon production cycle, including for cleaner fish) and the regulatory requirements (including the Certificate of Fish Health Transfer and associated screening) are considered to offer high biosecurity and reduce the risk that a secondary organism will be unintentionally transported. The recent import of salmon eggs from Iceland to Newfoundland is considered to be minor, and also to come from a relatively biosecure source. Overall, the trans-waterbody movement of animals (of all aquatic species, and therefore including salmon and cleaner fish) is variable across the regions based on DFO movement data, and provide an estimated reliance of 18%, 25%, and 65% of production for New Brunswick, Newfoundland, and Nova Scotia respectively. Maine is considered to have, by proxy, 36% reliance on such movements. All movements originate at typically highly-biosecure facilities. The final numerical deduction for Criterion 10X – Introduction of Secondary Species for New Brunswick is -0.4 out of -10; for Newfoundland is -0.6 out of 10; for Nova Scotia is -1.4 out of 10, and for Maine is -0.8 out of 10.

In summary, as noted above, each of the four production regions are assessed separately here.

- In Maine (US), the direct impacts of the net pen production system are mostly limited to the immediate farm area. Chemical use is very low. There have been no reported escapes since 2003, and very few farmed fish are seen in rivers. Sea lice numbers and mortality of wildlife and are considered to be low. The final numerical score for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Maine (US) is 5.04 out of 10. With no red criteria, the final rating is yellow and a recommendation of Good Alternative.

- In New Brunswick (Canada) the direct impacts of the net pen production system are mostly limited to the immediate farm area. Chemical use to has declined rapidly, but sea lice numbers on farms are occasionally very high, including during parts of the outmigration period for juvenile wild salmon. Reported escapes have been high but declining and affect a small number of farms. Escapees are detected in rivers, but substantial proportions may be trapped and removed. The final numerical score for Atlantic salmon (*Salmo salar*) farmed in marine net pens in New Brunswick (Canada) is 3.53 out of 10. With three red criteria (Chemical Use, Escapes and Disease), the final rating is red and a recommendation of Avoid.
- In Newfoundland (Canada), the direct impacts of the net pen production system are mostly limited to the immediate farm area. Chemical use has declined rapidly, but continues, and there are minimal data available on sea lice numbers on farms. Escapes have been high but declining and affect few sites, but moderate numbers of escapees have been detected in rivers and genetic introgression has been shown to occur following large escapes. The final numerical score for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Newfoundland (Canada) is 3.78 out of 10. With three red criteria (Chemical Use, Escapes and Disease), the final rating is red and a recommendation of Avoid.
- In Nova Scotia (Canada), the direct impacts of the net pen production system are mostly limited to the immediate farm area. Chemical use is very low, and pesticides have not been used since 2014 to control sea lice. The detection of escaped fish in rivers has been low, but there are fewer opportunities to recapture them. The final numerical score for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Nova Scotia (Canada) is 4.96 out of 10. With no red criteria, the final rating is yellow and a recommendation of Good Alternative.

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Introduction

Scope of the analysis and ensuing recommendation

Species: Atlantic salmon (*Salmo salar)*
Geographic coverage: Atlantic North America; United States (Maine) and Atlantic Canada (New Brunswick, Newfoundland and Labrador, Nova Scotia)
Production method: Marine net pens

Species Overview

Atlantic salmon (hereafter, *salmon*) are native to the eastern (European) and western (North American) North Atlantic Ocean. As a primarily anadromous species[2], salmon hatch in freshwater. Juveniles, called 'parr,' remain in freshwater rivers and streams for 1-5 years before undergoing smoltification, a physiological process that prepares them for life in the marine environment. Salmon smolts, typically weighing 20-30 grams (g) in the wild, migrate to the ocean where they remain a pelagic species for up to four years, feeding primarily on smaller fish and squid and achieving most of their lifetime growth. At the onset of maturation, salmon cease feeding and return to the freshwater system in which they hatched to spawn. Spawning salmon are typically 8-13 kilograms (kg) in weight. While most Atlantic salmon die after spawning, a small percentage may return to sea as 'kelts' (NOAA 2015a).

Production System

Domesticated male and female broodstock are individually strip-spawned and their eggs and sperm are mixed for fertilization to occur. It takes approximately 500 degree-days[3] for salmon eggs to hatch, and another 50 degree-days for the yolk sac to be completely absorbed (FAO 2004). In Atlantic North America, juvenile salmon are raised in land-based, freshwater hatcheries until they have smolted and reached 40-120 g in weight—typically 8-16 months post-hatch (FAO 2004). Upon transfer to saltwater net pens, fish are on-grown for approximately two years until they reach their harvest weight of 4-6 kg. This production system is used in both the United States and Canada for production of salmon. The following assessment reflects only the marine net pen growout phase of salmon aquaculture in Atlantic North America, as the hatchery/nursery phase is not considered to be a major source of environmental impacts.

Production Statistics

Salmon farming began in Atlantic Canada in New Brunswick in 1978 with the first harvest in 1979, but it was slow to develop, and harvests did not exceed 5,000 mt until 1990 (Chang et al., 2011; FAO Fishstatj). By the late 1990s, production in other eastern Canadian provinces was

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[2] There are many landlocked resident freshwater populations of Atlantic salmon in Newfoundland, called Ouananiche (https://www.britannica.com/animal/ouananiche)

[3] A measure of fish development attained by calculating the duration of time fish spend in a particular water temperature (i.e., 4 days in 10° C = 40 degree-days)

also developing, but still at a small scale; harvests in Newfoundland and Labrador (hereafter referred to as Newfoundland) were less than 1,000 mt (610 mt in 1997) and had just exceeded 1,000 mt in Nova Scotia (1,100 mt in 1997) (Chang, 1998). In the US state of Maine, the first harvest was recorded in 1986, and exceeded 5,000 mt in 1991 (FAO Fishstatj).

Atlantic salmon are currently farmed in the same four regions of Atlantic North America: the state of Maine in the US and the Canadian provinces of New Brunswick, Nova Scotia, and Newfoundland. The approximate areas are shown in Figure 1.

Figure 1: Approximate map of farming areas in Maine and three Canadian provinces in Atlantic North America (yellow ovals). The size of the yellow ovals relates to the approximate geographic spread of sites, and not the number of sites or the scale of production. Map copied and edited from Google Earth.

Table 1 shows the approximate number of active[4] sites in recent years (note there are additional licensed sites, but not all are active at any one time). In 2020, there were a total of approximately 84 active sites. Production in Atlantic North America is dominated by one company which operates an average of 79% of the active sites in Table 1 (varying from 77% to 82% in the 2014 to 2020 timeframe). A second company operates the remainder. The dominant producer is the sole operator in Nova Scotia and Maine. A third company has recently established sites in Placentia Bay in Newfoundland but does not plan to stock them until spring 2022[5].

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[4] Active sites are those with fish currently in the water. With the potential for sites to have fish in them for short periods (e.g., at the beginning or the end of a year), the figures in Table 1 are considered approximate.

[5] https://www.fishfarmingexpert.com/article/grieg-postpones-first-stocking-in-newfoundland-as-precaution-against-isa/

Table 1: Approximate number of active salmon farming sites in four regions from 2014 to 2020 by region for all companies. Data from J. Wiper, pers. comm. (2021).

	2014	2015	2016	2017	2018	2019	2020
New Brunswick	47	45	43	42	43	43	44
Newfoundland	21	19	17	16	16	16	19
Nova Scotia	10	10	8	9	10	11	9
Maine	13	11	13	13	13	13	12
Total	91	85	81	80	82	83	84

Annual production figures from different sources lack consistency. Data from the UN Food and Agriculture Association (FAO) show annual total production in all regions of Atlantic North America has varied around approximately 50,000 mt in recent years (Figure 2) and was 52,281 mt in 2018 (FAO – 2021 FishstatJ database). Of this 2018 total, 36,174 mt (69%) was produced in Atlantic Canada, and 16,107 mt was produced in the US (Maine, 31%). As discussed below, it is considered here that the FAO figures do not include the production of Newfoundland.

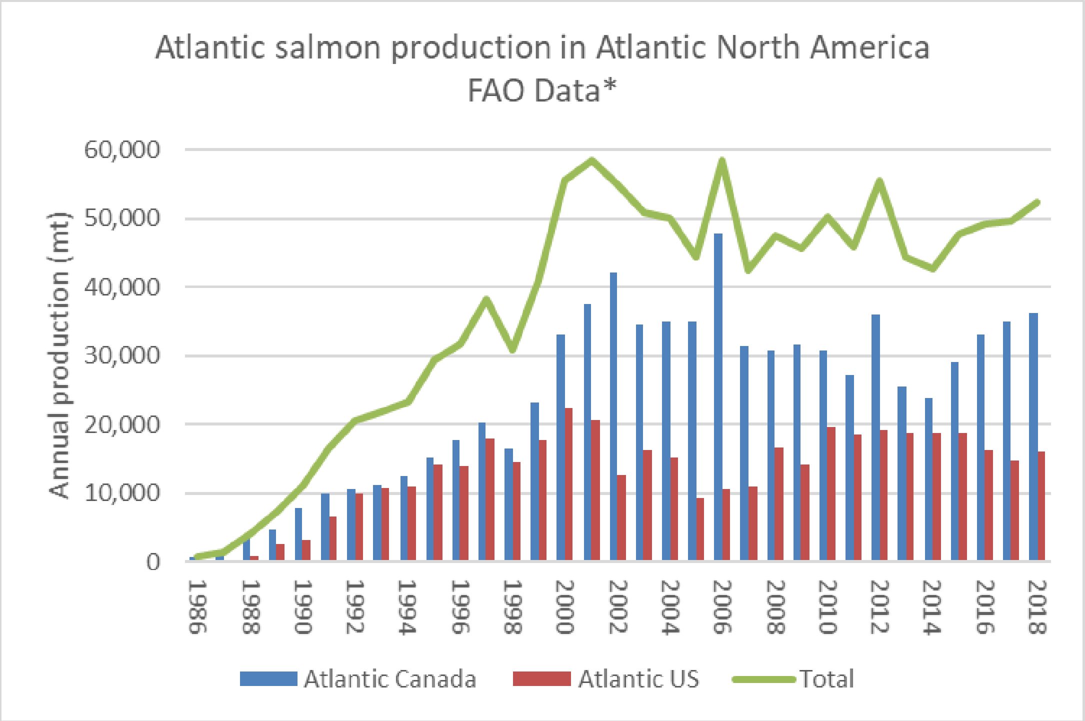

Figure 2: FAO figures for annual production in all regions of Atlantic North America. Data from the FAO FishstatJ 2020 dataset. *Note, it is considered here that these data do not include Newfoundland.

Statistics Canada publishes data on aquaculture production and value by province, with figures for salmon published up to 2019 (as of September 2021); however, this dataset is complicated by the lack of a salmon-specific value for Newfoundland[6]. The figure for total finfish production

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[6] The "Newfoundland Seafood Industry in Review 2019" also publishes figures as "total salmonids", without differentiation between species. https://www.gov.nl.ca/ffa/files/2019-SIYIR-WEB.pdf

must be used instead and is considered a close approximation of salmon production[7], however, due to this differentiation, it appears that Newfoundland farmed salmon production is missing from the Canadian total figures for farmed Atlantic salmon and from the FAO dataset. The Maine Department of Marine Resources does not publish annual farmed salmon production data for confidentiality reasons (due to the single company operating there). Figure 3 shows the available production data for the three Canadian provinces (from Statistics Canada) and for Maine (from FAO).

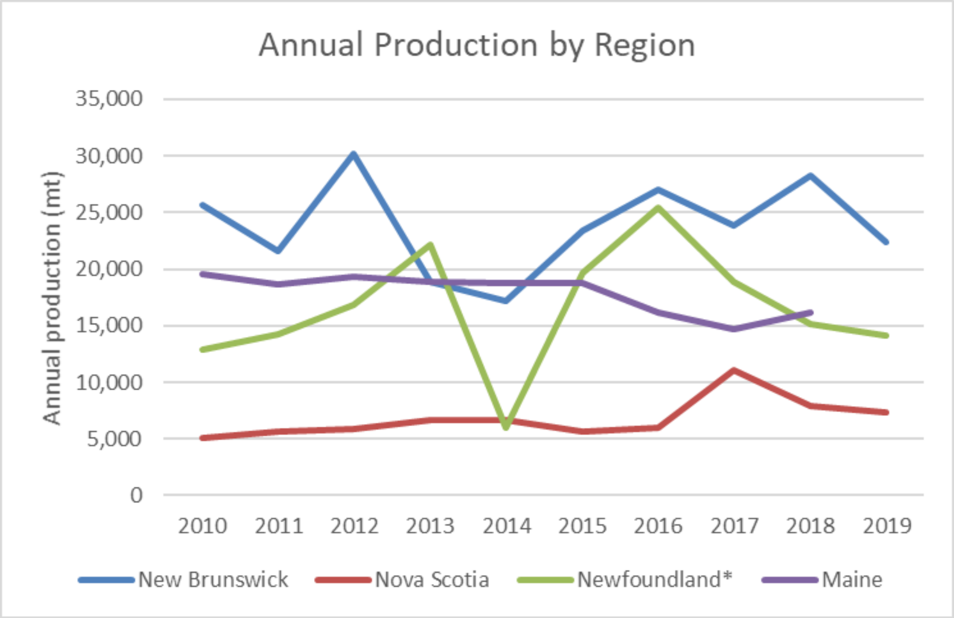

Figure 3: Estimated annual production in the Atlantic North America region using FAO data for Maine and Statistics Canada data for Canadian provinces. *The Canadian figures include the total finfish production figures for Newfoundland on the basis that Atlantic salmon dominates finfish production in the region.

In summary, the total annual production of Atlantic salmon in the Atlantic North America region varies around 70,000 mt (67,388 mt estimated in 2018; 74,607 mt in 2016), with approximately 41% of production in New Brunswick, with 24%, 22% and 12% in Maine, Newfoundland, and Nova Scotia respectively.

Import and Export Sources and Statistics

Atlantic salmon produced in Maine are largely considered to remain in the US, whereas Fisheries and Oceans Canada summary of Canada's seafood trade with the US[8] shows it is an important export market for Canadian farmed salmon, taking 91% by value of all salmon exported from Canada. Fisheries and Oceans Canada (DFO) figures shows the total salmon export from Canada was 86,000 mt in 2019, and Atlantic salmon in turn represent 87% (by value). British Columbia is the source for most exports to the US (63,000 mt in 2019) and New

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[7] There is also a small component of steelhead trout https://www.findnewfoundlandlabrador.com/invest/aquaculture/#:~:text=Newfoundland%20and%20Labrador's%20aquaculture%20industry,water%20ideally%20suited%20for%20aquaculture

[8] https://publications.gc.ca/collections/collection_2021/mpo-dfo/Fs1-91-2019-eng.pdf

Brunswick is the dominant exported on the east coast (14,652 mt in 2019). Exports to the US from Nova Scotia and Newfoundland represented only 4% of the Canadian total in 2019.

Common and Market Names

Scientific Name	*Salmo salar*
Common Name	Atlantic salmon
United States	Atlantic salmon
Spanish	Salmón del Atlántico
French	Saumon de l'Atlantique
Japanese	Taiseiyō sake

Product Forms

Atlantic salmon is available in all common fish presentations, particularly whole fish, fillets, and smoked.

Criterion 1: Data Quality and Availability

Impact, unit of sustainability and principle

- Impact: Poor data quality and availability limits the ability to assess and understand the impacts of aquaculture production. It also does not enable informed choices for seafood purchasers or enable businesses to be held accountable for their impacts.
- Unit of sustainability: The ability to make a robust sustainability assessment.
- Principle: Having robust and up-to-date information on production practices and their impacts available for analysis

Criterion 1 Summary
Maine, US and Atlantic Canada

C1 Data Category	Data Quality
Production	7.5
Management	7.5
Effluent	5.0
Habitat	5.0
Chemical Use	7.5
Feed	5.0
Escapes	7.5
Disease	2.5
Source of stock	7.5
Wildlife mortalities	5.0
Introduction of secondary species	5.0
C1 Data Final Score (0-10)	**5.91**
	Yellow

Brief Summary

Atlantic North America does not have the comprehensive publicly available databases for aquaculture data that are available in Norway and Scotland, and within Canada, relevant data are much more readily available for British Columbia compared to the Atlantic provinces. Recent publicly available data are also limited from the industry associations or the government in Maine. Nevertheless, there are many useful sources of data and information including industry datasets (e.g., sea lice reports for New Brunswick from the Atlantic Canada Fish Farmers Association), Canadian Food Inspection Agency (CFIA) and DFO data (e.g., antimicrobial and pesticide use), provincial data such as seabed monitoring reports (including those provided on request for this assessment), personal communications with industry representatives, and from NGOs. Data relevant to many aspects of this assessment were provided by the region's dominant producer (representing approximately 80% of production) and acknowledged here.

The availability of academic studies relevant to this assessment are variable across subject areas; for example, information on the interactions of escaping farmed salmon with endangered wild salmon populations is much more readily available than the interactions of pathogens or parasites with the same wild fish. Examples from other countries were used with caution when relevant. The regulatory requirements and their differences across federal, provincial, and state organizations are publicly available, but often challenging to interpret in a practical context, particularly as they continue to evolve over time. While there are differences in data availability across different topics between the US and Canada, and between the Canadian provinces, the overall data availability is considered to be moderate to good across all regions and the final numerical score for Criterion 1 – Data is 5.91 out of 10 for Atlantic North America.

Justification of Rating

Industry and Production Statistics

Details regarding the Atlantic North American net pen salmon farming industry, including the size, farm locations, production statistics, export markets, etc., are generally easily accessible, but may be limited in their regional specificity and timeliness (for example, the Maine Department of Marine Resources does not publish production figures for confidentiality reasons and Newfoundland is the only Province in the Statistics Canada[9] dataset that does not report a salmon-specific value). The United Nations Food and Agriculture Organisation (FAO) FishstatJ database can be used to generate annual production figures; however, after analysis here, it appears that the FAO data do not include figures from Newfoundland. The number of active sites in each region was provided by an industry representative, and the Canadian provinces and the State of Maine have mapped databases showing the location, company name and basic license information (e.g., Nova Scotia's site mapping tool[10], and New Brunswick's[11]). Overall, the industry is well understood with respect to the number and distribution of farm sites, but the total and regional production remains unclear. The data score for the independent category of Production Data is 7.5 out of 10.

Management and Regulations

The regulatory system in the Atlantic North America region is complicated by federal and provincial systems in place in the three Canadian provinces and the additional federal and state system in Maine in the US. In contrast, only two large companies are operational with largely consistent (albeit company-specific) management practices across the region. The dominant company provided considerable information on their practices for this assessment. In Canada, the federal Aquaculture Activities Regulations (AAR) came into force in 2015 and details are available on the DFO website[12], but the evolving situation in each province makes a robust understanding of governance challenging. Similarly in Maine, the federal and state regulations are available, but challenging to navigate in a practical context. In Canada, the 2018 Spring Reports of the Commissioner of the Environment and Sustainable Development (Report 1 was on salmon farming[13]) provided a critique of DFO's management and enforcement of regulations

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[9] https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210010701

[10] https://novascotia.ca/fish/aquaculture/site-mapping-tool/

[11] https://www2.gnb.ca/content/gnb/en/departments/10/aquaculture/content/masmp.html

[12] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/aar-raa-eng.htm

[13] https://www.oag-bvg.gc.ca/internet/English/parl_cesd_201804_01_e_42992.html

in the industry (noting some aspects have since been at least partially addressed). Overall, the management and regulatory information for the various regions of Atlantic North America is largely available, even if their evolution is difficult to interpret from a practical perspective in current production. The data score for management and regulations is 7.5 out of 10.

Effluent

There is no regulatory requirement for monitoring of soluble effluent in Atlantic North America, and therefore no specific data, but there is a substantial body of relevant literature from these and other regions that can be used to draw robust conclusions. For seabed benthic monitoring, the regulatory requirements at the provincial and federal level are largely available (e.g., the Canadian federal Aquaculture Activities Regulations and the provincial Environmental Monitoring Programs and associated sampling protocols), but some confusion remains in their specific regional application and consistency of interpretation. Publicly available benthic monitoring data from recent years is only publicly available from Nova Scotia[14] (for example the Maine Department of Marine Resources only publishes data up to 2008, and from New Brunswick Department of Environment and Local Government up to 2014[15]). New Brunswick provided additional data up to and including 2020 for this assessment. The industry's largest producer also provided aggregated results from 2009 to 2019 for all regions. There is also a substantial body of academic literature on salmon net pen benthic or other effluent impacts in Atlantic North America (e.g., Hamoutene et al., 2018; McIver et al., 2018, Howarth et al., 2019; Verhoeven et al., 2018; Chang et al., 2011). In addition, international studies such as Price et al. 2015, Keeley et al. 2015) and key studies from other regions (e.g., Grefsrud et al., 2021a,b, from Norway, and Tett et al., 2018 from Scotland) can be carefully used to make comparisons. Effluent impacts to specific species such as lobsters in Atlantic North America have been reviewed by Milewski et al. (2021). While information on the coordinated management of the industry in Aquaculture Bay Management Areas is available, there is little information with which to robustly quantify the risk of cumulative impacts at the waterbody level. Overall, the partial data availability and substantial body of research provide a good but at times limited understanding of the impacts and/or the risks of impacts of soluble and particulate effluent wastes, and the data score is 5 out of 10.

Habitat

Locational data available for all regions in addition to readily available satellite images allows a simple overview of salmon farm locations and habitats, but there are few specific data on the impacts of the infrastructure or their operation (other than the discharge of nutrient wastes addressed in Criterion 2 – Effluent). The review of McKindsey (2011) provides a useful list of potential impacts associated with the infrastructure, and other academic studies provide additional information on the attraction or repulsion of wildlife, hydrodynamics, and other operational activities such as the use of submerged lights. In general, these potential impacts

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[14] https://data.novascotia.ca/

[15] https://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/water/content/marine_aquaculture.html

have been poorly studied and are difficult to quantify. Regulatory information on siting and leasing, including requirements for baseline surveys, are available in all regions, but the differences across federal and provincial or state organizations are challenging to interpret on a practical basis. The data score for the habitat impacts of the floating net pen farming system is 5 out of 10.

Chemical Use

DFO publishes (through Open Canada) annual data for each Canadian site by province from 2016 to 2019 (as of September 2021) showing the annual number of treatments and the annual quantity of each type of antimicrobial used. In addition, the largest producer in the region provided data in the same categories (plus the relative use in grams active ingredient per mt of production), for the three Canadian provinces and Maine, from 2014 to 2019 (J. Wiper, pers. comm., 2020). Therefore, the DFO data set covers all Canadian producers but is limited in temporal coverage (to 2018) and does not include Maine, whereas the company dataset is available to 2019 and includes Maine, but is limited by the exclusion of the second operating salmon farming company. Given the rapidly changing chemical use practices, these characteristics resulted in some data gaps, but the differences were minimized by selective analysis and comparison where possible. Comparisons were made to data on antimicrobial use in other regions (as referenced in Criterion 4). The 2018 Spring Report noted that DFO did not validate self-reported chemical use information and had not determined how it could do this. Therefore, the data used in this assessment obtained either from DFO or directly from industry are taken at face value but cannot be independently verified. Monitoring results from the Canadian Food Inspection Agency (CFIA) Therapeutant Residue Non-compliance Testing Program were obtained from CFIA (in 2019 and 2020)[16], and notices of violations of the Pest Control Products Act are available from Health Canada[17]. Other examples of illegal chemical use are available from general media (e.g., Smith, 2018).

A separate analysis of US chemical use in salmon farming was available in Love et al. (2020), and information on resistance and potential impacts are primarily available from earlier academic studies (Burridge & Van Geest, 2014; Jones et al., 2012; ACFFA, 2010, 2014b; Jones et al., 2013; Igboeli et al., 2012, 2013). Background information on antifoulant use is available in Bloecher and Floerl (2020) and elaborated by regional specific information from the primary producer (J. Wiper, pers. comm., 2020). While there are some limitations in the data, there are sufficient to provide a clear understanding of the chemical use in Atlantic North America, and the data score for chemical use is 7.5 out of 10.

Feed

Data on key feed details (specific values and sources of fishmeal and fish oil, but general ingredient group values for crop and land animal ingredients) were provided by the primary

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[16] Obtained by ATIP: Access to Information and Privacy (https://atip-aiprp.apps.gc.ca/atip/welcome.do). Reference numbers A-2019-00072 and A-2020-00203.

[17] https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/public/protecting-your-health-environment/compliance-enforcement/enforcement-bulletins.html

producer, representing approximately 80% of feed use in the region. Additional data were required to generate an approximate complete feed formulation and were obtained from company annual reports and the Mowi industry handbook[18], and from the specific ingredients in each category from the reference diets of Mørkøre et al. (2020) and Aas et al. (2019). As such a best-fit feed composition was created that is considered to adequately represent the Atlantic North America feeds for the purposes of this assessment. Fish meal and oil yield values from the primary source fishery species were obtained from Parker and Tyedmers (2012). The Global Feed Lifecycle Initiative (GFLI) database was used for the feed footprint calculations. With requirement to estimate several feed data values required for the assessment (as described above), the data score for Feed is 5 out of 10.

Escapes

Escape reporting requirements vary by region in Atlantic North America (Keyser et al., 2018). Data on the reported numbers of escapes are available from DFO for the Canadian provinces (to 2017 only, accessed September 2021) and from the Maine Department of Marine Resources (DMR). The DMR website reporting does not have a 'last-updated' publication date, and therefore searches for media stories on escapes or newsfeeds from organizations such as the Atlantic Salmon Federation[19] are needed to validate these data sets and to extend them to the present day. Limitations in the escapes reporting requirements mean that confidence in these escapes data is somewhat limited. Regulations and containment codes of practice were available from similar sources (e.g., Newfoundland[20] and Nova Scotia[21]. Older escape data were available from the compilation of Morris et al. (2008). Minimal official data on recaptures are available, but Keyser et al. (2018) reviewed the captures of escaped fish in each region. In addition, specific data are also available, e.g., the numbers of farm-origin fish returning to Maine rivers was obtained from reports of the US Atlantic Salmon Assessment Committee, and those for the Magaguadavic River in New Brunswick were obtained from the Atlantic Salmon Federation (ASF). Evidence of genetic introgression was available from several recent studies (e.g., Wring et al., 2018; Sylvester et al., 2019, 2018; Bradbury et al., 2020), and the status of wild salmon populations were available from the ASF and the International Council for the Exploration of the Seas (ICES). Overall, there is a large amount of information and data on various aspects associated with aquaculture escapes and their interactions with wild salmon; nevertheless, it remains challenging to robustly quantify the scale of any impacts and therefore to determine the appropriate level of concern. The data score for escapes is therefore 7.5 out of 10.

Disease

The Canadian Food Inspection Agency (CFIA) provides information on the low number of federally reportable diseases in Canada[22] and annual records of their presence in all Canadian

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[18] https://mowi.com/investors/resources/

[19] https://www.asf.ca/news-and-magazine/salmon-news

[20] https://www.gov.nl.ca/ffa/files/Salmonid-Code-of-Containment-Updated-March-2020.pdf

[21] https://novascotia.ca/just/regulations/regs/fcraquamgmt.htm#TOC2_7

[22] https://inspection.canada.ca/animal-health/aquatic-animals/diseases/reportable-diseases/federally-reportable-aquatic-animal-diseases/eng/1339174937153/1339175227861

provinces. In the US, the Animal and Plant Health Inspection Service (APHIS) of the US Department of Agriculture also runs a sampling program for the Infectious Salmon Anemia (ISA) virus. Chemical treatment data also provided some indications of disease and parasite prevalence for the dominant producer. Nevertheless, there are very few data available on pathogen detections on farms, mortality rates, carcass classifications or other data available in other regions. Recent academic studies highlight the potential for salmon farms to act as reservoirs for potentially poorly studied pathogens (e.g., Di Cicco et al., 2018; Kent, 2011; Shea et al., 2020, Bateman et al., 2021). Teffer et al. (2020) provided the first quantitative molecular screening of dozens of infectious agents in wild and escaped Atlantic salmon but noted that our understanding of the mechanisms and frequency of infectious agent transmission among wild fishes is still in its infancy. Studies in other salmon farming regions are useful in giving some indication of the appropriate level of concern (e.g., Madhun et al., 2021; Grefsrud et al., 2021a,b; Wallace et al., 2017) while others (or the same) also highlight the uncertainties in farm-wild pathogen interactions (e.g., Sommerset et al., 2021; Kibenge, 2019; Grefsrud et al., 2021a,b). Nevertheless, their applicability to the northwest Atlantic is uncertain. With regard to sea lice, the Atlantic Canada Fish Farmers Association (ACCFA) publish annual sea lice reports for New Brunswick[23], including aggregated data for each Bay Management Area (BMA). The Newfoundland Aquaculture Industry Association (NAIA) began publishing minimal provincially-aggregated monthly sea lice count data in May 2021, and the single producer in Maine and Nova Scotia provided one year of similar data for 2020 (J. Wiper, pers. comm., 2021). Unlike other regions, there is no monitoring of sea lice on juvenile wild salmon. Overall, the data are very limited and the score for Disease is 2.5 out of 10.

Source of Stock

It is well-known that commercial salmon aquaculture (as opposed to salmon hatcheries for wild stock supplementation) is sustained by broodstock that are several generations domesticated, and production is entirely independent of the need to source wild fish. A DNA traceability system, Offspring™, was developed specifically for use by the main producer in the Atlantic North American industry, and a document was provided that summarizes the program's structure and status. Glebe (1998) also provides a historical review of Canada's east coast salmon aquaculture breeding programs, demonstrating a long-term reliance on hatchery-raised domesticated fish. The use of cleaner fish is increasing, and specific information on their sourcing is limited, but the Environmental Preview Report for a proposed hatchery in Newfoundland[24] reviewed the relevant background information, including the fishery sources, and COSEWIC[25] provides information on the status of the species and their fisheries. In combination, the data score for Source of Stock is 7.5 out of 10.

Wildlife Mortalities

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[23] https://www.atlanticfishfarmers.com/sea-lice-reports

[24] https://www.gov.nl.ca/ecc/files/env-assessment-projects-y2020-2062-EPR.pdf

[25] https://wildlife-species.canada.ca/species-risk-registry/species/speciesDetails_e.cfm?sid=1365

Information on marine mammal regulations In the Atlantic Canadian provinces are available from DFO[26], and marine mammal predator control is governed nationally by the Marine Mammal Regulations under the Fisheries Act. In Maine, lethal control measures of marine mammals are prohibited in the US by the Marine Mammal Protection Act of 1972 (MMPA) (NOAA 2007). There are few data available on mortality numbers, but indirect data from harbor seal stock assessments (NOAA, 2020) and the 2018 Spring Report on salmon farming support the conclusion that mortality numbers are low. Stock assessments are available for key species of seals, and previous data provided by industry for 2013 indicate that other species that may be impacted. Overall, there is sufficient regulatory evidence to give confidence that mortalities are limited to exceptional cases, but without specific data, the data score for Wildlife Mortalities is 5 out of 10.

Introduction of Secondary Species

In Canada, the National Code on Introductions and Transfers of Aquatic Organisms[27] guides Introductions and Transfers Committees with the assessments of proposals to move aquatic organisms from one body of water or rearing facility to another. It includes a list of relevant authorities and the associated legislation. The CFIA provides aggregate data on all intentional movements of aquatic animals into Canadian provinces[28], and although the data do not allow a specific assessment of a single species such as Atlantic salmon, they allow an approximation to be made. Similar data for Maine did were not readily available. The CFIA is also the federal lead for the delivery of the National Aquatic Animal Health Program (NAAHP), which outlines biosecurity procedures and the Pan-Atlantic finfish policy called the Certificate of Health for Transfer (COHFT). Similar information on movement requirements is available from the US Animal and Plant Health Inspection Service[29]. With limited practical data on fish movements across the industry, the data score for the Introduction of Secondary Species is 5 out of 10.

Conclusions and Final Score

Atlantic North America does not have the comprehensive publicly available databases for aquaculture data that are available in Norway and Scotland, and within Canada, relevant data are much more readily available for British Columbia compared to the Atlantic provinces. Recent publicly available data are also limited from the industry associations or the government in Maine. Nevertheless, there are many useful sources of data and information including industry datasets (e.g., sea lice reports for New Brunswick from the Atlantic Canada Fish Farmers Association), Canadian Food Inspection Agency (CFIA) and DFO data (e.g., antimicrobial and pesticide use), provincial data such as seabed monitoring reports (including those provided on request for this assessment), personal communications with industry representatives, and from NGOs. Data relevant to many aspects of this assessment were provided by the region's dominant producer (representing approximately 80% of production) and acknowledged here. No specific feed data were available.

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[26] https://www.dfo-mpo.gc.ca/aquaculture/protect-protege/removal-fish-retraits-poissons-eng.html

[27] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/it-code-eng.htm#7

[28] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/rep-rap-eng.htm

[29] https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/monitoring-and-surveillance/sa_nahss/animal-health-monitoring-and-surveillance

The availability of academic studies relevant to this assessment are variable across subject areas; for example, information on the interactions of escaping farmed salmon with endangered wild salmon populations is much more readily available than the interactions of pathogens or parasites with the same wild fish. Examples from other countries were used with caution when relevant. The regulatory requirements and their differences across federal, provincial, and state organizations are publicly available, but often challenging to interpret in a practical context, particularly as they continue to evolve over time. While there are differences in data availability across different topics between the US and Canada, and between the Canadian provinces, the overall data availability is considered to be moderate to good across all regions and the final numerical score for Criterion 1 – Data is 5.91 out of 10 for Atlantic North America.

Criterion 2: Effluent

Impact, unit of sustainability and principle

- Impact: Aquaculture species, production systems and management methods vary in the amount of waste produced per unit of production. The combined discharge of farms, groups of farms or industries contribute to local and regional nutrient loads.
- Unit of sustainability: The carrying or assimilative capacity of the local and regional receiving waters.
- Principle: Not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level.

Criterion 2 Summary

Maine, New Brunswick, Newfoundland, Nova Scotia

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0-10)	**4**	Yellow

Brief Summary

Salmon farms discharge large quantities of waste nutrients and depend on coastal waterbodies to assimilate them. While small nutrient increases can be detected at considerable distances from the farm and at the waterbody scale, the potential for soluble nutrients to exceed the local or waterbody carrying capacity is low. Data from benthic monitoring for all regions show high compliance with provincial and federal thresholds, but with significant declines in performance in recent years (e.g., from close to 100% in 2019 to 70% in 2020 – noting that farms not meeting the thresholds, in addition to fallowing, must subsequently demonstrate a return to compliance before receiving approval for continued operation). There is some indication that the monitoring parameters and sampling methods used are not optimal, and comprehensive research from these and other salmon farming regions show farms have a substantial cyclical impact in the immediate farm area during the production-fallow cycle. In Atlantic North America, there continues to be the potential for poorly understood impacts to commercially important lobster that may occur in the immediate area. The proximity of sites indicates a potential for cumulative impacts at the waterbody or regional scale in densely farmed areas such as the Bay of Fundy (which are largely managed collectively in Bay Management Areas), but there is currently no evidence of such cumulative impacts. Given the available body of research and monitoring data, the Evidence-Based Assessment method was used, and overall, there are considered to be frequent yet temporary impacts within the immediate vicinity of the farm, and the final score for the Criterion 2 - Effluent is 4 out of 10 for all regions.

Justification of Rating

Salmon excrete both soluble and particulate wastes primarily as a result of incomplete digestion and absorption of their feeds, and salmon net pen aquaculture represents a substantial release of nutrients and particulate matter into the environment in which farms are sited. These discharges are in addition to anthropogenic nutrients released into coastal waters by populations (sewage), industry, and agriculture (Grefsrud et al., 2021a,b).

The assessment below is separated into soluble effluents (and their impacts in the water column) and particulate wastes (and their impacts on the seabed), but it is important to note that these impacts are connected; that is, increased production of phytoplankton and zooplankton in the water column also leads to increased settlement of organic material to the seabed (with consequences for bottom water oxygen concentrations and effects on animal communities in the sediments). Also, the breakdown and resuspension of concentrated wastes on the seabed below net pens returns nutrients to the water column and/or results in resettlement in distant locations (Grefsrud et al., 2021a,b).

Soluble effluent

The potential impacts of soluble nutrient releases from fish excretion such as increased phytoplankton production vary primarily by location (for example, in enclosed or semi-enclosed waterbodies verses open coasts) and the intensity of production (Grefsrud et al., 2021a,b; Hoddevik, 2019). There is no legal requirement for routine monitoring of soluble effluent from marine net pen fish farms in the US or Canada, but there is now a rich literature (partly from Canada, but also from other countries that have more extensive monitoring and research) with which to robustly reflect on the likely impacts in Atlantic North America.

At the site level, Brooks and Mahnken (2003) showed that “in no case was dissolved inorganic nitrogen significantly increased at >30 m down current when compared to up current reference”. Howarth et al. (2019) noted increases in dissolved nitrogen are likely to be small, short lived, and difficult to detect as they are dispersed, assimilated by marine organisms and lost to the atmosphere through volatilization. Previous research in Newfoundland found no differences in water column quality near salmon farms, and in both Blue Hill Bay, Maine and three bays in New Brunswick, no near-field or far-field increases in chlorophyll were found (Tlusty et al., 2005; Sowles, 2005; Harrison et al., 2005).

Despite this, previous research in New Brunswick to quantify nutrient fluxes demonstrated that the salmon aquaculture industry is cumulatively the largest source of “anthropogenic waste” (i.e., carbon, nitrogen, and phosphorus) in the region (Strain and Hargrave, 2005). This is supported by recent research in Norway (where annual production is approximately 1.3 million mt of farmed salmon compared to 50,000 mt in Atlantic North America), which shows aquaculture is the major source of anthropogenic soluble nutrients to coastal waters along the large majority of the coast (Grefsrud et al., 2021a,b).

Yet the nutrients from salmon farming at the coastal scale are typically minor compared to those delivered by oceanographic processes such as upwelling, and extending the Norwegian example, the increase in phytoplankton production due to nutrient emissions from fish farming varies from 1.0% to 17.7% across Norway’s 13 production regions (Grefsrud et al., 2021a,b), which is well below the 50% increase classified as eutrophication by Svasand et al. (2017)

referencing OSPAR (2010). Even in the densest farming region in Norway (the Hardangerfjord, where a single fjord produces more than all four regions of the industry in Atlantic North America combined), the in-situ measurements of phytoplankton show "very good" to "good" environmental condition at all monitoring stations, and there is a low risk of environmental effects as a result of increased nutrient supply from aquaculture (Grefsrud et al., 2021a, Husa et al., 2014).

In Atlantic North America, studies have shown similar increases at the bay scale; for example, Howarth et al. (2019) detected changes in nutrient ratios in macroalgae distant from farm sites, including at Port Mouton in Nova Scotia (which has received considerable study), and while excess nitrogen input has been apparent, the finfish aquaculture in Port Mouton Bay[30], when in operation, was estimated to increase anthropogenic nitrogen loading by only 14% (McIver et al. 2018; Nagel et al. 2018). Similarly, Murphy et al. (2019) and Nagel et al. (2018) studied nutrient impacts to seagrass beds in Nova Scotia, and while 64% of the 21 bays studied were at risk of seagrass decline based on nitrogen loading rates, only two bays had aquaculture facilities (one of which was Port Mouton). In Port Mouton, these studies indicated aquaculture (and fish processing) contributed approximately 20% of the total nitrogen input, but it must be noted that the farm in Port Mouton was in poor location with a very shallow water depth of only 10-12 m (McIver et al.,2018) and according to benthic monitoring results (discussed below), the site has not been in operation since 2015.

More generally, the review by Price et al. (2015) concluded modern operating conditions have minimized impacts of individual fish farms on marine water quality; effects on dissolved oxygen and turbidity have been largely eliminated through better management, and near-field nutrient enrichment of the water column is usually not detectable beyond 100 m of the farm (when formulated feeds are used, feed waste is minimized, and farms are properly sited in deep waters with flushing currents). However, when sited nearshore, extra care should be taken to manage farm location, size, biomass, feeding protocols, orientation with respect to prevailing currents, and water depth to minimize near- and far-field impacts, and Price et al. caution that regardless of location, other environmental risks may still face this industry; for example, significant questions remain about the additive (i.e., cumulative) impacts of discharge from multiple, proximal farms, potentially leading to increased primary production and eutrophication.

Overall, although site sizes have increased, better site selection and modern operating conditions (e.g., farms sited in non-depositional locations and advanced feeding strategies) have reduced the concern for soluble nutrients discharged from farms to significantly impact the ecosystems which receive them. Very near-field nutrient elevations may be present, and the distance to the limit of detection (in the water column or after uptake by macroalgae) can be considerable for which there is some concern for the cumulative discharge from multiple,

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[30] The farm in Port Mouton has predominantly produced rainbow trout but is considered here due to the similar nutrient outputs (noting trout typically have a high eFCR and higher relative waste production)

closely sited farms, but overall, the comprehensive research indicates that soluble nutrient effluent from salmon farms in Atlantic North America are not a high concern.

Benthic impacts

Intensive fish farming activities generate a localized gradient of organic enrichment in the underlying and adjacent sediments as a result of settling particulate wastes (primarily feces), which strongly influences the abundance and diversity of infaunal communities. While the settlement (or dispersal) characteristics of particulate wastes have been well-studied (e.g., Verhoeven et al., 2018), they remain complex, with the localized deposition and decomposition varying greatly by site according to characteristics such as depth, current speed, and seabed type (Keeley et al., 2020, 2019, 2015, 2014).

Provincial benthic monitoring programs have been in existence since 1989/90, and continue in Nova Scotia and New Brunswick, in addition to meeting the national DFO requirements under the Aquaculture Activities Regulations established in 2015[31]. In Maine, benthic monitoring is also required, and the protocols that were initially based on the recommendations of Wildish et al. (1999) were updated in 2015 to those developed by the US Environmental Protection Agency (J. Wiper, pers. comm., 2020). While the programs vary in detail, they all include core similarities such as monitoring targeted at peak biomass and peak feeding, separate methods for soft and hard seabeds, and common indicators of impact (including visual presence of indicator organisms and bacterial mats in visual video surveys of hard bottoms, and redox, sulfide and organic matter for soft seabeds). The Department of Fisheries and Aquaculture in Nova Scotia provides a readily accessible example with its Standard Operating Procedures for Environmental Monitoring of Marine Aquaculture Sites in Nova Scotia (June 2020)[32], and Table 2 shows the environmental quality definitions. A similar example is available from the New Brunswick Department of Environment and Local Government[33].

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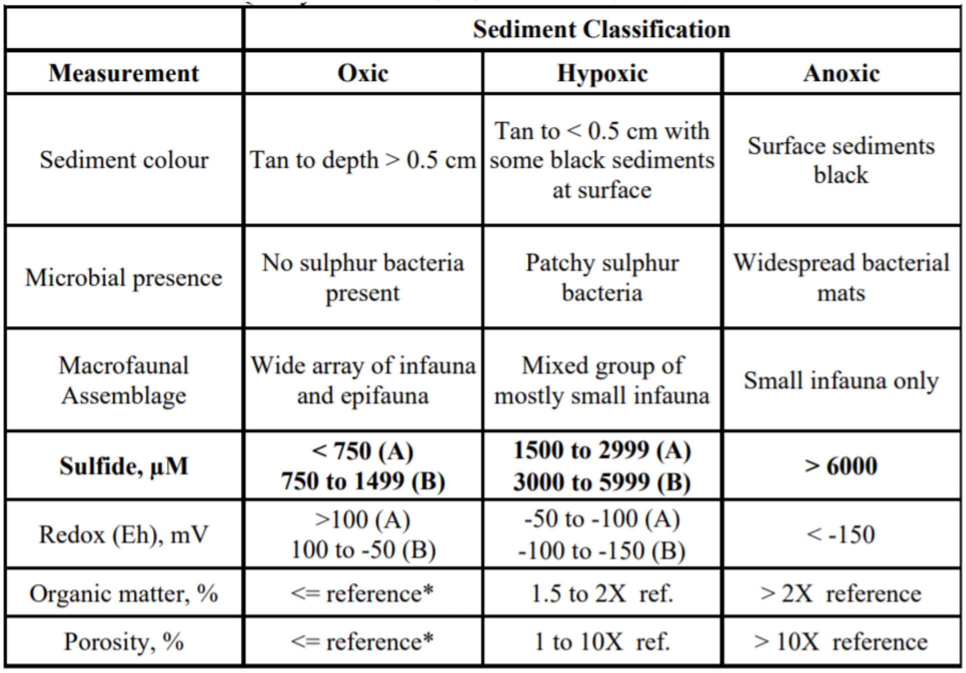
[31] A version updated October 5, 2020 is available here: https://laws.justice.gc.ca/PDF/SOR-2015-177.pdf

[32] https://novascotia.ca/fish/aquaculture/aquaculture-management/

[33] https://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/water/content/marine_aquaculture.html

Table 2: Environmental quality definitions from the 2020 Environmental Monitoring Program Framework for Marine Aquaculture in Nova Scotia. Note sulfide is highlighted as the primary indicator.



	Sediment Classification		
Measurement	**Oxic**	**Hypoxic**	**Anoxic**
Sediment colour	Tan to depth > 0.5 cm	Tan to < 0.5 cm with some black sediments at surface	Surface sediments black
Microbial presence	No sulphur bacteria present	Patchy sulphur bacteria	Widespread bacterial mats
Macrofaunal Assemblage	Wide array of infauna and epifauna	Mixed group of mostly small infauna	Small infauna only
Sulfide, µM	**< 750 (A) 750 to 1499 (B)**	**1500 to 2999 (A) 3000 to 5999 (B)**	**> 6000**
Redox (Eh), mV	>100 (A) 100 to -50 (B)	-50 to -100 (A) -100 to -150 (B)	< -150
Organic matter, %	<= reference*	1.5 to 2X ref.	> 2X reference
Porosity, %	<= reference*	1 to 10X ref.	> 10X reference

With the focus on sulfide (for soft bottom sites), and with relevance to the analyses below, further details are provided here on the sulfide levels from the Nova Scotia Environmental Monitoring Program.

- Oxic A <750 µM and Oxic B 750 – 1,499 µM: Sites classified as Oxic A or Oxic B are considered to have low environmental effects on the marine sediments.
- Hypoxic A 1,500 – 2,999 µM: Sites classified as Hypoxic A may be causing adverse environmental effects on marine sediments.
- Hypoxic B 3,000 – 5,999 µM: Sites classified as Hypoxic B are likely causing adverse environmental effects on the marine sediments.
- Anoxic ≥ 6,000 µM: Sites classified as Anoxic are considered to be causing adverse environmental effects on the surrounding marine sediments.

Publicly available monitoring data are only provided for recent years by Nova Scotia[34]. The New Brunswick Department of Environment and Local Government has data to 2014 available publicly[35], but provided data up to 2020 on request for this assessment. In addition, aggregated data for all regions have been provided for this assessment by the industry (J. Wiper pers. comm., 2020). Examples of recent benthic monitoring reports from each region were also provided by the same industry representative.

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[34] https://data.novascotia.ca/

[35] https://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/water/content/marine_aquaculture.htm

The benthic data from Nova Scotia and New Brunswick, averaged over all sampled sites in each province, are shown in Figures 4 and 5 respectively. Due to different reporting methods, the data for Nova Scotia are presented as annual indicator values (for which environmental quality thresholds are provided in Table 2) and as percentages of sites per environmental quality category for New Brunswick.

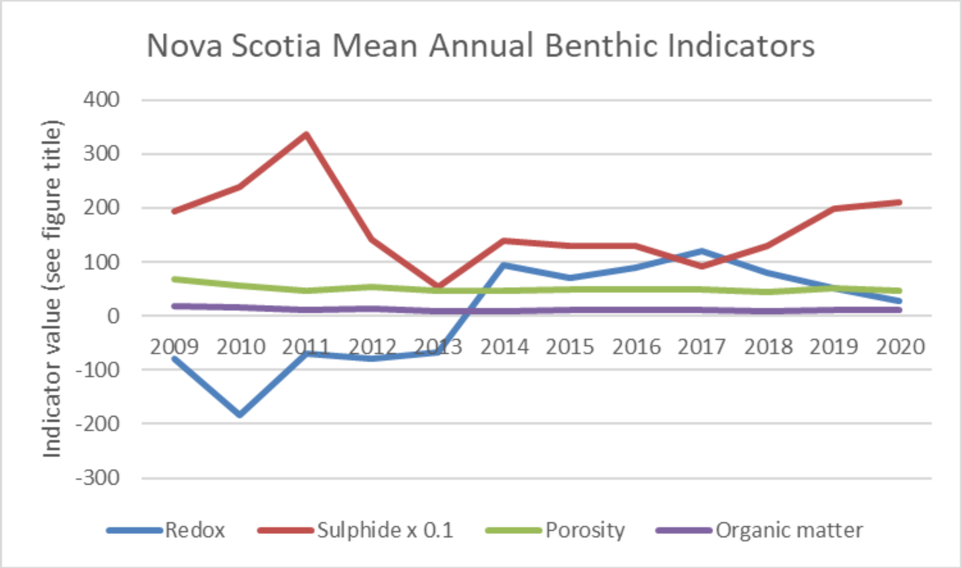

Figure 4: Temporal analysis of Nova Scotia benthic monitoring data from 2009 to 2020. Values are means of all samples from all sites each year (not including reference samples). Indicator units are redox (mVNHE), sulfide (µM) (note values for sulfides are divided by 10, for example, the peak value in 2011 is 3,360 µM), porosity (%)[36], organic matter (%). The relevant environmental quality classifications are shown in Table 2. Data from Nova Scotia Environmental Monitoring program.

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[36] According to the Nova Scotia Environmental Monitoring Program, Porosity is the percentage (%) of pore volume or void space, or the volume within any material (e.g., bottom sediment) that can contain fluids. Porosity is an indirect measure of grain size and is used to detect changes in sediment consistency which may result from sedimentation of feces and excess feed.

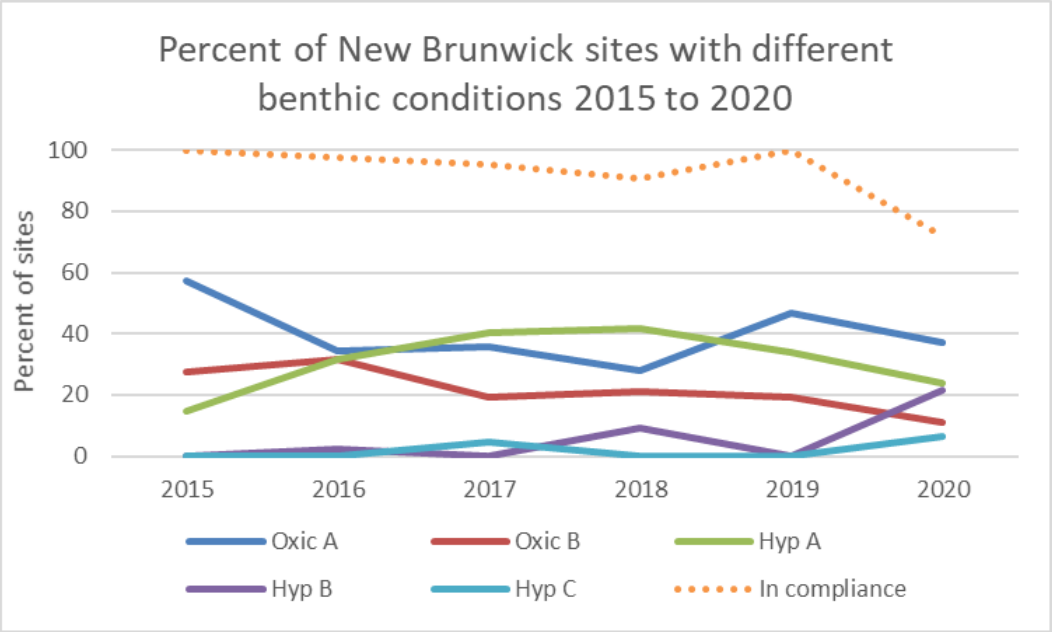

Figure 5: New Brunswick benthic monitoring results showing the percentage of sampled sites in each of five environmental quality categories (of which the New Brunswick categories are similar to those of Nova Scotia in Table 2), and the percentage of sites that are compliant (i.e., Oxic A, Oxic B, Hypoxic A). Data provided by the New Brunswick Department of Environment and Local Government.

In Nova Scotia (Figure 4), the data show trends of improvement over the 2009 to 2017 period; that is, the mean redox levels have increased from negative to positive values, sulfide has decreased after a peak in 2011, and porosity and organic matter have minor declines. However, from 2018 to 2020, there was a reversal of this trend with increasing average sulfides levels and decreasing redox. In 2020, the average sulfides level was 2,115 µM which would be in the Hypoxic-A category. Sites in this category "may be causing adverse environmental effects on marine sediments", but no actions are required until the Hypoxic B threshold is exceeded (i.e., 3,000 µM sulfides). The average Nova Scotia Redox value of 27 mVNHE in 2020 is in the Oxic B category. In New Brunswick (Figure 5), there has been a general decline in compliance (dotted line) over this 2015 to 2020 period with a steep decline from 2019 to 2020. On average over this period, 92.5% of sampled sites complied.

To provide a performance comparison across the four regions, three classifications groups based on common sulfide values were established based on the Canadian Aquaculture Activities Regulations (AAR) and the provincial Environmental Monitoring Programs (EMP). For soft seabeds, these were Oxic (0-1,499 µM sulfide), Hypoxic[37] (1,500-5,999 µM sulfide) and Anoxic (>6,000 µM sulfide), and for hard bottoms with visual surveys, below threshold (<70% presence of bacterial mats) and above threshold (>70% presence of bacterial mats). Figure 6 shows the aggregated monitoring results by region for the dominant company from 2014 to

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[37] Note in the specific example of the Canadian AAR, the limit for sulfides is 3,000 µM, and therefore the "hypoxic" category in Figure 6 straddles this value. Therefore, the hypoxic category includes both "pass and "fail" sites according to these federal regulations.

2019, which have been verified (for Nova Scotia and New Brunswick) by direct comparison with the available public data. Note these results also include some from the Newfoundland Farm Fallow Monitoring Program (FFM) which required sampling when farms were active and fallow prior to the adoption of the AAR in 2015.

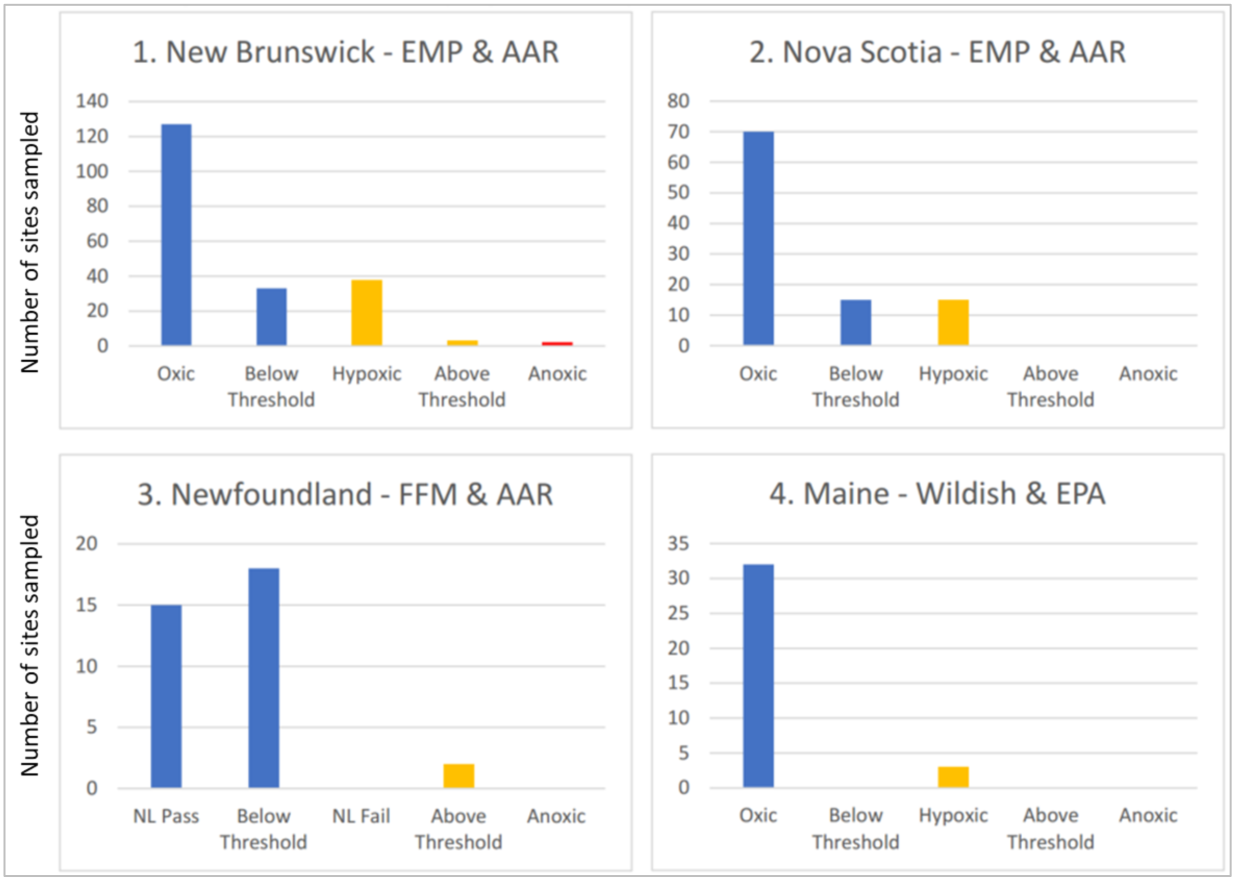

Figure 6: Benthic monitoring results for each region of Atlantic North America for the dominant company from 2014 to 2020 during which time the monitoring regulations included Canadian provincial Environmental Monitoring Programs (EMP) and Federal Aquaculture Activities Regulations (AAR), the earlier Farm Fallow Monitoring Program (FFM) in Newfoundland (which provided simple pass-fail results), and the change from the Wildish protocol to the Environmental Protection Agency (EPA) methods in Maine. See the main text above for explanations of the thresholds. Graphs provided by J. Wiper, pers. comm., (2021) and verified for Nova Scotia and New Brunswick with publicly available data (or data supplied on request).

Given that "Oxic" and "NL Pass" are positive results for soft bottom sites, and "below threshold" is a positive result for hard bottom sites, it can be seen that although the types of sites vary (i.e., there are a higher proportion of hard bottom sites in Newfoundland[38]), the results are predominantly positive. The repercussions of exceeding the thresholds mean that a

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[38] Along the South Coast of Newfoundland, most salmonid farms are located in deep bays or fjords with predominantly patchy hard bottom substrates containing localized depositional areas in seafloor depressions. At these aquaculture sites, deposition from finfish aquaculture results in the formation of a flocculent matter containing little to no natural sediment formed of a viscous composite of decomposing fish feed, fish feces, and microbes

site cannot be stocked until the values drop below the regulated values. For example, in the Canadian federal AAR, the site cannot be stocked again if the samples exceed the threshold of 3,000 µM (AAR regulations, October 5th 2020, Section 10,1,c) or if the visual monitoring shows the presence of *Beggiatoa* species or similar bacteria (i.e., bacterial mats), marine worms, or barren substrate in more than 70% of the sampling locations (AAR regulations, October 5th 2020, Section 10,2,b).

When comparing the mean sulfide levels from samples taken close to the net pens with those taken at reference stations[39] at sites in Nova Scotia, the expected increases in sulfides at the site can be seen (Figure 7). While the average annual site samples vary from 548 µM to 3,338 µM sulfide, the reference samples vary from 142 µM to 553 µM.

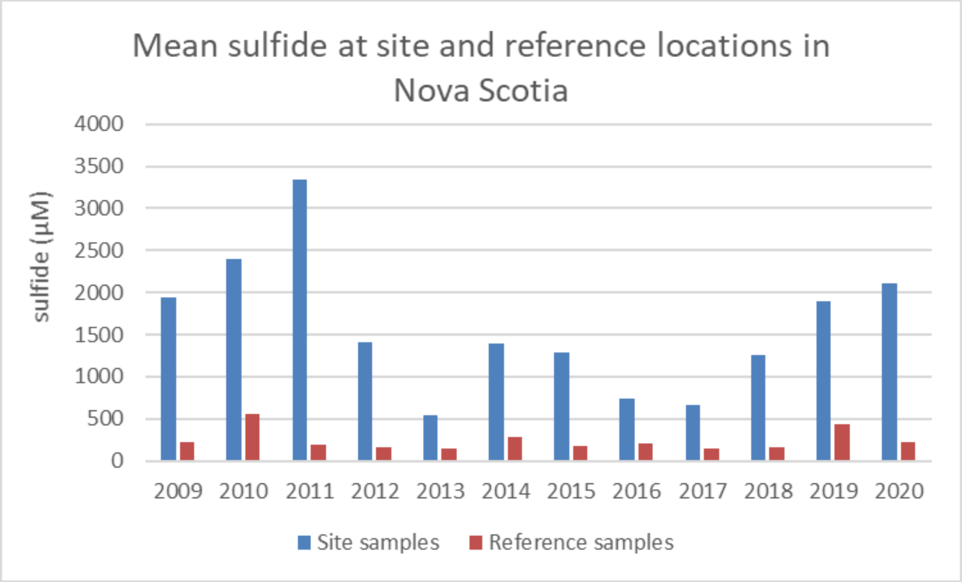

Figure 7: Mean sulfide levels in Nova Scotia from 2009 to 2020, comparing samples taken at the edge of the net pens and at reference locations. Data from Nova Scotia Environmental Monitoring program.

Figure 8 shows another analysis of the same Nova Scotia sulfide data (i.e., relating to soft sediment sites only), showing the categorical results are largely dominated by samples below 1,500 µM (Oxic A, B) with >80% of samples in 2017 and 2018, but these results are substantially worse in 2019 and 2020 with just over half the samples (51%) at <1,500 µM and 37.2% of samples >3,000 µM. On average, over this time period (2009 to 2020), 19.9% of Nova Scotia benthic samples have been >3,000 µM sulfide, and in the last three years (2018 to 2020) it was 24.0%. In the same period (2018 to 2020), 4.2% of benthic samples had >6,000 µM sulfide indicating substantial impacts in localized areas (see the discussion around Figure 9 below).

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[39] Reference stations are located between 100 and 300 meters from the lease boundary, in the direction of the dominant current, and must be positioned in an area with a similar depth and sediment type to what is found at stations sampled within the lease boundary.

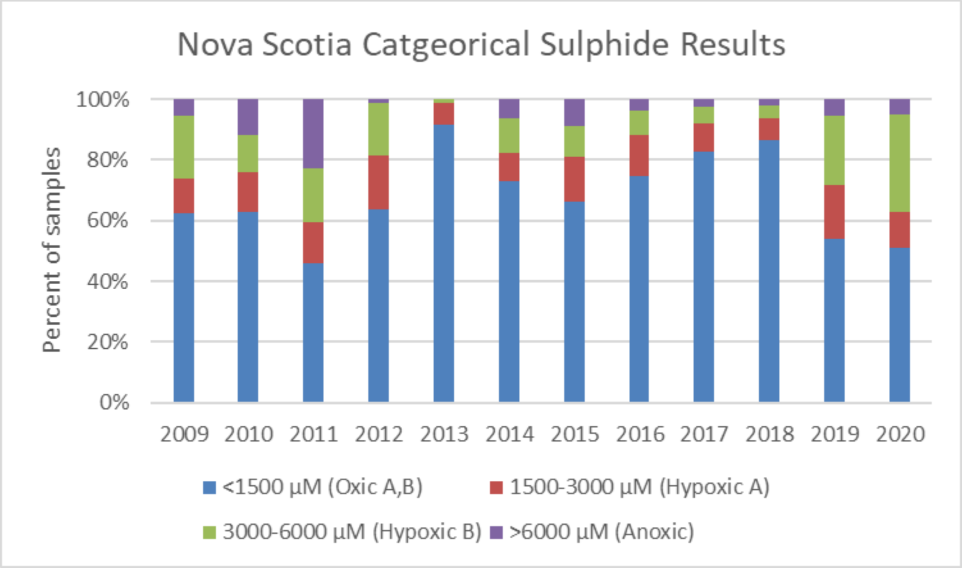

Figure 8: Analysis of all benthic sulfide samples from Nova Scotia from 2009 to 2020 (not including reference station samples). Data from Nova Scotia Environmental Monitoring program.

As discussed here, the regulatory requirements are primarily linked to the sulfide indicator (for soft sediment seabeds), but Cranford et al. (2017) report substantial errors in these measurements depending on the site-specific sediment mineralogy. The errors resulted in overestimations of the free sulfides, attributed to the presence of metal sulfide complexes in the sediment, and while Cranford et al. (2017) were able to detect variations in the oxygen levels in sediment pore water at distances up to at least 425 m from the farm, substantial sulfidic and hypoxic stress were limited to the areas immediately adjacent to the net pens. With regard to the visual indicators, Hamoutene et al. (2018) consider the regulatory thresholds for hard bottom finfish aquaculture sites to underestimate the impact on taxonomic richness and that they should be re-evaluated to meet conservation objectives. They found that “the present regulatory threshold (70%) based on bacteria mats, OPC, and barren stations would likely correspond to a 100% reduction in richness in the near-cage area (within 50m from net pens).”

Despite these concerns, these results are similar to the conclusions of numerous studies in other countries, where despite the potentially large loss of nutrients and a marked deposition and accumulation beneath and in the immediate vicinity of the net pens themselves, there is often a sharply declining gradient of benthic sulfide concentration with increasing distance from, and sometimes even within, the pen array. As such, a growing volume of evidence from several regions supports the notion that the far-field ecological impact in the benthos are minimal, unless the site is in a particularly poor location (e.g., Grefsrud et al., 2021a,b; Mayor et al., 2010; Mayor and Solan, 2011; Keeley et al., 2013; Price et al., 2015). This can perhaps be best visualized by considering Figure 9 below. Taken directly from Chang et al. (2011), Figure 9 shows plots of six salmon farms in southwestern New Brunswick that show the distribution and gradients of benthic sulfide concentrations. At two of these sites, small anoxic areas of high impact are shown with sulfides levels exceeding 6,000 µM, and samples from these locations would be reflected in the purple uppermost bars in Figure 8, but overall, these plots demonstrate the steep decline in impact (as indicated by sulfides levels) with increasing distance from the net pens. Areas that exceed the 3,000 µM threshold in the Canadian AAR are very localized under the net pens. The site lease areas mostly have low levels of sulfides, consistent with the high percentage of samples with sulfides levels <1,500 µM in the results presented above.

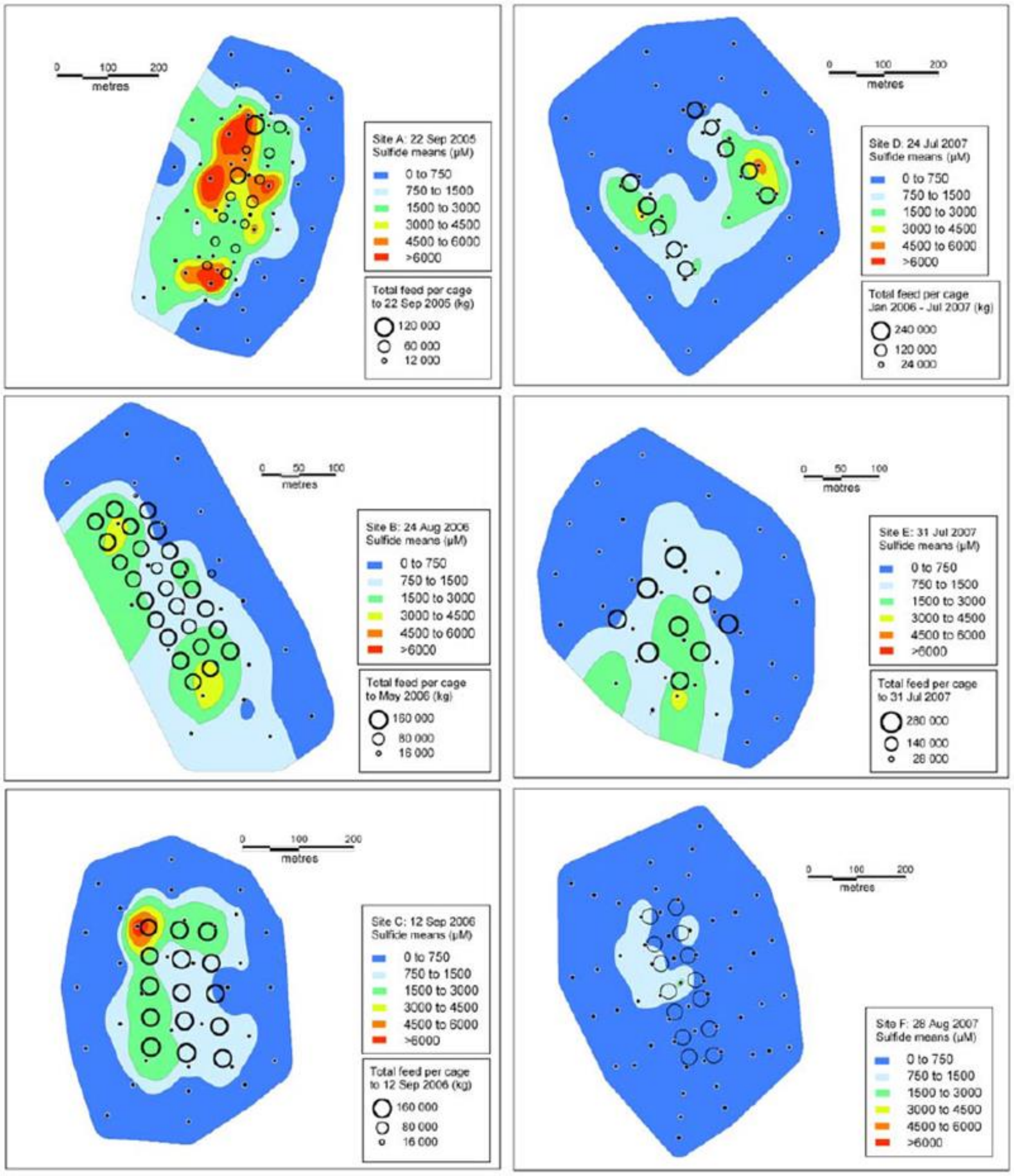

Figure 9: A contour plot showing mean benthic sulfide concentrations sampled during summer at six salmon farm sites in New Brunswick. Black dots on each plot indicate sampling location. Circles represent approximate cage location with the size of a given circle determined by the feed input to that cage. Site F was actively feeding, but feed input data were not available. Image from Chang et al. (2011).

More recently, Verhoeven et al. (2018) studied the changes in seabed bacterial communities at a salmon farm in Newfoundland, and noted four clusters of “recently disturbed”, “intermediate impact” and “high impact” bacterial assemblages that differed markedly from a fourth “low impact” cluster obtained >500 m from the net pens. In keeping with the other results presented here, while noting large scale phylum shifts and a decline in bacterial biodiversity in the “high impact” cluster, these samples were most often collected immediately under the net pens, and the “intermediate impact” cluster was located from 20-40 m from the pens.

As a specific example of selected impacts, Figure 10 shows images captured from video sampling in May 2020 at a site in Newfoundland. Emphasizing that most of the samples at this site showed no impact, the selected images were taken below the edge of the net pen array (i.e., at 0 m) and have been selected as the worst examples to illustrate the reported presence of 10% coverage of *Beggiatoa*-like bacterial species, 15% coverage of marine worms (opportunistic polychaete complexes, OPC), and the presence of uneaten feed and shell debris. Overall, this site showed the presence[40] of *Beggiatoa* bacterial mats and OPC at 31% (11 of 35) of the video stations (taken at 20 m intervals on transects out to 100 m from the cage edge), and as this did not exceed the 70% threshold, the site was approved to continue operation under the AAR Monitoring Standard (Section 11(1)(b)) after the province-mandated 4-month fallow period.

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[40] “Presence” is defined here as >5%. Below this value, the bacterial mats are considered not present.

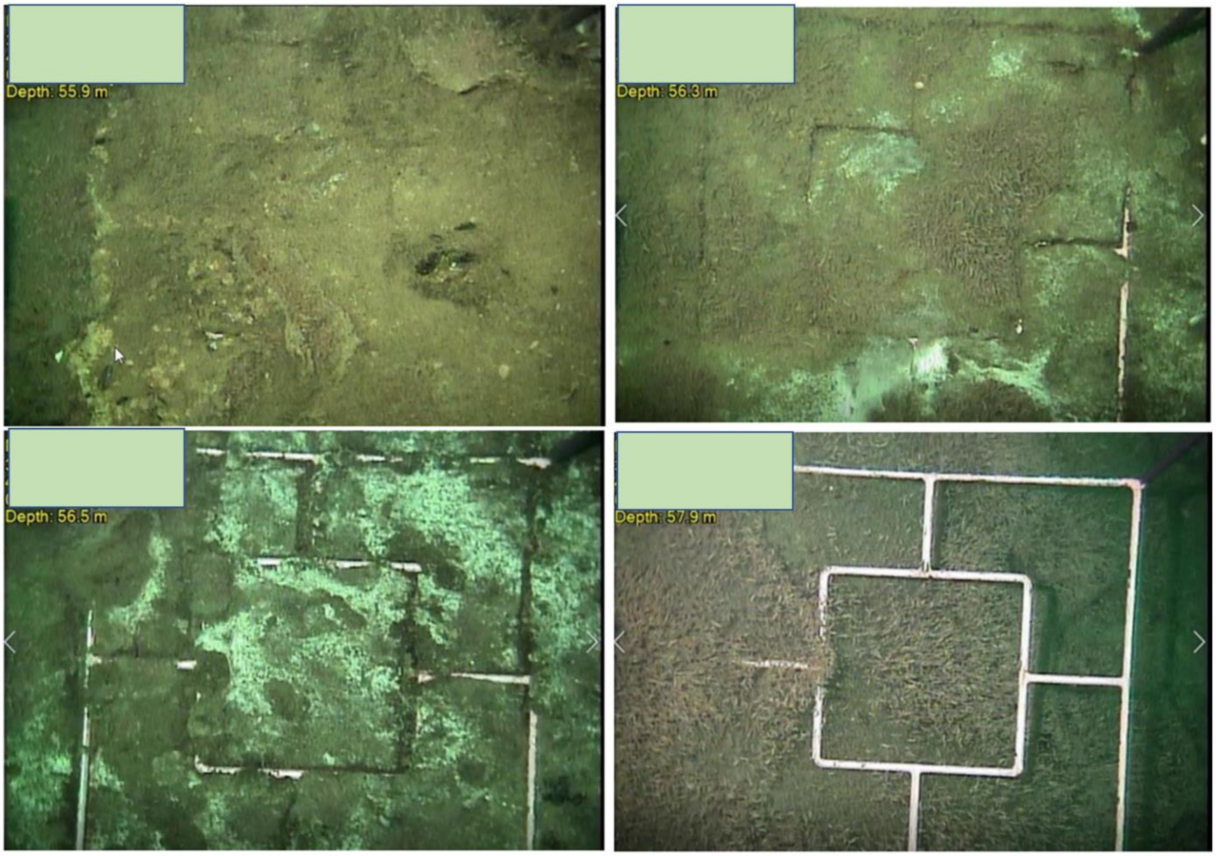

Figure 10: Video stills from a site in Newfoundland (site details blanked for privacy) taken at the cage edge on a transect selected to show the worst visible examples of impact at this site (most of the samples at this site showed minimal impact). Depth approximately 56 m. The inner square quadrat is 0.5 m x 0.5 m. Examples of white *Beggiatoa* bacterial mats can be seen in the lower left and upper right images, with opportunistic polychaete complexes (marine worms) in the two right images. With lower impacts on other transects, this site passed the AAR monitoring requirements. Images provided in a benthic sampling report by J. Wiper pers. comm. (2020).

It is now a globally typical practice for salmon farm sites to be fallowed between production cycles for a variety of reasons (e.g., breaking parasite life cycles in addition to benthic recovery). The Aquaculture Activities Regulations for Canada do not mandate a fallow period (instead, all sites must be shown to be compliant with the thresholds before restocking) but provincial requirements such as the 4-month period in Newfoundland are in place in addition to other measures such as the coordination of fallowing across all sites in Aquaculture Bay Management Areas (BMA - see the cumulative impacts section below).

Keeley et al. (2015) showed that although significant recovery is evident at fallowed sites in the first six months, full recovery is often not completed before restocking occurs. This can create a complex ‘boom and bust’ cycle of opportunistic taxa as one production cycles ceases (at harvest) and is then reestablished (at restocking). For full recovery, Keeley et al. (2015) and references therein show estimates vary between 6 months and five years or more and are highly environment- and situation-specific. Nevertheless, regardless of whether fallow periods are used or not, the regulatory systems in Atlantic North America are intended to prevent unacceptable impacts to benthic habitats over long time periods (multiple production cycles) by ensuring all sites either meet the thresholds at peak biomass, or before restocking if necessary. While this may maintain an ongoing impact, Keeley et al. (2015) show these impacts are not irreversible and relatively rapidly reversible by reducing the load, fallowing and/or removing the farm.

With particular regard to commercially important species such as lobsters, Milewski et al., (2021) reviewed the state of knowledge of environmental interactions between American lobster[41], their habitat and fishery, and marine finfish aquaculture. Their review of the published scientific literature revealed that many interactions (or potential interactions) are poorly studied or unknown. Of the limited number of studies reviewed by Milewski et al. (2020), some show repulsion of lobsters from farming areas (indicated by lower numbers, lower catches or lower catch per unit effort), some show no impact on lobster distribution, and some show attraction to fish farms because of the presence of uneaten feed which, in turn, can positively affect the fishery by enhancing local abundance. With regard to particulate wastes and the changes to benthic conditions discussed above, the limit of detection can be at a considerable distance from the farm, but impacts are likely to concentrated in the immediate farm area with the exception of the limited numbers of farms located in demonstrably poor locations (such as the much-studied Port Mouton site[42], studied by Milewski et al. (2018), Cullain et al. (2018), Nagel et al. (2018), McIver et al. (2018), Milewski and Smith (2019)), and not in production since 2015). Within the heavily impacted areas under and close to the net pens (see Figure 9 above), decapods are known to detect and be vulnerable to dissolved sulfides, ammonium and hypoxic conditions, and common behavioral responses in lobster species include a reduction in movement to conserve energy and movement to oxic areas. The potential longer-term population-level consequences (e.g., recruitment, fecundity, density, and sex structure) of hypoxia, sulfides and ammonia on lobsters (and crustaceans in general) have not yet been studied (Millewski et al., 2021), but from the analysis above, if these impacts occur, they again appear likely to be largely limited to the small areas of the total habitat found under and near fish farms.

Finally, changes in the fatty acid profile of lobsters have been detected due to the consumption of waste feed (or the consumption of rock crab which are more likely to eat the waste feed) but the impacts (if any) to individuals or to broader populations is not known. Other potential impacts to lobsters are noted where relevant in Criterion 3 – Habitat, and Criterion 4 – Chemical Use, and Milewski et al. (2021) emphasized the as-yet poorly studied potential for combined and cumulative impacts on lobsters from net pen aquaculture from effluent and chemical use.

Cumulative effluent impacts

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[41] Global lobster catches are dominated by the American lobster (*Homarus americanus*) landed entirely in Atlantic Canada and northeastern United States (Milewski et al., 2021).

[42] The water depth at the former site in Port Mouton was very shallow 10-12 m (McIver et al., 2018), and benthic data show it has not been in operation since 2015.

The previous analysis has demonstrated that although the primary impacts of particulate wastes are limited to the immediate farm area, detectable impacts have been reported at distances of several hundred meters from the net pens. Consideration of site maps and aerial images (e.g., Google Earth) shows some sites may be separated by similar distances and may operate simultaneously within BMAs, so it is considered that there may be some potential for overlap, even if it is towards the limit of their range and/or at a minimal cumulative intensity.

BMAs have been established in the Bay of Fundy, covering part of Maine and all of New Brunswick (map provided in Appendix 1[43]) and in the Coast of Bays region of Newfoundland and Labrador (Ratsimandresy et al., 2020). The BMAs were first introduced to address fish health issues, but they also facilitate synchronized production, including stocking and fallowing regimes. The boundaries of each BMA are based on a combination of oceanographic, fish health and business considerations, and while not considered here to be a comprehensive ecosystem-based management plans which explicitly limit the total size, concentration, or cumulative impacts of the industry, there are controlled growth and exclusion zones incorporated.

Mass mortality events

A mass mortality event occurred at ten salmon farm sites in Fortune Bay and Harbour Breton Bay on the south coast of Newfoundland in August and September 2019 (MUN, 2020). The most likely cause of the mortality was unusually high water temperatures leading to a series of conditions that resulted in low oxygen levels sufficient to cause 100% mortality at six sites, and 33% to 50% in the remaining four sites (MUN, 2020). While media reports of the event indicated dire environmental impacts (a potentially massive buildup of organic matter on the seabed and bird mortalities from the fats and organic matter dispersed during collection of the mortalities), two independent reports reviewing the events and studying the impacts are referred to here; the first from the Fisheries and Marine Institute of Memorial University of Newfoundland (referenced here as MUN, 2020), and the second from MAMKA (a collaboration of two Mi'kmaq communities: Qalipu First Nation and Miawpukek First Nation) (referenced here as MAMKA, 2020). The Memorial University report confirmed the cause of the mortalities and reviewed the cleanup operations but did not assess any environmental impacts. The MAMKA report was an objective assessment of the environmental impacts of the mortality event, funded by the company responsible.

The deceased fish were recovered by divers and seiner vessels, and disposed of on land (the majority were rendered for further utility) and contrary to the media reports, aside from some organic material (particularly fats) contained in water pumped from seiner vessels, the majority of the deceased salmon biomass was not disposed of in the marine environment (MUN, 2020). From the benthic surveys (in MAMKA, 2020), minor patches of *Beggiatoa* bacterial mats (an indicator of organic deposition) were visible on three of 25 transects; otherwise, the seabed below and in the vicinity of the sites were considered unimpacted.

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[43] Further details can be mapped here: https://nbdnr.maps.arcgis.com/apps/webappviewer/index.html?id=24c65e8718724c5db1de77899172630d&locale=en

Shoreline surveys in November 2019 were conducted on 84.9 km of the coast and 1.6 km (1.9%) were found to be impacted with white fat deposits and organic debris. These impacts had fully recovered by secondary surveys in April 2020. No seabirds were found to be contaminated with fish oil. This event (or similar events where the majority of the fish are recovered) is therefore not considered to have caused a lasting impact on the immediate (benthic) or far-field (shoreline) environments.

Conclusions and Final Score

Salmon farms discharge large quantities of waste nutrients and depend on coastal waterbodies to assimilate them. While small nutrient increases can be detected at considerable distances from the farm and at the waterbody scale, the potential for soluble nutrients to exceed the local or waterbody carrying capacity is low. Data from benthic monitoring for all regions show high compliance with provincial and federal thresholds, but with significant declines in performance in recent years (e.g., from close to 100% in 2019 to 70% in 2020 – noting that farms not meeting the thresholds, in addition to fallowing, must subsequently demonstrate a return to compliance before receiving approval for continued operation). There is some indication that the monitoring parameters and sampling methods used are not optimal, and comprehensive research from these and other salmon farming regions show farms have a substantial cyclical impact in the immediate farm area during the production-fallow cycle. In Atlantic North America, there continues to be the potential for poorly understood impacts to commercially important lobster that may occur in the immediate area. The proximity of sites indicates a potential for cumulative impacts at the waterbody or regional scale in densely farmed areas such as the Bay of Fundy (which are largely managed collectively in Bay Management Areas), but there is currently no evidence of such cumulative impacts. Given the available body of research and monitoring data, the Evidence-Based Assessment method was used, and overall, there are considered to be frequent yet temporary impacts within the immediate vicinity of the farm, and the final score for the Criterion 2 - Effluent is 4 out of 10 for all regions.

Criterion 3: Habitat

Impact, unit of sustainability and principle

- Impact: Aquaculture farms can be located in a wide variety of aquatic and terrestrial habitat types and have greatly varying levels of impact to both pristine and previously modified habitats and to the critical "ecosystem services" they provide.
- Unit of sustainability: The ability to maintain the critical ecosystem services relevant to the habitat type.
- Principle: being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats.

Criterion 3 Summary
Maine, US and Atlantic Canada

C3 Habitat parameters	Value	Score
F3.1 Habitat conversion and function (0-10)		8
F3.2a Content of habitat regulations (0-5)	3	
F3.2b Enforcement of habitat regulations (0-5)	4	
F3.2 Regulatory or management effectiveness score (0-10)		4.80
C3 Habitat Final Score (0-10)		**6.93**
Critical?	No	Green

Brief Summary

Salmon farm net pens and their supporting infrastructures contribute much physical structure to nearshore habitats and are known to modify the physical environment at the farm location by modifying light penetration, currents, and wave action as well as providing surfaces for the development of rich assemblages that may further increase the complexity of the habitat. An average salmon farm comprises approximately 50,000 m^2 of submerged artificial substrates that can be colonized by a large suite of hard-bottom associated species that may not otherwise find suitable habitat in a given area (e.g., muddy bottoms or in the water column). These additional species may have a variety of direct and cascading effects on the surrounding ecosystem, including inadvertently supporting the persistence and distribution of non-native species. Salmon farms also attract a variety of wild animals as fish aggregation devices or artificial reefs (including predators such as seals that may prey on wild salmon smolts migrating past farms) or may repel other wild animals through disturbance such as noise, lights or increased boat traffic. Changes in behavior of wild fish around fish farms and even of their flesh quality due to the consumption of waste feed have been reported. A key aspect of these potential impacts is their circumstantial variability, their limited study, and the challenge of their quantification, particularly in the context of the more obvious impacts of soluble and particulate effluent wastes (assessed in Criterion 2 - Effluent).

The regulatory systems and their enforcement for siting and licensing are available, including requirements for baseline studies or assessments, but they are often challenging to interpret in a practical context as they evolve across multiple provincial and federal agencies. Their application to impacts other than effluent wastes on the seabed is typically unclear, but the site licensing process and its enforcement are considered to be largely effective. Further, the literature indicates that the realization of any or all of these potential impacts does not significantly impact the functionality of the ecosystems in which farms are sited. More basically, the siting of net pen arrays does not result in habitat conversion in the same way that, for example, pond construction does, and the removal of farm infrastructure would immediately restore all baseline biophysical processes. Overall, (noting that soluble and particulate wastes are addressed in Criterion 2 – Effluent) the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management effectiveness regarding the known impacts of the floating net pens appears moderate. The final score for Criterion 3 – Habitat is of 6.93 out of 10.

Justification of Rating

Please note the operational impacts to seabed habitats beneath salmon farms resulting from settling particulate wastes are addressed in Criterion 2 – Effluent.

Factor 3.1. Habitat conversion and function

Data on site locational coordinates are typically available in all regions, and satellite images readily allow an overview of general salmon farm habitats. An example of a salmon farm in Nova Scotia is shown in Figure 11. It is apparent from such images that the floating net pen containment system does not result in any gross functional conversion of surface habitats compared to (for example) the construction of ponds, but that is not to say there are no habitat impacts.

Taken together, the net pens and their supporting infrastructures, the floats and weights, and the mooring ropes, buoys and anchors contribute much physical structure to nearshore habitats (McKindsey, 2011). These added structures are known to impose on the physical environment at the farm location by modifying light penetration, currents, and wave action as well as providing surfaces for the development of rich biotic assemblages that may further increase the complexity of the habitat (McKindsey, 2011). An average (Norwegian) salmon farm comprises approximately 50,000 m^2 of submerged artificial substrates that represent potential settlement space for biofouling organisms (Bloecher et al. 2015).

Figure 12 shows a typical mooring pattern of anchor lines (at a Norwegian salmon farm randomly selected from the Directorate of Fisheries mapped database), and the positioning of the anchors (notably at approximately 1 km from southeast end of the net pen array in this example) shows the extent of the structures.

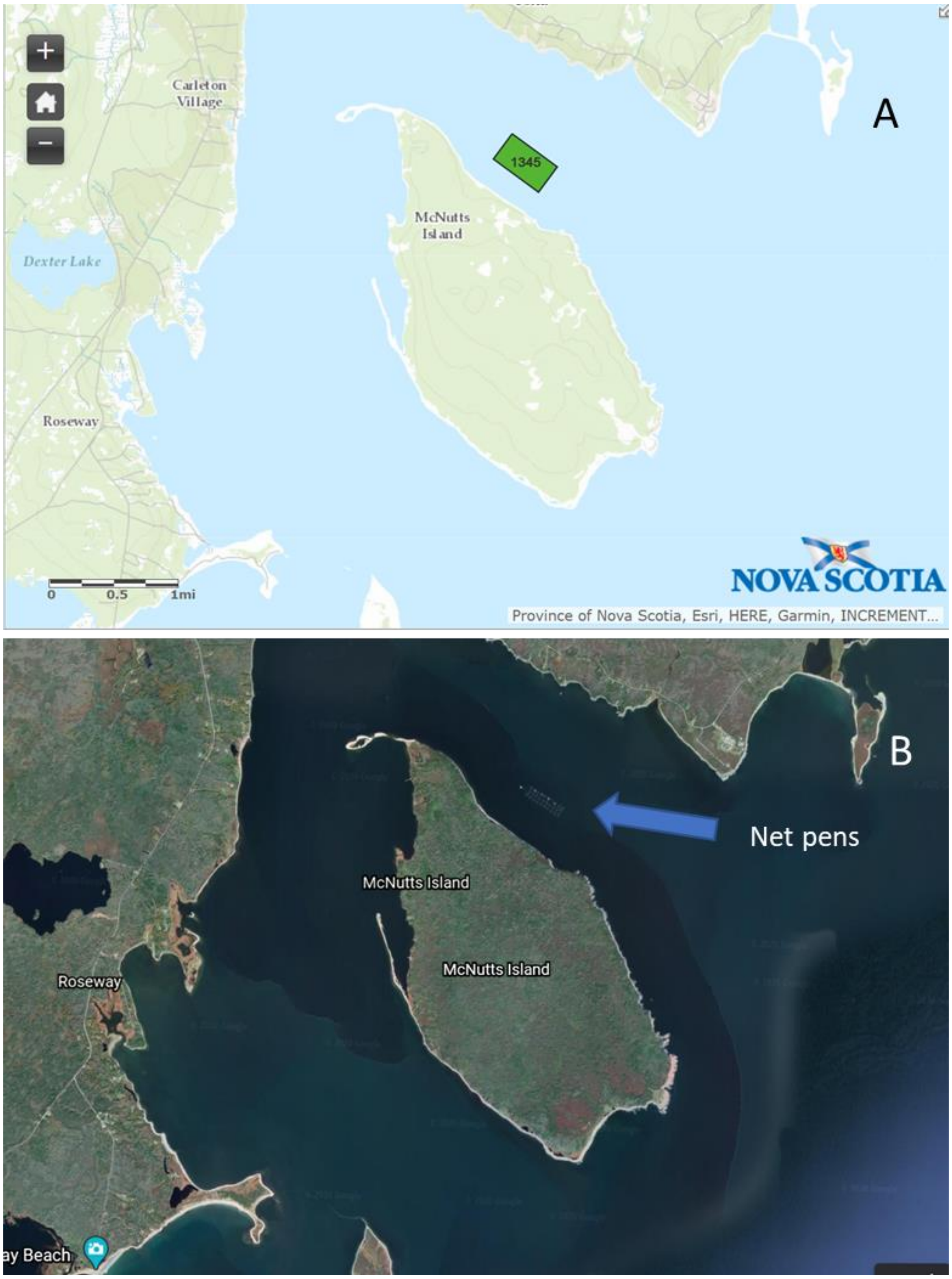

Figure 11: An example of a site location and lease area from the Nova Scotia mapping tool[44] (top image) and a satellite image of the same area from Google Earth (bottom image), providing an overview of the relevant surface habitats.

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[44] https://novascotia.ca/fish/aquaculture/site-mapping-tool/

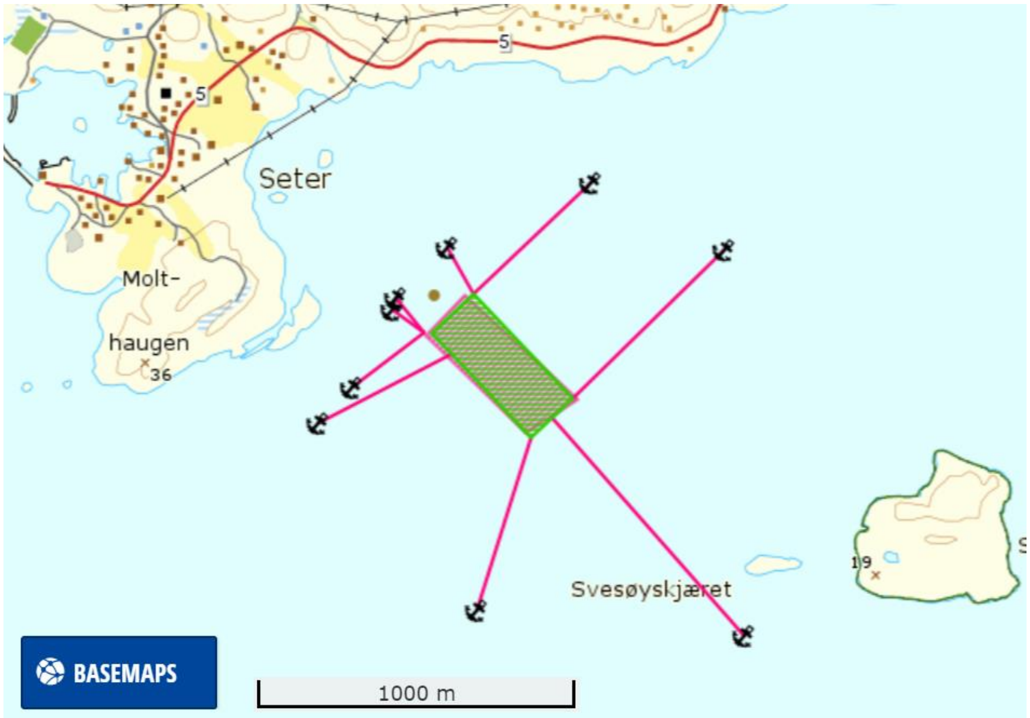

Figure 12: Illustration of the anchoring array of a salmon farm. Image copied from the Directorate of Fisheries' mapped database (https://kart.fiskeridir.no/)

McKindsey (2011) provided a detailed review of "Aquaculture-related physical alterations of habitat structure as ecosystem stressors", and for net pen finfish aquaculture the report is summarized as follows:

> On-bottom structures include anchoring devices for floating net pen fish farm, and vertical structure added to the water column include ropes and cage/net structures as well as buoys, etc. This infrastructure can be colonized by a large suite of hard-bottom associated species that may not otherwise find suitable habitat in a given area (e.g., muddy bottoms or in the water column). These have a variety of direct and cascading effects on the surrounding ecosystem. These structures also modify wave action and current regimes which may influence various ecosystem processes. Cage and netting structures may trap a variety of large organisms but data on this effect are rare.

McKindsey (2011) noted an overriding issue in all discussions of these potential stressors is the fact that most proposed effects due to the addition of structure related to fish cage aquaculture are confounded by the addition of large quantities of feed to the environment (and thereby the soluble and particulate fecal wastes discussed in Criterion 2 – Effluent), and any observable impacts may be due, at least in part, to this factor. McKindsey also noted that the effects related to the addition or modification of physical structure are not well studied, most effects have not been quantified, and the discussion of effects in the scientific literature is largely based on extrapolations from other systems. Noting the publication date of 2011, McKindsey also noted that major recent reviews on aquaculture-environment interactions (at that time) did not discuss the implications of these structures or did so only in a very limited way.

A search for relevant literature since 2011 adds additional potential impacts. For example, DFO – in a 2017 information webpage on the Alteration of Habitats[45] – also notes the use of underwater lights may influence the behavior of wild fish by attracting them to—or causing them to avoid—farm sites, but also notes the lights do not penetrate more than a few meters beyond marine nets, suggesting that their use has minimal effect on the surrounding environment. Milewski et al. (2021) note that the potential impacts of noise and lights associated with finfish farms on lobster larvae and adults have not been examined. Floerl et al. (2016) note a large number of fish (and mussel) farms in North America, Europe and New Zealand support extensive populations of biofouling invasive species, and the in-situ cleaning of fouled net pens may inadvertently support the persistence and distribution of such species within aquaculture regions by the localized dispersal of non-indigenous propagules and fragments, or by the use of farm structures as stepping stones for range expansion (Bloecher and Floerl, 2020). In New Zealand, MPI (2013) also note the potential for impacts to benthic habitats due to shading, but in keeping with McKindsey (2011), they note that no studies exist that separate the effects of shading from that of benthic enrichment, presumably because they occur concurrently, and the latter is thought to be the dominant stressor.

In addition to biofouling organisms attached directly to the farm infrastructure substrates, Callier et al. (2018) reported the attraction and repulsion of wild animals to/from marine finfish farms (and bivalve aquaculture) and considered the effects related to the farm infrastructure acting as fish aggregating devices or artificial reefs, the provision of food (e.g., farmed animals, waste feed and feces, and fouling organisms associated with farm structures) and some farm activities (e.g., increased boat activity and cleaning). Callier et al. noted the distribution of mobile organisms associated with farm structures varies over various spatial (vertical and horizontal) and temporal scales (season, feeding time, day/night period). Also, the attraction/repulsion mechanisms have a variety of direct and indirect effects on wild organisms at the level of individuals and populations and may have implication for the management of fisheries species and the ecosystem in the context of marine spatial planning. Nevertheless, also in keeping with McKindsey et al. (2011), Callier et al. (2018) also noted considerable uncertainties regarding the long-term and ecosystem-wide consequences of these interactions.

DFO (2014) note the abundance of predators (i.e., seals) near Atlantic salmon farms in the Bay of Fundy has been suggested as a source of post-smolt mortality of wild salmon and as a potential limit to recovery for the endangered Inner Bay of Fundy salmon populations. However, DFO also note that Atlantic salmon in the Bay of Fundy have many potential predators and there is insufficient data on the form and extent of predation to assess the current impact on persistence and recovery. As such, the impacts of seals, birds and other predators, both near salmon farms and in other areas, remains an unresolved issue that has the potential to affect recovery.

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[45] https://www.dfo-mpo.gc.ca/aquaculture/protect-protege/alteration-habitat-eng.html

Uglem et al. (2020) also note salmon farms attract large amounts of wild fish which consume uneaten feed pellets. In Newfoundland, Goodbrand et al. (2013) detected large abundances of wild fish below and adjacent to sea cages, and using hydroacoustic survey methods, also found evidence that sea cage aquaculture can affect the abundance and distribution of wild fish within the larger farm bay environment. Otterå et al. (2014) and Skilbrei et al. (2016), note saithe (*Pollachius virens*) are by far the most numerous fish visitors to fish farms (on the Norwegian coast) and show evidence of establishing core residence areas close to fish farms such that the aquaculture industry is influencing the local saithe distribution. Again, Otterå et al. (2014) conclude large-scale population effects are difficult to prove, but note it is possible that the dynamic relationship between the coastal and oceanic phases of saithe has been altered. Uglem et al. (2020) also note the modified diet of the wild fish aggregating at salmon farms (i.e., the consumption of salmon feed pellets) may reduce the flesh quality of the fish, influencing the local fisheries (although they noted the changes in flesh quality were small).

With regard to impacts of net pen structures to the hydrodynamic characteristics of affected habitats, Herrera et al. (2018) noted (at a single salmon farm site in Chile) that the presence of the net pens modified the natural hydrodynamics of the channel, attenuating the intensity of the local velocity magnitude and generating recirculation and retention zones near them. They also noted that the effects were not confined locally because the perturbations introduced by the presence of net pens were propagated far from them. Similarly, a study in Norway (Michelsen et al., 2019) indicated some impact from the salmon farm on the measured current flow at distances from 90 to 320 m around it. However, these studies on water movements related primarily to animal welfare and the distribution of pollutants, and it is not known if changes to the hydrodynamics have any other significant habitat impacts.

For the industry in Maine and Atlantic Canada, there do not appear to be any focused research efforts or other similar data to indicate the degree of impact resulting from the placement or presence of net pen arrays. Overall, however, the floating net pen salmon farm containment system is unusual amongst food production systems in that the “construction” of the farm has a relatively low direct habitat impact, yet the addition of the physical infrastructure and the site operations still have a variety of potential impacts on the habitats of the farm site. In addition, it is important to note that the inshore subtidal habitats in which salmon farms are located are important for the early marine stages of endangered wild salmon populations in Atlantic North America (see Criterion 6 – Escapes). The evidence reviewed above emphasizes both the complexity and uncertainty regarding the scale of the impacts and the appropriate level of concern, but the examples cited do not indicate the loss of any critical ecosystem services from the affected habitats. As such, the habitats are considered to be maintaining functionality with minor-moderate impacts, and the score for Factor 3.1 Habitat conversion and function is 8 out of 10.

Factor 3.2. Habitat and Farm Siting Management Effectiveness

Factor 3.2a: Content of habitat management measures

In both Canada and Maine, there is a permitting process for salmon farming operations, and all applications in are each reviewed by several agencies and are subject to public hearing and consultation. In Canada, both federal and provincial entities are involved in aquaculture regulation, and in Maine, federal and state agencies are involved. Each principal agency has resources for siting, regulation, and enforcement published on their respective websites:

Canada

- Department of Fisheries and Oceans Canada
    - http://www.dfo-mpo.gc.ca/index-eng.htm
- Environment and Climate Change Canada
    - https://www.canada.ca/en/environment-climate-change.html
- Transport Canada
    - https://tc.canada.ca/en
- New Brunswick Department of Agriculture, Aquaculture and Fisheries
    - https://www2.gnb.ca/content/gnb/en/departments/10/aquaculture.html
- Newfoundland and Labrador Department of Fisheries, Forestry and Agriculture
    - https://www.gov.nl.ca/ffa/
- Nova Scotia Department of Fisheries and Aquaculture
    - https://novascotia.ca/fish/

Maine

- National Oceanographic and Atmospheric Administration
    - http://www.nmfs.noaa.gov/aquaculture/
- Maine Department of Marine Resources
    - http://www.maine.gov/dmr/aquaculture/
- Maine Department of Environmental Protection
    - https://www.maine.gov/dep/

In Maine, farmers must acquire a General Permit for Net Pen Aquaculture from the Maine Department of Environmental Protection (DEP) and comply with the Aquaculture Lease Regulations from the Department of Marine Resources (DMR). Canadian-sited farms must acquire leases and licenses from their respective provincial governments, and also follow the Federal Aquaculture Activities Regulations.

With regard to the potential impacts outlined in Factor 3.1 above, in Canada, DFO (in their 2017 information page on Alteration of Habitat) note the impact of aquaculture infrastructure is determined by the extent, intensity, timing and location of the disruption to habitat, and that these factors are considered by Canadian aquaculture (i.e., provincial) regulators when reviewing lease or license applications for new aquaculture facilities. As such, DFO (which reviews license and lease proposals and provides advice to provincial decision makers) states only those locations that present minimal risk to fish or fish habitat are approved, and in addition, where effects may be more severe on a seasonal basis, regulators may put measures in place to restrict the duration, timing, or extent of aquaculture activities.

The Aquaculture Activities Regulations mandate (Section 35; 15) that during the installation, operation, maintenance or removal of an aquaculture facility, the owner or operator of the facility takes reasonable measures to mitigate the risk of serious harm to fish outside the facility that are part of a commercial, recreational, or Aboriginal fishery. DFO defines "Serious harm to fish" as the "death of fish or any permanent alteration to, or destruction of, fish habitat". As such, the owner or operator of the facility must submit a survey conducted in accordance with the Monitoring Standard[46] that identifies the fish and fish habitat on the seabed that is leased for the operations of the facility and in the water column above the seabed (AAR, 8; 1). The AAR Monitoring Standard describes the "Survey for Baseline Information for New Sites and Expansion of Existing Sites", which includes the "Survey of Fish and Fish Habitat", but these requirements focus on benthic habitats, thereby ignoring the majority of the potential impacts described in Factor 3.1 above, perhaps with the exception of the physical impact of anchoring systems on the surveyed benthic habitats. While it is possible different rules apply in Canadian provincial regulations, the site-level focus of the net pen system is typically also on benthic indicators of waste discharge impacts.

This is similar to Maine's General Permit for Net Pen Aquaculture[47] in the US, which is also focused on the discharge of pollutants, as is the Department of Marine Resources Aquaculture Lease Regulations[48] (Chapter 2.10) which require a department-approved environmental characterization and baseline, including a sediment & benthic characterization, and a water quality characterization. It is not clear if additional environmental impact assessments are required for new or existing (e.g., expanding) sites that would take account of the potential impacts in Factor 3.1. While fallowing of sites after harvest is now considered standard practice and is coordinated in Bay Management Areas, the effect of fallowing on the suite of potential impacts described in Factor 3.1 are uncertain.

Overall, the regulatory and management content is focused on benthic impacts from nutrient wastes and may not fully address the potential impacts outlined in Factor 3.1. Given the uncertainty attributed to these impacts and the apparent dominance of benthic impacts, this is perhaps not surprising, and overall, the management system is considered to require farms to be sited according to ecological principles or environmental considerations at the site level. There appears to be limited consideration of potential cumulative habitat impacts associated with the combined infrastructures of the industry, but the industry is largely organized in BMAs which require coordination for many of the most important farm activities. With consideration of the uncertainties in the scale of the impacts described in Factor 3.1 and the comprehensive nature of the site licensing process, the score for Factor 3.2a is 3 out of 10.

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[46] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/doc/AAR-Monitoring-Standard-2018-eng.pdf

[47] https://www.maine.gov/dep/water/wd/net-pen-aquaculture/index.html

[48] Chapter 2 of the Department of Marine Resources Regulations https://www.maine.gov/dmr/laws-regulations/regulations/index.html

Factor 3.2b. Siting Regulatory or Management Effectiveness

The authoritative bodies responsible for enforcing salmon aquaculture in both Canada and Maine are generally the same as those listed in Factor 3.2a above. The transparency of siting regulations and management enforcement in Atlantic North America is generally good, although the variations across the provinces/state, particularly with the ongoing evolution of the regulatory structures, are challenging to interpret.

In Maine, the location, size, effective and expiration dates, conditions, history, and current owner/operator of each farm site is publicly available on the Maine DMR website. In Canada, there is a Marine Aquaculture Site Mapping program, where a web-based interactive tool is available for public use, and displays farm site locations in each province, their size, and their owner/operator. In both regions, proposed aquaculture leases are available for review, and avenues, instructions, or opportunities for public comment are apparent. For example, the general findings, details of the public comment period, and the decision on the renewal application for the farm site shown in Figure 12 (Site #1345 in Nova Scotia) are available from Nova Scotia's Department of Fisheries and Aquaculture "Information for the Public" website[49]; however, there appear to be few publicly available details on the site's baseline surveys as outlined in Factor 3.2a.

Overall, the enforcement organizations are identifiable and active, but with regard to the potential impacts outlined in Factor 3.1, the activities are perhaps limited in their effectiveness and/or have some gaps in transparency. Nevertheless, the enforcement of the site licensing process is robust and the score for Factor 3.2b - Enforcement of habitat management measures, is therefore 4 out of 10. Factors 3.2a and 3.2b combine to give a management effectiveness score of 4.8 out of 10 for Factor 3.2.

Conclusions and Final Score

Salmon farm net pens and their supporting infrastructures contribute much physical structure to nearshore habitats and are known to modify the physical environment at the farm location by modifying light penetration, currents, and wave action as well as providing surfaces for the development of rich assemblages that may further increase the complexity of the habitat. An average salmon farm comprises approximately 50,000 m^2 of submerged artificial substrates that can be colonized by a large suite of hard-bottom associated species that may not otherwise find suitable habitat in a given area (e.g., muddy bottoms or in the water column). These additional species may have a variety of direct and cascading effects on the surrounding ecosystem, including inadvertently supporting the persistence and distribution of non-native species. Salmon farms also attract a variety of wild animals as fish aggregation devices or artificial reefs (including predators such as seals that may prey on wild salmon smolts migrating past farms) or may repel other wild animals through disturbance such as noise, lights, or increased boat traffic. Changes in behavior of wild fish around fish farms and even of their flesh

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[49] https://novascotia.ca/fish/aquaculture/public-information/. The specific details for site #1345 are here: https://novascotia.ca/fish/aquaculture/public-information/public-notice/2018renewals/AQ1345-Decision.pdf

quality due to the consumption of waste feed have been reported. A key aspect of these potential impacts is their circumstantial variability, their limited study, and the challenge of their quantification, particularly in the context of the more obvious impacts of soluble and particulate effluent wastes (assessed in Criterion 2 - Effluent).

The regulatory systems and their enforcement for siting and licensing are available, including requirements for baseline studies or assessments, but they are often challenging to interpret in a practical context as they evolve across multiple provincial and federal agencies. Their application to impacts other than effluent wastes on the seabed is typically unclear, but the site licensing process and its enforcement are considered to be largely effective. Further, the literature indicates that the realization of any or all of these potential impacts does not significantly impact the functionality of the ecosystems in which farms are sited. More basically, the siting of net pen arrays does not result in habitat conversion in the same way that, for example, pond construction does, and the removal of farm infrastructure would immediately restore all baseline biophysical processes. Overall, (noting that soluble and particulate wastes are addressed in Criterion 2 – Effluent) the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management effectiveness regarding the known impacts of the floating net pens appears moderate. The final score for Criterion 3 – Habitat is of 6.93 out of 10.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

- Impact: The use of chemical treatments can impact non-target organisms and lead to ecological and human health concerns due to the acute or chronic toxicity of chemicals and the development of chemical-resistant organisms.
- Unit of sustainability: Non-target organisms in the local or regional environment, presence of pathogens or parasites resistant to treatments.
- Principle: Limit the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms

Criterion 4 Summary

Maine, US

C4 Chemical Use parameters		**Score**
C4 Chemical Use Score (0-10)		**8.0**
Critical?	No	Green

Nova Scotia, Canada

C4 Chemical Use parameters		**Score**
C4 Chemical Use Score (0-10)		**8.0**
Critical?	No	Green

New Brunswick and Newfoundland, Canada

C4 Chemical Use parameters		**Score**
C4 Chemical Use Score (0-10)		**2.0**
Critical?	No	Red

Brief Summary

Antimicrobial use in Atlantic North America has declined since at least 2012. Data from the dominant producer that operates approximately 80% of active sites in the region (and is the only operator in Nova Scotia and Maine) show the average treatment frequency has been less than 0.5 treatments per site per year since at least 2014. In 2020, with only eight treatments across the four regions, antimicrobial use was 0.12 treatments per site. There have been no antimicrobial treatments in Maine since 2017 and there were none in Nova Scotia in 2020. The highest antimicrobial use has been in New Brunswick, with an average number of treatments per site per year between 2017 and 2020 of 0.33. While the performance of the secondary producer (in New Brunswick and Newfoundland) may differ from these data, it is considered highly likely that the frequency of antimicrobial use is still less than one treatment per site per year in these two regions. The dominant treatments (oxytetracycline and florfenicol) are listed as highly important for human medicine by the World Health Organization, highlighting the importance of continued prudent use.

Accurately describing pesticide use in Atlantic North America is challenged by variable data availability in the most recent years, combined with rapid changes in production practices and pesticide use over the same period. Data from the only producer in two regions show there has been no pesticide use in Maine since 2018 and none in Nova Scotia since at least 2016. In the other two Canadian provinces, New Brunswick and Newfoundland, pesticide use has been high prior to 2018 with multiple treatments per site per year on average. In New Brunswick, pesticide use has been high with multiple treatments per year on average. The dominant producer (operating approximately 80% of active sites in New Brunswick) still uses in-feed treatments at a frequency of <0.7 treatments per year but has almost eliminated bath treatments. Data from DFO indicate there is likely some ongoing use of in-feed and bath treatments by the secondary producer in New Brunswick. In Newfoundland, pesticide use has also been high (half of Newfoundland's active sites received 10 or more pesticide treatments in 2018). The dominant producer (operating just over half of the sites) has almost eliminated bath treatments and also eliminated in-feed treatments, but the available data indicate there is likely some ongoing use of in-feed and bath treatments by the secondary producer in Newfoundland, although the exact frequency is uncertain.

The impacts on non-target organisms (including commercially important species such as lobster) of in-feed and bath pesticide treatments continue to be challenging to quantify in the field, but are likely to have been considerable, at least in the immediate farm area during periods of high pesticide use. In addition, the known cases of illegal pesticide use and the detections of residues of chemicals not approved for use in Canada remain a concern although they are considered to represent exceptional cases at the typical farm level. The recent rapid decrease in pesticide use limits these concerns (particularly in areas where pesticide use has been minimal or has largely been eliminated in recent years). The previous high levels of pesticide use have also contributed to the resistance to some treatments observed in the region, but while such genetic changes to sea lice populations may linger, the recent decline in chemical use limits further development.

Overall, the data demonstrate that chemical treatments have been consistently used less than once per site per year in both Maine and Nova Scotia; for both of these regions, the final score for Criterion 4 – Chemical Use is 8 out of 10. For New Brunswick and Newfoundland, with minor antimicrobial use, the uncertainly with the ongoing pesticide use by the secondary producer necessitates some precaution. Although the most recent data implies low use by the primary producer, the relatively recent (e.g., 2018) high frequency of use, combined with the data uncertainty particularly for the secondary producer results in a final score for Criterion 4 – Chemical Use of 2 out of 10 for New Brunswick and Newfoundland on a precautionary basis. While the recent rapid decline in chemical use is recognized here, additional data (particularly from DFO and ideally reinstating the publication of frequency values) to confirm the ongoing reduction would be needed to allocate a trend adjustment (see the Seafood Watch Aquaculture Standard for details).

Justification of Rating

This assessment focuses on antimicrobials and sea lice pesticides as the dominant veterinary chemicals applied to salmon farming. While other types of chemicals may be used in salmon aquaculture (e.g., antifoulants, anesthetics), the risk of impact to the ecosystems which receive them is widely acknowledged to be less than that for antimicrobials and pesticides, and they are discussed where relevant below. In both the US and Canada, chemical therapeutants may be used only under prescription by a licensed veterinarian. Provisions for off-label use (e.g., for emergency treatment, research, etc.) exist in both regions (Burridge and Van Geest, 2014).

Two primary data sources were used in this analysis. Firstly, following the establishment of the federal Aquaculture Activities Regulations in 2015, DFO now publishes (through OpenCanada) annual chemical use data for each Canadian site (organized by province) from 2016 to 2019 (as of September 2021), showing the annual number of treatments (of antimicrobials and sea lice pesticides) and the annual quantity of each type of chemical used (note the 2019 data no longer include the number of treatments). Secondly, the largest producer in the region provided detailed data on the total and relative use in the same categories plus prescription numbers and treatments per site for all treatments for the three Canadian provinces and Maine from 2014 to 2019 (with some datasets from 2012). The dominant producer is the only operator in Maine and Nova Scotia; therefore, these data are directly representative of production in these two regions. The DFO dataset is therefore limited in temporal coverage and does not include Maine, whereas the company dataset is limited by the exclusion of the second salmon farming company in New Brunswick and Newfoundland. These differences were minimized by selective analysis and comparison where possible.

It is also important to note here the findings of the 2018 Spring Reports of the Commissioner of the Environment and Sustainable Development (Report 1 was on salmon farming; OAG, 2018) which noted the Aquaculture Activities Regulations required industry to self-report the amount, type, and timing of its deposits of drugs and pesticides, but also found that the Department (DFO) did not validate self-reported information and had not determined how it could do this. Therefore, the data used in this assessment obtained either from DFO or directly from industry are taken at face value but cannot be independently verified.

Antimicrobial use

Figure 13 presents the DFO annual total antimicrobial use data (in kg per year of active ingredient) for the three Canadian provinces from 2016 to 2019, combined with the equivalent data from the major (and only) producer in Maine. Note the different scale of the y-axis for oxytetracycline. Over this period, the total antimicrobial use declined from 13,816 kg in 2016 to 2,898.1 kg in 2019. Of the 2,898.1 kg total antimicrobial use in 2019, oxytetracyline dominates with 2,746.6 kg (94.8%). Florfenicol represents the current remainder with 151.5kg (5.2%). The total use of oxytetracycline was high in Newfoundland in 2016 and 2017 (6,996 kg in 2016), but declined to 230.6 kg in 2019. In 2018 and 2019, New Brunswick was the dominant antimicrobial user with the highest consumption of both oxytetracycline and florfenicol. After 1 treatment of oxytetracyline in Maine in 2016, there were no antimicrobial treatment in Maine from 2017 to 2019 (a longer time series of data for Maine is presented below in Figure 15).

The total antimicrobial use (and also the relative use presented below) is quite variable over time in each region – likely due to the relatively low number of treatments overall, and therefore variability with small increases and decreases in the number of treatments per year. In addition, the dose rate for oxytetracycline and therefore the amount used per treatment for oxytetracycline is much higher than for florfenicol (the average treatment of oxytetracycline in Canada in 2018[50] was 457.8 kg versus 25.3 kg for florfenicol), therefore the use of even small numbers of treatments of oxytetracycline greatly affects the total and relative use in kg or kg/mt of production.

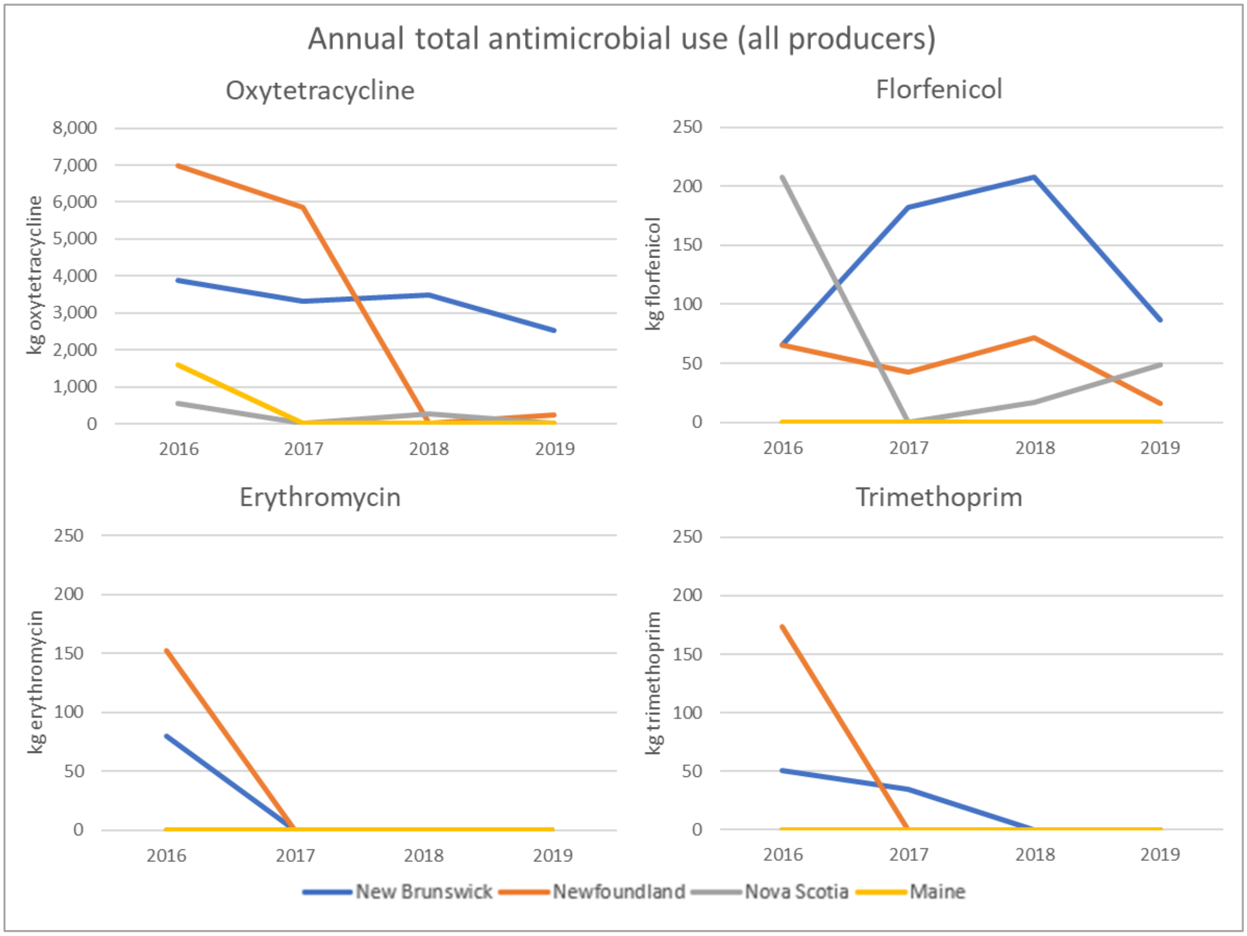

Figure 13: Annual total antimicrobial use (in kg active ingredient) in each region from 2016 to 2019 for four types of antimicrobials. Note the different y-axis scale for oxytetracycline. Data from DFO (for the Canadian regions) and from J. Wiper (pers. comm., 2021) for Maine. These graphs represent all producers in each region.

By comparing the annual total antimicrobial use with the annual regional production, the annual relative use of antimicrobials per mt of farmed salmon production can be calculated and shown in Figure 14 (again noting the different scale to the y-axis for oxytetracycline). This

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[50] 2018 is used here as the last year of DFO data that presents the number of treatments in addition to the quantity used.

shows a similar pattern to the total use, with the same variability due to small increases or decreases in the numbers of treatments. For example, the increase in relative florfenicol use in Nova Scotia (Figure 14 – top right, grey line) is due to zero treatments in 2016 and 2017, one small treatment in 2018, and one larger treatment in 2019.

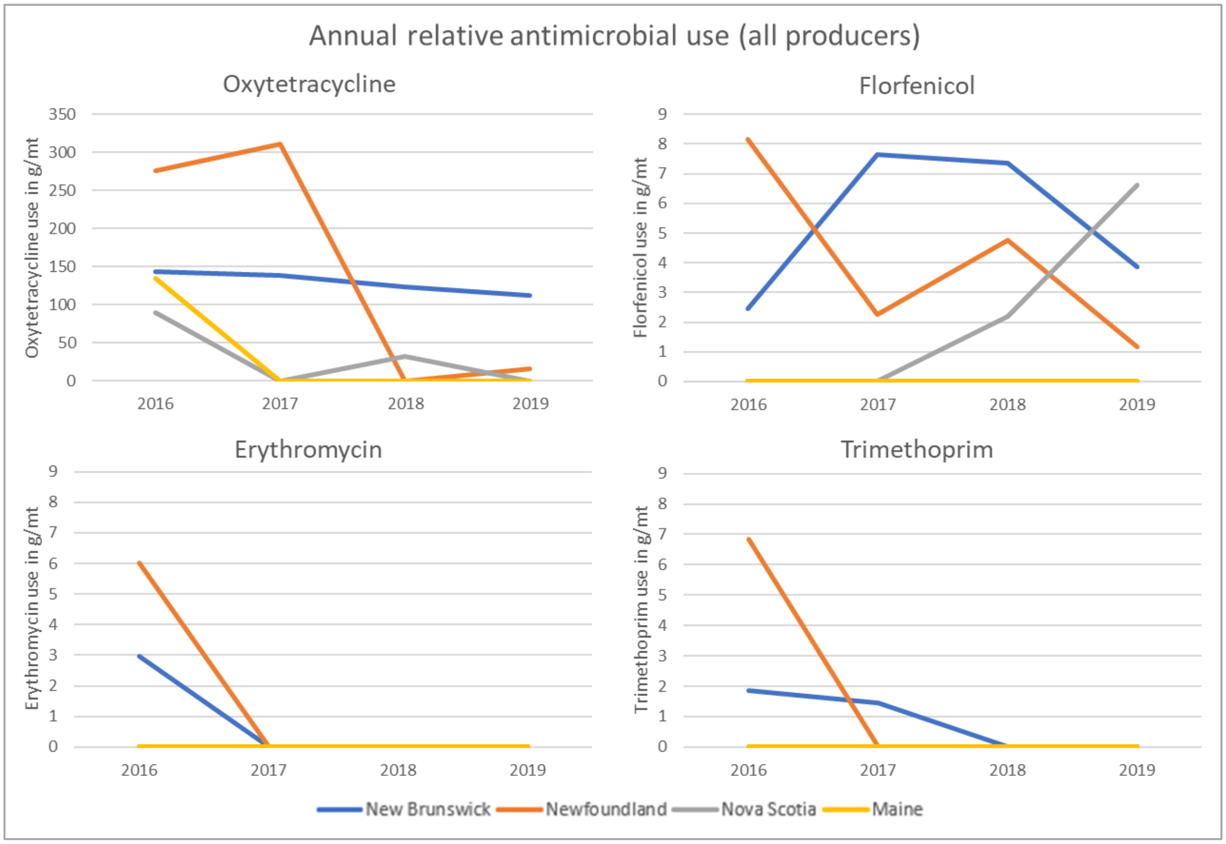

Figure 14: Annual relative antimicrobial use in each region from 2016 to 2019 for four types of antimicrobials. Note the different y-axis scale for oxytetracycline. Data from DFO (for the Canadian regions) and from J. Wiper (pers. comm, 2021) for Maine. These graphs represent all producers in each region.

With regard to treatment frequency, the DFO data show that in 2019, nine Canadian sites were treated with antimicrobials, which is 12.9% of the 70 active sites in that year (Table 1). That is, approximately one in eight sites were treated with antimicrobials, and seven out of eight active sites were not. From 2016 to 2018, the DFO site-level reporting of antimicrobial use included the numbers of treatments or each antimicrobial per site in addition to the total use per site. In 2019 this was not provided. Of the 19 Canadian sites treated with antimicrobials in 2018, six sites were treated twice.

Given that a single company dominates production in the region (operating approximately 80% of active sites) and exclusively operates in Nova Scotia and Maine, the detailed data on prescription numbers provided by the dominant producer is used here to analyze the frequency of use. Figure 15 shows that with the exception of Newfoundland in 2017, there have been on average less than 0.5 antimicrobial treatments per site per year between 2014 and 2020. While it is not known if the antimicrobial use by the secondary producer in Canada is similar to the dominant one, even if were substantially higher, it is likely that the industry-wide average will still be less than one treatment per site per year.

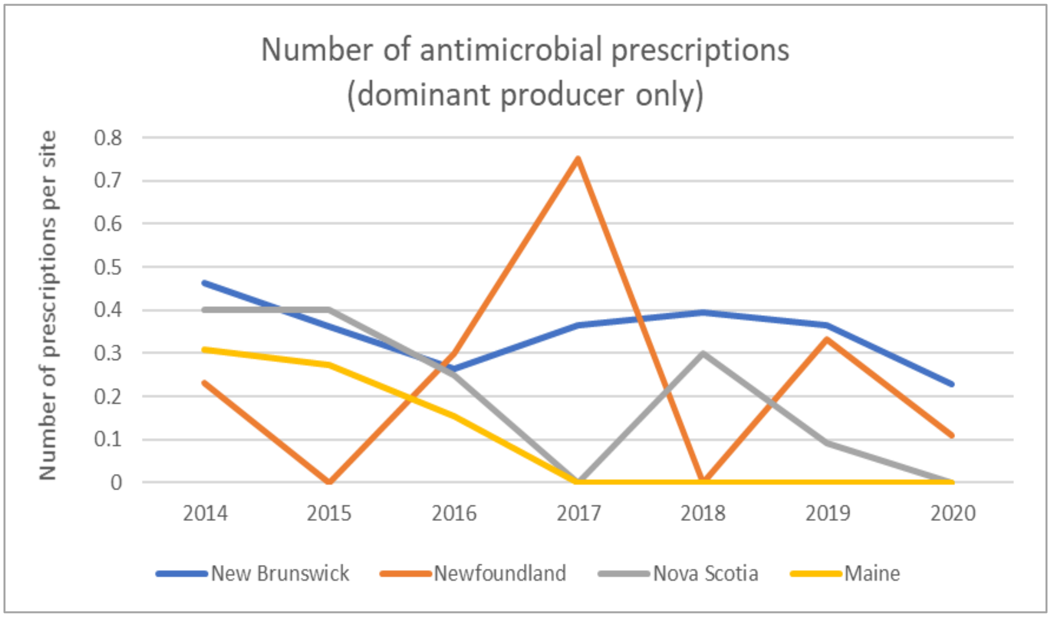

Figure 15: Number of antimicrobial prescriptions per site per year in all four regions for the dominant producer. Data provided by J. Wiper (pers. comm., 2021).

Given the variability across regions and years due to the low number of total treatments, overall trends can be difficult to see. Therefore Figure 16 shows the annual number of antimicrobial treatments per year for the dominant producer combined for all regions (i.e., three Canadian provinces and Maine) and shows a long-term decline in both the number of prescriptions per year (bars) and in the number of prescriptions per site per year (green line).

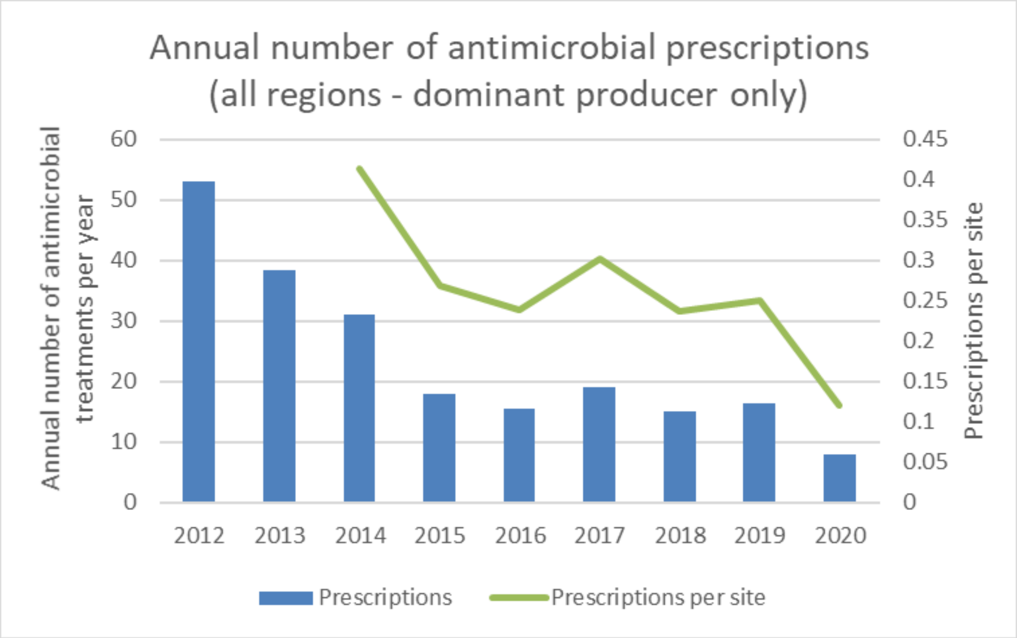

Figure 16: Annual number of antimicrobial treatments for the dominant producer in all four regions of Atlantic North America from 2012 to 2020. Data provided by J. Wiper, pers. comm., (2021).

In summary, antimicrobial use in Atlantic North America has declined since at least 2012 and is currently considered to be less than one treatment per site per year. Love et al. (2020) also report antimicrobial use in Maine is occasional. Data from the dominant producer that operates approximately 80% of active sites in the region (and operates exclusively in Nova Scotia and Maine), shows the average frequency was 0.12 antimicrobial treatments per site in 2020, with zero treatments in Maine since 2017 (and zero in Nova Scotia in 2020). The average number of treatments (of the dominant producer) has been less than 0.5 per site per year since at least 2014, and in 2020 there were only eight antimicrobial treatments across the four regions. The highest antimicrobial use has been in New Brunswick, with an average number of treatments per site per year between 2017 and 2020 of 0.33. While the performance of the secondary producer (in New Brunswick and Newfoundland) may differ from these values, it is considered highly likely that the frequency of antimicrobial use is still less than one treatment per site per year in these two regions.

Antimicrobial resistance

A particular concern in connection with the use of antimicrobials is the development of resistant bacteria, which enhances antimicrobial resistance genes in the environment as well as in the piscine and human microbiome (Love et al., 2020). Antimicrobial resistance is a worldwide public health crisis where the overuse or misuse of antimicrobials in any setting—aquaculture, agriculture, or human medicine—can compromise the treatment of bacterial infections in animals and humans (Ferri et al., 2017).

The development of antimicrobial resistance is a predictable, natural process and ancient among bacteria; however, the current global use of antimicrobial agents in human and veterinary medicine, including terrestrial animal agriculture and aquaculture, is an important driving force for increased antimicrobial resistance selection and evolution. The two types of antimicrobials most commonly used in Atlantic Canada (oxytetracycline and florfenicol) are both listed as highly important for human medicine by the World Health Organization (WHO, 2019) and have been found to select for antimicrobial resistant bacteria when used in aquaculture production (Love et al., 2020, and references therein). The two minor antimicrobials, trimethoprim (not used since 2017) and erythromycin (not used since 2016), are highly- and critically important for human medicine respectively.

Love et al. (2020) reviewed the complex dynamics of antimicrobial resistance in aquaculture (both independently, and by comparison to other users), including the specifics of oxytetracycline and florfenicol, but they ultimately fail to quantify a specific level of concern within the broader concerns about resistance in general. Although every use of antimicrobials potentially selects for resistance genes in bacteria, currently, there is no evidence that antimicrobial use in Atlantic North American salmon farming has resulted in the development of clinical antimicrobial resistance (i.e., resulting in failed treatments), and the frequency of use is low. Nevertheless, there is inevitably some concern regarding any antimicrobial use.

Sea lice pesticides

The pesticides used in eastern Canada and Maine include emamectin benzoate and ivermectin (both provided to the fish as medicated feed), and azamethiphos and hydrogen peroxide (both applied as bath treatments to the fish in the net pens) (Table 3). The registration and approval for use for these chemicals varies between the US and Canada (see the Chemical use regulations and management section below).

Table 3: The pesticides currently used, their tradename, and their route of administration, for the treatment of sea lice in Atlantic salmon aquaculture in Atlantic North America.

Active Chemical	Tradename	Administration Method
Azamethiphos	Salmosan®	Bath
Hydrogen peroxide	Interox® Paramove® 50	Bath
Emamectin benzoate	SLICE®	In-feed
Ivermectin	Ivomec®	In-feed

Figure 17 shows the DFO annual total pesticide use data (in kg per year of active ingredient) for the three Canadian provinces from 2016 to 2019, combined with the equivalent data (estimated[51]) from the major (and only) producer in Maine. Note the different scale of the y-

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[51] These data did not specify quantities of pesticides used for Maine, but provided numbers of prescriptions from which average quantities per prescription from other regions were used to estimate the total quantity used. Where data showed zero prescriptions, the zero values in Figure 18 are considered robust.

axis for different treatment types (for example, hydrogen peroxide has a relatively low toxicity and is applied as a liquid in large volumes).

Over this period, the total pesticide use (not including hydrogen peroxide) declined substantially from 966.2 kg in 2016 to 257.9 kg in 2019, while the total use of hydrogen peroxide decreased from 287,462 kg in 2016 to 11,767 kg in 2018, but increased substantially to 424,990 kg in 2019 (mostly as a result of increased use in New Brunswick). Of the 257.9 kg total in 2019 (not including hydrogen peroxide), 95.1% by weight was azamethiphos. With the exception of a small treatment of emamectin benzoate in 2019, Nova Scotia had zero pesticide use from 2016 to 2019. Maine used small amounts of emamectin benzoate in 2016 and 2017 but used zero pesticides in 2018 and 2019.

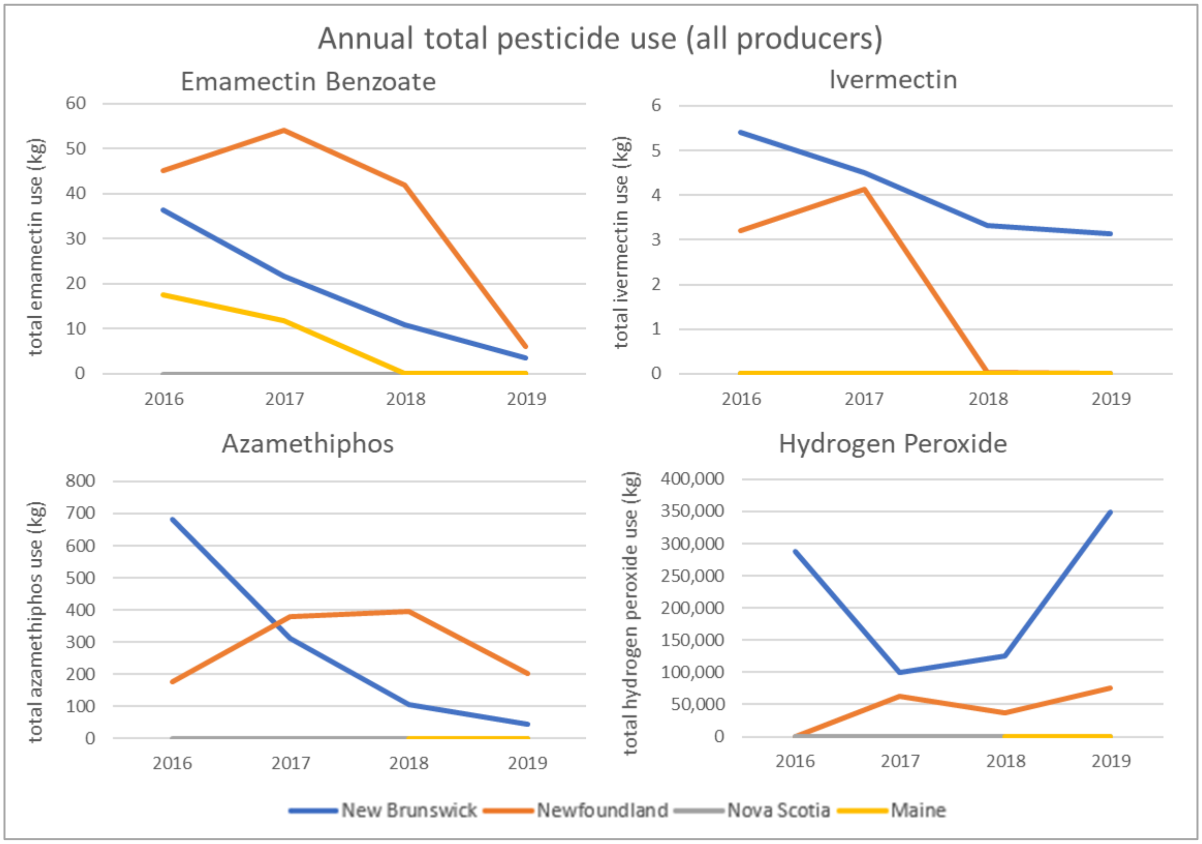

Figure 17: Annual total pesticide use for all regions and all producers. Note the variable y-axis scales. Data for Canadian provinces from DFO, and for Maine are estimated from data provided by J. Wiper (pers. comm., 2021).

By comparing the annual total pesticide use with the annual regional production, the annual relative use of pesticide per mt of farmed salmon production can be calculated and shown in Figure 18 (again noting the different scales for each y-axis). This shows a similar pattern to the total use in Figure 17.

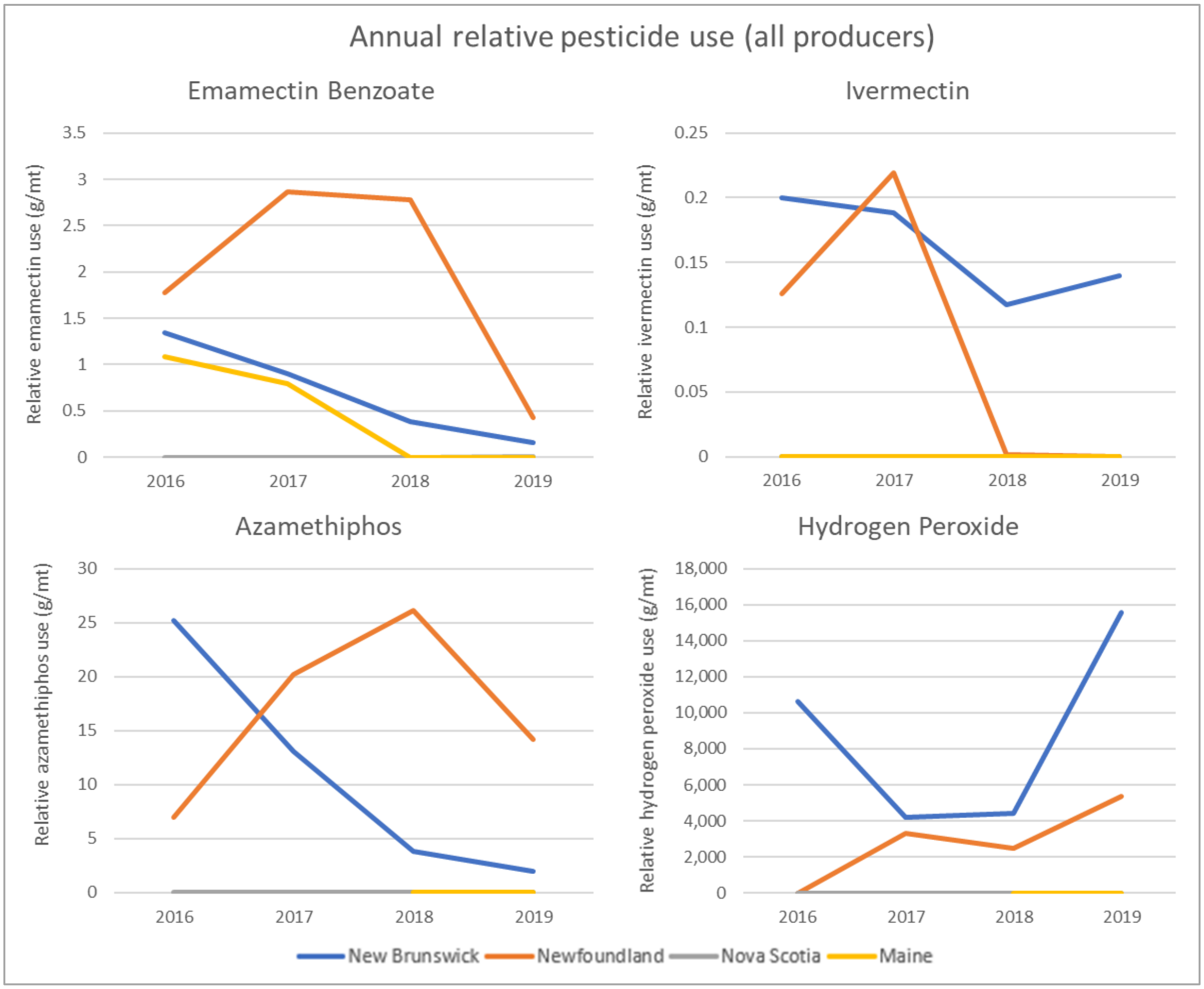

Figure 18: Relative pesticide use for all regions and all producers. Note the variable y-axis scales. Data for Canadian provinces from DFO, and for Maine are estimated from data provided by J. Wiper (pers. comm., 2021).

Analyzing the number and frequency of chemical pesticide treatments is complicated by the lack of frequency data in the DFO data in 2019, and the limited ability to differentiate prescription numbers for bath treatments in the data supplied by the dominant producer. The available frequency data from DFO from 2016 to 2018 shows a substantial decline in the total number of chemical treatments (Figure 19) with a reduction from 450 in 2016 to 231 in 2018.

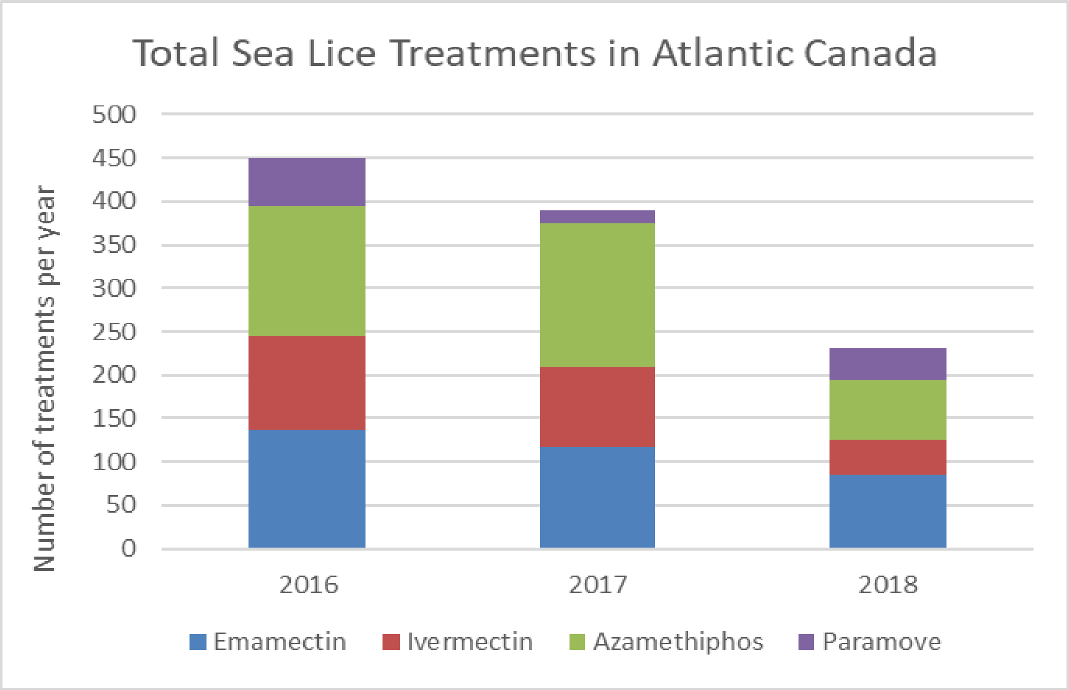

Figure 19: Total chemical sea lice pesticide treatments in Atlantic Canada (for all producers) from 2016 to 2019. Data from DFO.

When the number of treatments is analyzed by treatment type, and by region, the number of treatments per site per region can be calculated. This is shown in Figure 20. These values show considerable variation by treatment, region, and year. For example, Nova Scotia has zero pesticide treatments over this time period, yet other regions have had multiple treatments per site in many cases, particularly when all treatments are combined. Prior to these years, Gautam et al. (2016) note very high numbers of pesticide treatments in the Bay of Fundy, with more than 1,185 treatments involving azamethiphos and hydrogen peroxide applied over 57 sites from 2010 through 2015 (an average of 20.7 treatments per site).

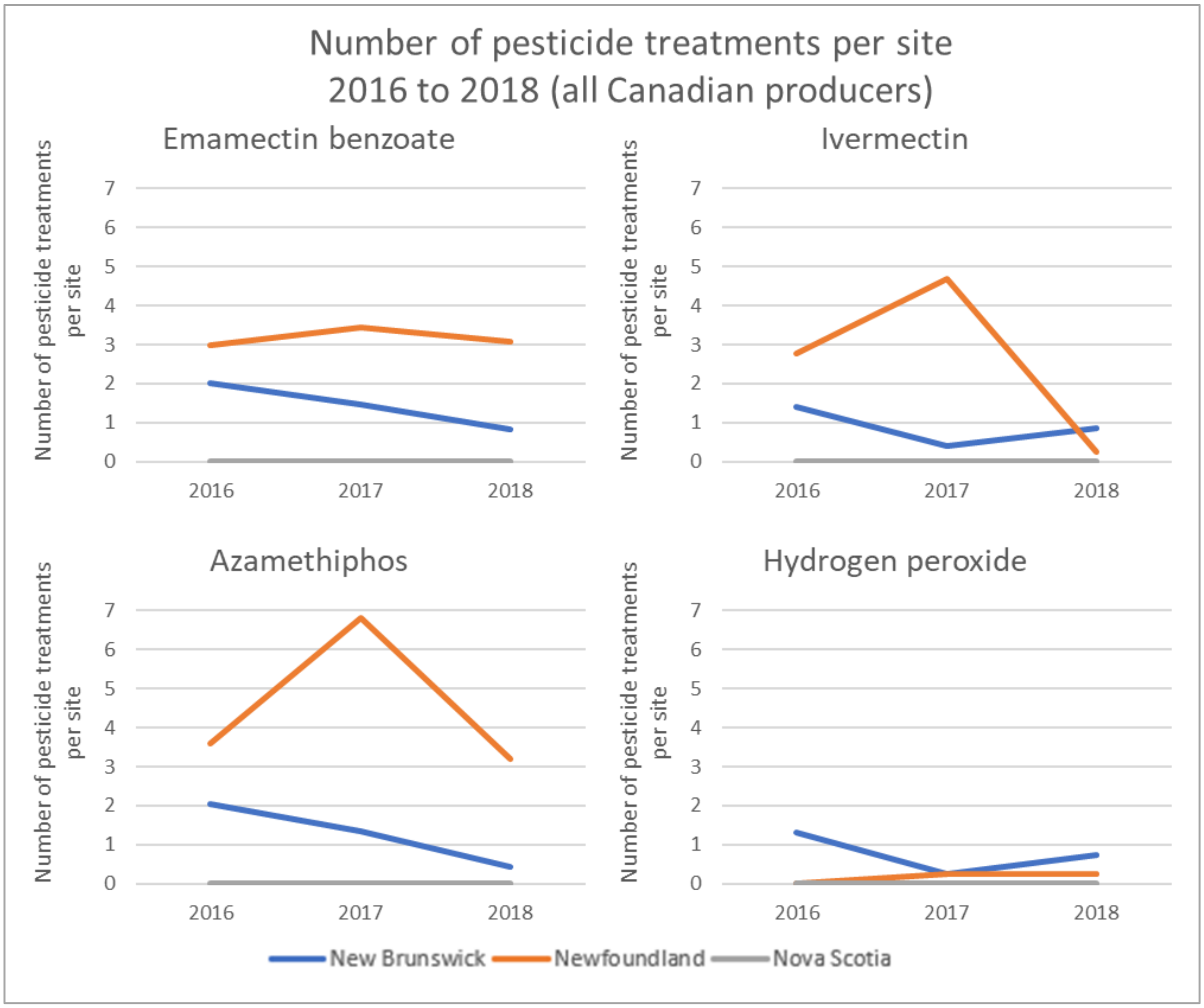

Figure 20: Average number of pesticide treatments per Canadian site (all producers) per year from 2016 to 2018 using DFO frequency data (not available in 2019).

Figure 21 shows the spread of the total number of treatments per site in 2018 (the most recent year in the DFO frequency data) in the three Canadian provinces. Again, Nova Scotia is distinctive in having zero treatments (i.e., 100% of active sites in 2018 received zero treatments). In New Brunswick, 37% of sites in 2018 received no treatments, and 25% of sites in Newfoundland received no treatments. However, there were many sites that received very high numbers of treatments in 2018; 50% of Newfoundland's active sites in 2018 received 10 or more pesticide treatments, as did 9% of New Brunswick's sites. One Newfoundland site received 17 pesticide treatments in 2018 (6 treatments of emamectin benzoate and 11 of azamethiphos). Nearly half (49.9%) of sites in New Brunswick and 68.8% of sites in Newfoundland received two or more treatments in 2018.

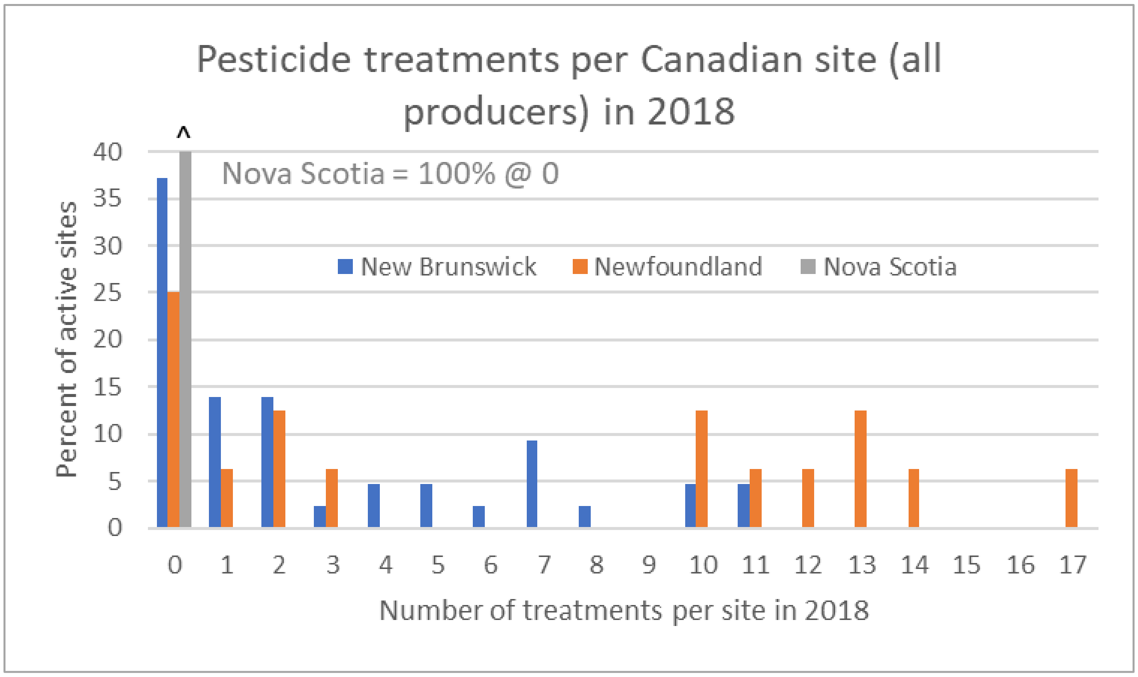

Figure 21: Percentage of active sites (of all producers) in each eastern Canadian province receiving different numbers of pesticide treatments in 2018. Data from DFO.

Since 2017, the major producer in eastern Canada (and sole producer in Maine) has invested in non-chemical treatment methods that have reduced pesticide use. These alternative methods include changes to the net pen structures to reduce the exposure to infective lice stages (sea lice skirts and periscope nets which both limit the entry of, or contact with, sea lice at the top of the water column), and alternative physical and biological treatments (J. Wiper, pers. comm., 2020). All sites in Newfoundland have had cleaner fish (the lumpfish *Cyclopterus lumpus*) stocked within the cages to remove sea lice from the salmon since 2017, and select farms were stocked with cleaner fish in New Brunswick in 2019 (J. Wiper, pers. comm., 2020). Further, the company has invested in physical treatments using warm water (thermolicers) and high-pressure water jets (hydrolicers) on well boats servicing the farms.

With regard to the reduction in pesticide bath treatments (azamethiphos and hydrogen peroxide), Figure 22 shows the increasing use of the alternative non-chemical methods since 2017 (green bars) has resulted in a corresponding decline in the proportion of bath treatments such that the dominant producer eliminated pesticide bath treatments in 2019. Only 2% of bath treatments in 2020 used chemicals (azamethiphos). Given that the use of hydrogen peroxide increased in New Brunswick in 2019 (Figures 17 and 18 above), it is clear that the secondary producer has not yet achieved this reduction in all regions.

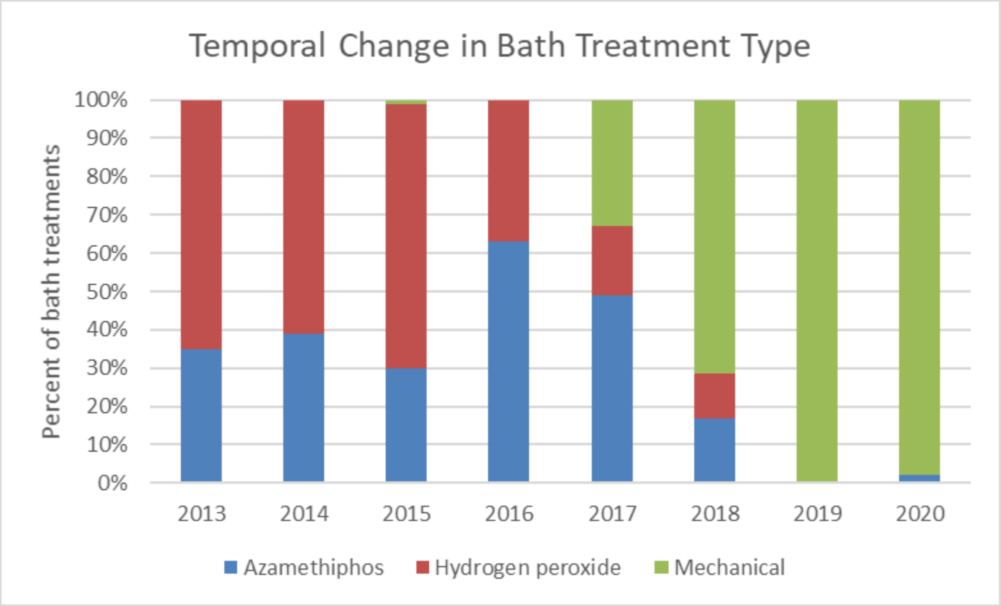

Figure 22: Temporal change in pesticide bath treatments and physical (non-chemical) treatments from 2013 to 2020 for the dominant producer (all regions) showing the percentage of chemical bath treatments using pesticides (azamethiphos and hydrogen peroxide) as they have been replaced by physical treatments (green bars). Data provided by J. Wiper, pers. comm., (2020).

With regard to the reduction of in-feed sea lice treatments (emamectin benzoate and ivermectin), Figure 23 shows that their use was eliminated by the dominant producer in Newfoundland, Nova Scotia, and Maine in 2018 and have not been used since then (according to the available data to the end of 2020). In New Brunswick, they continue to be used at a frequency of 0.7 treatments per active site in 2020 (the dominant producer had 23 in-feed pesticide prescriptions in 2020, 12 of emamectin benzoate and 11 ivermectin), but with approximately half of the active sites, the use by the secondary producer may be continuing.

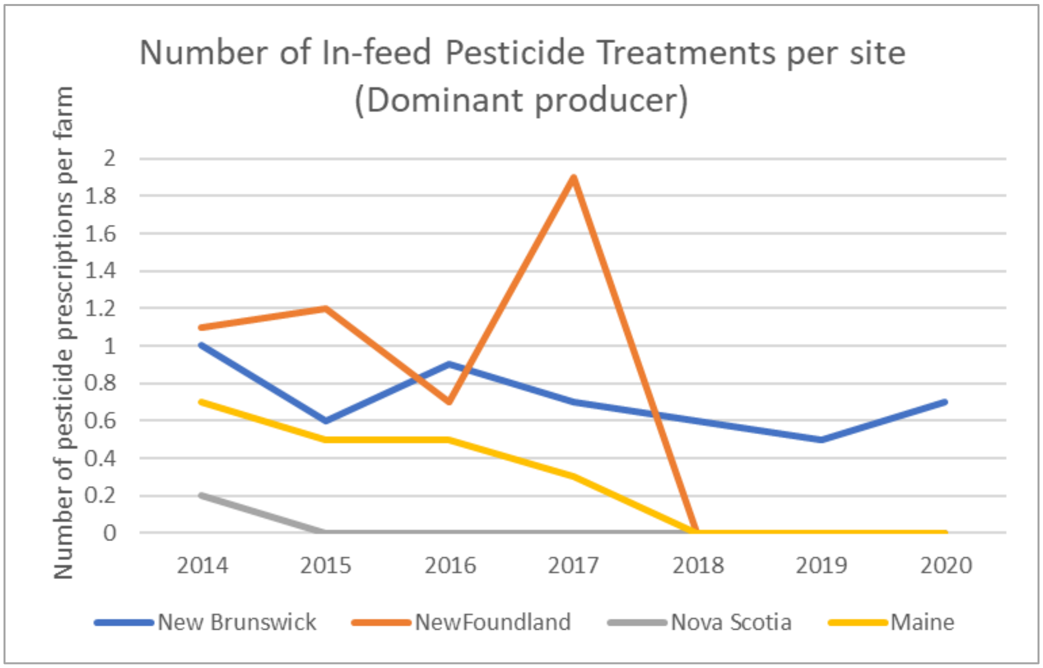

Figure 23: In-feed pesticide frequency of use by the dominant producer according to the number of prescriptions per site per region per year from 2014 to 2020. Data provided by J. Wiper, pers. comm., (2021).

As these more recent data represent only the dominant producer, it cannot be assumed that these rapid declines reflect all farmed salmon production in these regions (with the exception of Maine in which the dominant producer is the only one). Information available in the Atlantic Canada Fish Farmers Association (ACFFA) 2020 New Brunswick Sea Lice Management Report[52] (representing all producers) shows in-feed treatments continue to be used (as seen in Figure 23 above), but also reported 22.7% of sea lice treatments in 2020 used either azamethiphos or hydrogen peroxide. Figures 17 and 18 showed hydrogen peroxide use increased substantially in New Brunswick in 2019 and to a lesser extent in Newfoundland. Without knowing the total number of treatments (i.e., non-chemical and chemical) it is not possible to compare this figure with the analysis above, but it does indicate that not all producers have eliminated bath treatments and reduced in-feed treatments in the same way that the dominant producer has, at least in New Brunswick.

In summary, accurately describing pesticide use in Atlantic North America is challenged by variable data availability in the most recent years, combined with rapid changes in production practices and pesticide use over the same period. Data from the only producer in two regions show there has been no pesticide use in Maine since 2018 and none in Nova Scotia since at least 2016. In New Brunswick, pesticide use has been high with multiple treatments per year on average. The dominant producer (operating approximately 80% of active sites in New Brunswick) still uses in-feed treatments at a frequency of <0.7 treatments per year but has almost eliminated bath treatments. Data from DFO indicate there is likely some ongoing use of in-feed and bath treatments by the secondary producer in New Brunswick. In Newfoundland,

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[52] https://www.atlanticfishfarmers.com/sea-lice-reports

pesticide use has also been high (half of Newfoundland's active sites received 10 or more pesticide treatments in 2018). The dominant producer (operating just over half of the sites) has almost eliminated bath treatments and also eliminated in-feed treatments, but the available data indicate there is likely some ongoing use of in-feed and bath treatments by the secondary producer in Newfoundland, although the exact frequency is uncertain.

Pesticide resistance

The development of increased tolerance in sea lice (i.e., resistance) to chemical pesticides has been a feature of their use in most salmon farming regions; for example, in Norway (which implemented a national surveillance program in 2013), resistance has been noted in sea lice for dichlorvos, azamethiphos, emamectin benzoate, deltamethrin, cypermethrin and hydrogen peroxide for many years, and the annual Norwegian Fish Health reports note widespread resistance to most of these anti-louse chemicals all along the coast (Sommerset et al., 2021). Aquaculture has thus been described as a major driver of salmon louse population structure (Fjørtoft et al., 2020) to the extent that resistance genes are now well established within the louse populations associated with both wild and farmed salmon in Norway (Sommerset et al., 2021).

There are many studies that reflect a similar situation in Atlantic North America, although it is important to note that due to the panmictic nature of sea lice populations, the resistance genes themselves may not have originated in Canada; for example, Besnier et al. (2014) suggested resistance to emamectin benzoate originated in Scotland and spread quickly through the North Atlantic. Nevertheless, the repeated use of sea lice pesticides in Atlantic North America (an average of 20 treatments per site per year in the Bay of Fundy from 2010 to 2015) cannot be ignored (nor can the minimal use of pesticides in Nova Scotia and Maine). Resistance to azamethiphos and emamectin benzoate have been well described, particularly resulting from periods of the industry's development during which it relied on limited numbers of treatment types (for example, azamethiphos was the treatment of choice in the late 1990s, and emamectin benzoate was the only available anti-louse product for nearly ten years in the 2000s (Jones et al., 2012; Burridge & Van Geest, 2014; ACFFA, 2010, 2014b; Jones et al., 2013; Igboeli et al., 2012, 2013).

For the other two pesticide treatments used in Atlantic North America (hydrogen peroxide and ivermectin), there is less evidence of resistance in this region, but again, the experience of other salmon farming countries robustly reflects the concern. For example, the first treatment failures of hydrogen peroxide in Norway were noted in 2013 (Borno & Lie Linaker, 2015), and Sommerset et al. (2021) report that reduced sensitivity to hydrogen peroxide is increasingly widespread along the coast.

From a regional perspective within Atlantic North America, Igboeli et al. (2013) noted that although resistance to emamectin benzoate by multiple species of sea lice is indisputable, not all sea lice populations within a given area are resistant to the drug. In addition to temporal differences and differences in sensitivity between population, species and sex, Igboeli et al. (2013) reported strains of sea lice at Atlantic salmon farms near Grand Manan (a New

Brunswick island in the Bay of Fundy) to be more sensitive to emamectin than sea lice populations close to the mainland. It is not known if these conditions persist, but the general development of resistance to sea lice pesticides in Atlantic North America, like other salmon farming regions or countries, is apparent.

The ability to control sea lice on salmon farms is important to protect wild fish (see Criterion 7 – Disease), and in addition to the direct impacts of high sea lice numbers on the animal welfare of farmed salmon, sea lice may also facilitate bacterial infections and stimulate increased use of antimicrobials (Cabello and Godfrey, 2019). The recent large decrease in pesticide use reflected in the data presented above reduces the potential for the development or persistence of resistance. However, the industry is challenged with controlling sea lice in years of high infection pressure, particularly if non-chemical methods do not have the necessary capacity in an outbreak year such as 2017, and the longer-term establishment of resistance genes in sea lice populations remains a concern. This scenario has perhaps already been reflected in the past, with emergency authorizations of alternative pesticides following increasing resistance to existing authorized treatments; for example, the emergency registration of emamectin benzoate in 1999, and of azamethiphos, hydrogen peroxide, and deltamethrin in 2009 and 2010 (Armstrong et al., 2000; Burridge & Van Geest, 2014). The ineffectiveness of existing treatments due to resistance has also led to the illegal use of alternatives in the same years (i.e., 2009, 2010 and 2017; see the Regulation and Management section in this criterion below).

Overall, the recent decline in pesticide use reduces the concern with regard to the further development of resistance, but the effects of previous overuse of pesticides (particularly in New Brunswick and Newfoundland) on sea lice populations are likely to be maintained for some time.

Pesticides – potential impacts

The potential environmental risks of sea lice pesticides in Canada were reviewed by Burridge and Geest (2014) yet understanding the actual past and current impacts in the different regions of Atlantic North America is complicated by the recent rapid changes in sea lice control methods and the large declines in pesticide use discussed above. Large proportions of pesticide treatments (applied both in-feed or as a bath) can be discharged from the farms after treatment, but the presence of a chemical in the environment does not necessarily mean that it is causing harm (SEPA, 2018). Sea lice pesticides are non-specific (i.e., their toxicity is not specific to the targeted sea lice) and therefore may affect non-target organisms, in particular crustaceans, in the water column and on the seabed in the vicinity of treated net pens (Burridge et al., 2010; Love et al., 2020).

In-feed treatments (emamectin benzoate and ivermectin) tend to be dispersed in small amounts of uneaten feed and, predominantly, in fecal particles that settle to the seabed (Burridge et al., 2010). Samuelsen et al. (2015) and references therein showed that residues in settling organic particles (feces) can be more concentrated than in the feeds. Persistence and/or degradation in the sediment ultimately depends on the chemical nature of the product used and the chemical properties of the sediment and is highly complex (e.g., Hamoutene and

Salvo, 2020), and toxicity to non-target organisms of in-feed sea lice treatments tends to be of a chronic nature at low concentrations (Macken et al., 2015; Lillicrap et al., 2015). Samuelsen et al. (2015) showed that while pesticide residue levels in the sediments are low, particles containing residues have been found as far as 1,100 m from the treatment site.

Sea lice chemicals administered as bath treatments (azamethiphos and hydrogen peroxide) are released to the environment as a water column plume, and the consequence of these releases to nontarget organisms in the receiving environment depends upon the dilution and toxicity of the therapeutant, and whether the non-target organisms are exposed to the released therapeutant; the latter being controlled by the local current regime, the distribution, behavior, and sensitivity of the organisms in relation to the therapeutant (Page et al., 2014). Though some authors contest that such treatments may retain toxicity for a substantial period after release (Burridge et al., 2010), Macken et al. (2015) conclude that, as bath treatments such as azamethiphos, cypermethrin, deltamethrin and hydrogen peroxide have a rapid release, dispersion, and dilution post treatment, they primarily impact non-target organisms in an acute manner with limited potential for chronic impacts. In a study on the epibenthic copepod *Tisbe battagliai* (Macken et al., 2015), azamethiphos was acutely toxic at high concentrations but was found to cause no developmental effects at lower concentrations. More recently, Parsons et al. (2020) report that while azamethiphos is acutely toxic to European lobster larvae (*Homarus gammarus*) at levels below the recommended treatment concentrations, due the hydrodynamic models of dispersion, the impact zones around farms were relatively small (mean area of 0.04–0.2 km^2).

In a Norwegian risk assessment, Grefsrud et al. (2021a) considered many aspects of pesticide use including the quantity used, dilution and spread, product degradation, seasonal variation, overlaps in consumption and occurrence of non-target species, and the sensitivity of likely non-target species. As such, they conclude that when a farm is treated with the pesticides discussed here, it will probably have a local effect on non-target species, but they note that the effect will vary with the chosen treatment type, time of year and local conditions at the time of treatment/discharge. Overall, with consideration of all the available information, Grefsrud's comprehensive risk assessment concluded that the risk of environmental effects on non-target species through the use of emamectin benzoate and hydrogen peroxide was moderate, and low for azamethiphos (other pesticide types were assessed, but they dd not include ivermectin).

Eleven years ago, Burridge et al. (2010) highlighted the fact that: "*no studies (lab or field) have adequately addressed cumulative effects and salmon farms do not exist in isolation*". These authors state "*While the salmon industry has made significant progress in sea lice control using coordinated area treatments, multiple treatments within a single area may result in significantly different exposure regimes for non-target organisms than a single treatment*". In their 2018 report, the Scottish Environmental Protection Agency (SEPA) acknowledged that further work is still required to understand the wider-scale cumulative impacts. The multiple pesticide treatments occurring at many sites in Newfoundland and New Brunswick (up to 17 in 2019 – Figure 21), though have more recently declined, are of particular relevance to Burridge et al.'s (2010) and SEPA's sentiments.

In Atlantic North America, the fishery for the American lobster (*Homarus americanus*) is commercially important, and Milewski et al. (2021) reviewed the state of knowledge of environmental interactions between American lobster and marine finfish aquaculture. Milewski et al. (2021) note that aquaculture-lobster chemical interactions have received considerable study. While the potential acute and chronic toxicity of pesticides in the water column or in sediments, and/or temporary changes in behavior at lower sub-lethal concentration, are well established (typically in laboratory tests), they concluded that the magnitude of any impacts in practice will depend on local oceanography, bathymetry and hydrodynamics, farm production levels, proximity to lobster habitat, and the type and frequency of pesticide or other chemical use.

The challenge of quantifying impacts (or lack of impacts) in the field demonstrates the need for ongoing research, and within the DFO-led Aquaculture Collaborative Research and Development Program[53], the following research lines are either recently completed or ongoing:

- Effects of organophosphate aquaculture pesticide azamethiphos on American Lobster (*Homarus americanus*) larvae (stage I, II, III)
- The lethal and sublethal effects of anti-sea lice therapeutants on marine benthic and pelagic invertebrates
- The environmental effects of anti-sea lice pesticides on marine benthic species
- The environmental effects of anti-sea lice pesticides on marine zooplankton

The challenge of clearly identifying the impacts from the types, quantities and frequencies of pesticide use in the specific conditions at salmon farm sites in Atlantic North America is consistent with the conclusion of Urbina et al. (2019) that the real effects of these pharmaceuticals on the marine environment remain largely uncertain.

Antifoulants

Biofouling, the growth of organisms on submerged structures, is a serious challenge for global marine salmon aquaculture for four main reasons (Bloecher and Floerl, 2020):

- Occlusion of the net causes reduced water flow, increased drag and strain on structures and moorings, deformation of the fish holding area and reduced oxygen levels
- Increased disease and welfare risks as biofouling can harbor pathogens, parasites or other organisms that can lead to gill or skin damage
- Altered behavior of cleaner fish in the presence of an alternative food source
- Net pens represent opportunities for non-indigenous species by offering settlement space and stepping stones for range expansion.

The first stage of biofouling management has traditionally been prevention or minimization of biofouling growth using biocidal coatings on nets, for which copper is the main biocide used (Bloecher and Floerl, 2020). Over time, the product sloughs off the nets and may accumulate and persist for several years in sediments beneath the net pen array (Smith et al., 2005) and

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[53] https://www.dfo-mpo.gc.ca/aquaculture/acrdp-pcrda/index-eng.htm

there have been several studies demonstrating deleterious or mortality-inducing effects on species that may reside under or migrate past areas where farming operations are sited (see reviews by Burridge et al., 2010, 2011).

As such, copper coatings have been largely phased out in some regions and by some companies (Bloecher and Floerl, 2020), and in Atlantic Canada the dominant producer removed the last copper treated net in 2015 (instead, control is based primarily on physical net washing to remove growth at regular intervals) (J. Wiper, pers. comm., 2020).

Chemical use regulations and management

In the US, chemical application in aquaculture requires permitting administered by the US Environmental Protection Agency (EPA) (Rust et al., 2014), and therapeutants are regulated by the US Food and Drug Administration (FDA) (DEP, 2014). The antimicrobials oxytetracycline and florfenicol are approved for use in salmon, but there are no approved sea lice pesticides for salmon (FDA, 2020[54]). As such, salmon farmers in Maine have used cypermethrin (trade name Excis), ivermectin, emamectin benzoate, and hydrogen peroxide under an Investigational New Animal Drug (INAD) permit (ACFFA, 2019).

In Canada, Health Canada is responsible for regulating drugs and pesticides and their use, and the DFO's Aquaculture Activities Regulations (AAR) authorize and control deposits of drugs and pesticides into the ocean by aquaculture companies (OAGC, 2020). There is also an additional component of regulation at the provincial level (e.g., the Department of Environment and Local Government in New Brunswick). While the industry's rapid decline in pesticide use is commended (and noting the provincial variations in the quantity and frequency of pesticide use as described above), there are two aspects of concern with regard to pesticide management in Canada.

Firstly, Report 1 of the 2018 Spring Reports of the Commissioner of the Environment and Sustainable Development (OAGC, 2018) reviewed the controls on the effects of drugs and pesticides. The conclusion of the report was that DFO did not conduct adequate analysis to know whether its rules for drug and pesticide deposits at salmon farms would minimize harm to wild fish. In addition, the report concluded that DFO did not define limits on the amounts of drugs or pesticides that could be deposited or confirm the accuracy of information self-reported by aquaculture companies. While Health Canada conducts a risk assessment process for approved treatments, and product labels specify the conditions of use, the data presented here (e.g., Figure 21 showing 50% of sites in Newfoundland receiving 10 or more pesticide treatments in 2018 of more than one treatment type) demonstrate that there are no practical limits to the frequency of use and/or the combination of multiple treatment types.

Secondly, there are examples of illegal chemical use in eastern Canada and examples of residues of chemicals not approved for use being detected in farmed salmon. In 2017, a salmon farming company operating in New Brunswick was found guilty of knowingly using the pesticide

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[54] https://www.fda.gov/animal-veterinary/aquaculture/approved-aquaculture-drugs

Salmosan (azamethiphos) to control a sea lice outbreak before their application to use it had been granted (Smith, 2018). While there was concern regarding a potential impact to lobster holding facilities, there was no evidence of any direct harm to these containments, and the company received a fine of $12,000. In 2016 Health Canada issued two notices of violation[55] of the Pest Control Products Act a with a total penalty of $8,000 to a Newfoundland-based salmon farming company (subsequently bought by another company operating in the region) for the use of cypermethrin which is not approved for use in Canada. Previous illegal use of chemicals (also cypermethrin) in 2009 and again in 2010 (by a different company) on multiple sites in Canada was associated with an environmental impact to lobster holding facilities (Intrafish, 2011).

In addition, monitoring results from the Canadian Food Inspection Agency (CFIA) Therapeutant Residue Non-compliance Testing Program obtained in 2019 and 2020[56] show five detections of cypermethrin residues between 2014 and 2019, and single detections of crystal violet and gentian violet in 2019, none of which are approved for use in Canada (note none of the detections were above the testing program's action levels). This inspection program is Canada-wide (and therefore includes aquaculture samples from British Columbia and elsewhere), and while the Pesticide Compliance and Enforcement Report for 2015-2016[57] noted a high level of compliance in the aquaculture industry and a compliance rate of 96% in the Atlantic Region, it is not possible to conclude exactly where the sampled fish with detected residues were from, nor to conclusively determine that they are the result of illegal use of these chemicals in Canadian aquaculture facilities[58]. These examples (and the potential for other undetected uses) remain a concern, but when considered at the typical farm-level, the available data indicates the current frequency of detection does not exceed the definition of exceptional cases in the Seafood Watch Aquaculture Standard[59].

Conclusions and Final Score

Antimicrobial use in Atlantic North America has declined since at least 2012. Data from the dominant producer that operates approximately 80% of active sites in the region (and is the only operator in Nova Scotia and Maine) show the average treatment frequency has been less than 0.5 treatments per site per year since at least 2014. In 2020, with only eight treatments across the four regions, antimicrobial use was 0.12 treatments per site. There have been no antimicrobial treatments in Maine since 2017 and there were none in Nova Scotia in 2020. The highest antimicrobial use has been in New Brunswick, with an average number of treatments per site per year between 2017 and 2020 of 0.33. While the performance of the secondary

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[55] https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/public/protecting-your-health-environment/compliance-enforcement/enforcement-bulletins.html

[56] Obtained from CFIA by ATIP - Access to Information and Privacy. Reference numbers A-2019-00072 and A-2020-00203.

[57] https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/corporate-plans-reports/pesticide-compliance-enforcement-report-2015-2016.html#a3-1-4

[58] Note cypermethrin is legally used in neighboring Maine.

[59] Exceptional cases definition: use is clearly limited to a small minority of producers in an industry, or the frequency of use at the farm-level is no more than once in a three-year period

producer (in New Brunswick and Newfoundland) may differ from these data, it is considered highly likely that the frequency of antimicrobial use is still less than one treatment per site per year in these two regions. The dominant treatments (oxytetracycline and florfenicol) are listed as highly important for human medicine by the World Health Organization, highlighting the importance of continued prudent use.

Accurately describing pesticide use in Atlantic North America is challenged by variable data availability in the most recent years, combined with rapid changes in production practices and pesticide use over the same period. Data from the only producer in two regions show there has been no pesticide use in Maine since 2018 and none in Nova Scotia since at least 2016. In the other two Canadian provinces, New Brunswick and Newfoundland, pesticide use has been high prior to 2018 with multiple treatments per site per year on average. In New Brunswick, pesticide use has been high with multiple treatments per year on average. The dominant producer (operating approximately 80% of active sites in New Brunswick) still uses in-feed treatments at a frequency of <0.7 treatments per year but has almost eliminated bath treatments. Data from DFO indicate there is likely some ongoing use of in-feed and bath treatments by the secondary producer in New Brunswick. In Newfoundland, pesticide use has also been high (half of Newfoundland's active sites received 10 or more pesticide treatments in 2018). The dominant producer (operating just over half of the sites) has almost eliminated bath treatments and also eliminated in-feed treatments, but the available data indicate there is likely some ongoing use of in-feed and bath treatments by the secondary producer in Newfoundland, although the exact frequency is uncertain.

The impacts on non-target organisms (including commercially important species such as lobster) of in-feed and bath pesticide treatments continue to be challenging to quantify in the field, but are likely to have been considerable, at least in the immediate farm area during periods of high pesticide use. In addition, the known cases of illegal pesticide use and the detections of residues of chemicals not approved for use in Canada remain a concern although they are considered to represent exceptional cases at the typical farm level. The recent rapid decrease in pesticide use limits these concerns (particularly in areas where pesticide use has been minimal or has largely been eliminated in recent years). The previous high levels of pesticide use have also contributed to the resistance to some treatments observed in the region, but while such genetic changes to sea lice populations may linger, the recent decline in chemical use limits further development.

Overall, the data demonstrate that chemical treatments have been consistently used less than once per site per year in both Maine and Nova Scotia; for both of these regions, the final score for Criterion 4 – Chemical Use is 8 out of 10. For New Brunswick and Newfoundland, with minor antimicrobial use, the uncertainly with the ongoing pesticide use by the secondary producer necessitates some precaution. Although the most recent data implies low use by the primary producer, the relatively recent (e.g., 2018) high frequency of use, combined with the data uncertainty particularly for the secondary producer results in a final score for Criterion 4 – Chemical Use of 2 out of 10 for New Brunswick and Newfoundland on a precautionary basis. While the recent rapid decline in chemical use is recognized here, additional data (particularly from DFO and ideally reinstating the publication of frequency values) to confirm the ongoing reduction would be needed to allocate a trend adjustment (see the Seafood Watch Aquaculture Standard for details).

Criterion 5: Feed

Impact, unit of sustainability and principle

- Impact: feed consumption, feed type, ingredients used and the net nutritional gains or losses vary dramatically between farmed species and production systems. Producing feeds and their ingredients has complex global ecological impacts, and their efficiency of conversion can result in net food gains, or dramatic net losses of nutrients. Feed use is considered to be one of the defining factors of aquaculture sustainability.
- Unit of Sustainability: the amount and sustainability of wild fish caught for feeding to farmed fish, the global impacts of harvesting or cultivating feed ingredients, and the net nutritional gains or losses from the farming operation.
- Principle: sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains

Criterion 5 Summary

Maine, US and Atlantic Canada

C5 Feed parameters	Value	Score
F5.1a Forage Fish Efficiency Ratio	1.13	
F5.1b Source fishery sustainability score (0-10)		5.00
F5.1: Wild fish use score (0-10)		5.50
F5.2a Protein INPUT (kg/100kg fish harvested)	46.67	
F5.2b Protein OUT (kg/100kg fish harvested)	16.90	
F5.2: Net Protein Gain or Loss (%)	-63.79	3.00
F5.3: Species-specific kg CO2-eq kg-1 farmed seafood protein	13.13	7.00
C5 Feed Final Score (0-10)		**5.25**
Critical?	**No**	Yellow

Brief Summary

Feed data were provided by the primary producer representing approximately 80% of feed use in the region. Additional data points, where needed, were obtained from reference feeds in the academic literature and salmon farming company reports. While the formulation generated may not be specifically accurate, the key aspects relating to this assessment were considered to be sufficiently robust and representative of the broader region. Using total fishmeal and fish oil inclusions of 7.2% and 11.1% respectively, an eFCR of 1.3, and yield values modified according to the dominant use of Gulf menhaden, from first principles, 1.13 mt of wild fish must be caught to produce the fish oil needed to grow 1.0 mt of farmed salmon. With 70% of marine feed ingredients sourced from Gulf menhaden and with an unspecified remainder, the overall sustainability was moderate, and resulted in a Wild Fish Use score of 5.50 out of 10. There is a substantial net loss of 63.8% of feed protein (score 3 out of 10) and a low feed ingredient footprint of 13.13 kg CO_2-eq. per kg of harvested protein (score of 7 out of 10). Overall, the three factors combine to result in a final feed score for Criterion 5 – Feed of 5.25 out of 10.

Justification of Rating

The Seafood Watch Feed Criterion assesses three factors: wild fish use (including the sustainability of the source), net protein gain or loss, and the feed "footprint" based on the climate change impact (CCI, in units of CO_2-eq) of the feed ingredients necessary to grow one kilogram of farmed salmon protein. See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations.

Feed composition

The feed composition data for this assessment were mostly provided by the dominant producer, and as this represents approximately 80% of production in the Atlantic North America region, it is considered here to be sufficiently representative of production as a whole. Additional data points have also been compiled from publicly available global and regional data in Mowi's Salmon Industry Handbook (Mowi, 2020) and company reports, and from the specific ingredients in two salmon reference diets in Mørkøre et al. (2020) and Aas et al. (2019), both based on Norwegian feeds. Categorical data from industry reports highlight the key differences between European (i.e., the Norwegian) salmon feeds and those in North and South America, and these are considered to be robustly recognized; i.e., Europe typically does not use land animal ingredients in feeds, while the US and Canada (and Chile) do. Therefore, where there were gaps in the specific ingredient data from the primary producer[60], the alternative available data sources have been used to create a best-fit feed composition for Atlantic North America feeds as shown in Table 4, along with each ingredient's Global Feed Lifecycle Institute (GFLI) value (see Factor 5.3). While the feed composition used here may not reflect the exact ingredients and their inclusions used by the Atlantic North American industry, it is considered to be sufficiently representative of a typical US/Canadian salmon feed for this assessment.

Table 4: Best-fit feed composition and GFLI CCI/mt values from the available data.

Feed Ingredient	Inclusion (% of total feed)	GFLI CCI/mt value
Fishmeal	7.2	1.1843
Fishmeal byproducts	0.0	1.1843
Fish oil	11.1	0.8176
Fish oil byproducts	0.0	0.8176
Wheat	4	0.7813
Wheat gluten	4	3.9989
Soy protein concentrate	5.6	6.4170
Fava beans	2.4	0.7080
Corn gluten	2.4	1.5647
Rapeseed (canola) Oil	8.38	2.9154

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[60] For example, a total of 52.2% inclusion of "land animal ingredients" was allocated here to poultry meal and oil based on the typical ingredients and their inclusion in other references, resulting in the values of 46.4% and 5.8% respectively in Table 4.

Poultry meal	46.4	1.2334
Poultry oil	5.8	3.1717
Vitamin/minerals	3.6	No data
Total	100	

Economic feed conversion ratio (eFCR)

General eFCR values in the academic literature for Atlantic salmon (i.e., not specific to any region) are 1.3 (Tacon et al., 2021; Naylor et al., 2021; Tacon, 2020) and agree with the Norway specific value in Aas et al. (2019) and in Mowi's Industry Handbook (2021). The value of 1.3 is therefore used here.

Factor 5.1. Wild Fish Use

Factor 5.1a – Feed Fish Efficiency Ratio (FFER)

The FFER is calculated using the fishmeal and fish oil inclusion level (in Table 4), the eFCR value of 1.3, and the fishmeal and fish oil yield values from forage fish. In this case, these marine ingredients come primarily (69.9%) from Gulf menhaden (*Brevoortia patronus*) but the remaining species were not specified (J. Wiper, pers. comm., 2021). The yield values for fishmeal and fish oil from menhaden are 22.0% and 16.1% respectively (Parker and Tyedmers, 2012) and using a weighted calculation with the standard yield values for the other (unknown) species (22.5% and 5% respectively), the final weighted yield values used here were 22.2% for fishmeal and 12.8% for fish oil. Using these values, the Forage Fish Efficiency Ratio (FFER) is 0.42 for fishmeal and 1.13 for fish oil. This means that from first principles, 1.13 mt of wild fish must be caught to supply the fish oil needed to produce 1.00 mt of farmed salmon.

Factor 5.1b –Sustainability of the Source of Wild Fish

As noted above, 69.9% of the fishmeal and fish oil is sourced from Gulf menhaden, and this fishery is certified by the Marine Stewardship Council. This has a Sustainability Score of 6 out of 10. The remaining 30.1% of fish meal and oil come from fisheries that are either certified to the IFFO RS scheme[61] or are managed at least to the FAO Code of Conduct (J. Wiper, pers. comm., 2021), and these have a Sustainability Score of 4 out of 10. The weighted Sustainability Score for these fisheries is 5.4 out of 10. Rounding this score to the nearest integer, the final Seafood Watch sustainability score is 5 out of 10, and in combination with the FFER value of 1.13, results in a final score for Factor 5.1 - Wild Fish Use of 5.50 out of 10.

Factor 5.2. Net Protein Gain or Loss

Values for the total protein content of typical salmon feeds from the suite of references stated above average to 35.9% (with a small range of 35.0% to 36.4%). Aas et al. (2019) specify a whole-body composition of farmed salmon of 16.9% crude protein, and this value is used here.

Therefore, one ton of feed contains 359 kg protein; 1.3 tons of feed are used to produce 1.00 tons of farmed salmon (eFCR), and the net protein input per ton of farmed salmon production

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[61] International Fishmeal and Oil Organisation, Responsible Sourcing scheme

is 466.7 kg. With only 169 kg of protein in a ton of harvested whole salmon, there is a net loss of 63.8% of protein. This equates to a score of 3 out of 10 for Factor 5.2.

Factor 5.3. Feed Footprint

This factor is an approximation of the embedded climate change impact (CCI, in units of kg CO_2-eq including land-use change) of the feed ingredients required to grow one kilogram of farmed seafood protein. The calculation is performed by mapping the ingredient composition of a feed used against the Global Feed Lifecycle Institute (GFLI) database[62] to estimate the climate change impact of one metric ton of feed, followed by multiplying this value by the eFCR and the protein content of whole harvested salmon. If an ingredient of unknown or unlisted origin is found in the GFLI database, an average value between the listed global "GLO" value and worst listed value for that ingredient is applied; this approach is intended to incentivize data transparency and provision. Detailed calculation methodology can be found in Appendix 3 of the Seafood Watch Aquaculture Standard.

Calculations based on the GFLI values presented in Table 4 above and following the methodology in the Seafood Watch Aquaculture Standard indicate the CCI is 13.13 kg CO_2 eq per kg of farmed salmon protein. This equates to a score of 7 out of 10 for Factor 5.3.

Conclusions and Final Score

The final score is a combination of the three factors with a double weighting for the Wild Fish Use factor. Factors 5.1 (5.50 out of 10), 5.2 (3 out of 10), and 5.3 (7 out of 10) combine to result in a final score for Criterion 5 – Feed of 5.25 out of 10.

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[62] http://globalfeedlca.org/gfli-database/gfli-database-tool/

Criterion 6: Escapes

Impact, unit of sustainability and principle

- Impact: Competition, altered genetic composition, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations.
- Unit of sustainability: Affected ecosystems and/or associated wild populations.
- Principle: Preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes.

Criterion 6 Summary

Maine, US

C6 Escape parameters	Value	Score
F6.1 System escape risk (0-10)	6	
F6.1 Recapture adjustment (0-10)	0	0
F6.1 Final escape risk score (0-10)		6
F6.2 Competitive and genetic interactions (0-10)		4
C6 Escape Final Score (0-10)		**4**
Critical?	No	**Yellow**

Nova Scotia, Canada

C6 Escape parameters	Value	Score
F6.1 System escape risk (0-10)	4	
F6.1 Recapture adjustment (0-10)	0	0
F6.1 Final escape risk score (0-10)		4
F6.2 Competitive and genetic interactions (0-10)		4
C6 Escape Final Score (0-10)		**4**
Critical?	No	**Yellow**

New Brunswick and Newfoundland, Canada

C6 Escape parameters	Value	Score
F6.1 System escape risk (0-10)	2	
F6.1 Recapture adjustment (0-10)	0	0
F6.1 Final escape risk score (0-10)		2
F6.2 Competitive and genetic interactions (0-10)		4
C6 Escape Final Score (0-10)		**3**
Critical?	No	**Red**

Brief Summary

Best management practices to prevent escapes, such as Codes of Containment, are in place in every region in Atlantic North America and they have been effective in reducing the number of escapes over time. However, net pen systems are inherently vulnerable to both large-scale and small-scale fish escapes, and data show that escapes do still occur in the Atlantic North American industry, albeit with regional variation. Farms in Maine have not reported an escape since 2003, and farms in Nova Scotia have reported only 44 escaped fish in the past ten years. New Brunswick and Newfoundland have each reported many thousands of escaped fish over this time period. Escapees have been shown to disperse rapidly and recapture at sea is unlikely, but a second recapture opportunity occurs in rivers. The number of escaped fish entering rivers in the four regions is highly variable by river and by year, and while fish traps in some rivers allow the recapture and removal of (potentially all) escapees, the extent of their presence and operation across all rivers in the region is not known.

Although the industry in Atlantic North America has largely relied on local broodstocks, farmed Atlantic salmon are genetically distinct from their wild counterparts. Hybridization between escaped and wild salmon and genetic introgression have been demonstrated, particularly after a large escape of mature fish in Newfoundland. While the presence of hybrid offspring declines rapidly, determining the longevity of the introgression and quantifying the impact to affected wild populations remain challenging. Wild salmon populations in the North Atlantic have been in long-term decline (for many decades prior to salmon farming's introduction) and continue to decline in areas with and without salmon farms; nevertheless, several wild salmon populations in the vicinity of the salmon farming industry are of special concern, threatened, or endangered, and any contributions to their further decline or inhibitions of their recovery are a concern.

In Maine, there have been no reported escapes since 2003, very few escaped fish have been detected in rivers, and capture devices in important rivers allow their removal. The production system remains vulnerable, and escapees could potentially enter rivers in areas without recapture devices. The final score for Criterion 6 – Escapes for Maine is 4 out of 10. In New Brunswick, escape numbers have been high and escapees are detected in rivers, and though capture devices in important rivers allow their removal, escapees could enter rivers in areas with vulnerable populations in the Inner Bay of Fundy. The final score for Criterion 6 – Escapes for New Brunswick is 3 out of 10. In Newfoundland, escape numbers have been high and while typical numbers of escapees in rivers are moderate, there are fewer opportunities for recapture and studies of specific escape events have demonstrated genetic introgression in many rivers. The final score for Criterion 6 – Escapes for Newfoundland is 3 out of 10. In Nova Scotia, the number of reported escapes is very low and there have been few escaped fish detected in rivers, but recent and ongoing monitoring appear limited. There are fewer opportunities for recapture in rivers in Nova Scotia and escapees could potentially enter rivers in areas without recapture devices. The final score for Criterion 6 – Escapes for Nova Scotia is 4 out of 10.

Justification of Rating

This criterion assesses the risk of escape (Factor 6.1) with the potential for impacts according to the nature of the species being farmed and the ecosystem into which it may escape (Factor 6.2). The potential for recaptures is a component of Factor 6.1. See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations.

Factor 6.1. Escape Risk

Reported escapes from salmon farms

As long as aquaculture facilities are not fully contained, the escape of farmed fish into the wild is considered to be inevitable, and the net pens used in salmon farming offer the greatest opportunity for escapes as there is only a net barrier between the fish and the wild (Glover et al., 2017). Fish escapes into natural habitats are caused by several internal and external factors and result in the occasional release of a large number of individuals (escape events) and/or the recurrent release of a small number of fish (chronic or leakage escapes) (Atalah & Sanchez-Jerez, 2020).

As a result of these losses (and the potential ecological and direct financial implications), Codes of Containment or similar protocols are now in effect either as voluntary codes or incorporated in regulatory requirements. Newfoundland recently updated its Code of Containment (March 2020[63]), whereas Maine has implemented many of the same aspects into the aquaculture regulations that require a containment management system that is audited annually (Bridger et al., 2015). The situation is similar in Nova Scotia, where the containment requirements have been incorporated in the Aquaculture Management Regulations in 2019[64] including requirements for audits of the containment management systems, and New Brunswick, where containment requirements are included in the aquaculture regulations[65].

Salmon farmers in all regions are required to report escapes, although the circumstances vary under provincial and state regulations. Keyser et al. (2018) identified significant differences in escape reporting requirements across the Atlantic North America region. In New Brunswick, an escape of 100 or more salmon is considered a breach of containment and must be reported to the provincial registrar within 24 hours (General Regulation NB Reg 91-158, Section 14.1). In Newfoundland, the Code of Containment states any escape must be reported to the Department of Fisheries, Forestry and Agriculture within 24 hours (NL-DFFA, 2020), with a similar requirement in Nova Scotia. In Maine, not all escapes are reported – only those involving more than 50 fish larger than 2 kg within a 24-hour period, or escapes involving the loss of more than 25% of the net pen biomass if the fish involved are smaller than 2 kg (Bridger et al., 2015). While these requirements are based on pragmatic limitations of counting accuracies for smaller fish, this would potentially allow the escape of thousands of fish to go unreported in Maine (e.g., if there were 30,000 fish of less than 2 kg in a net pen, then more

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[63] https://www.gov.nl.ca/ffa/files/Salmonid-Code-of-Containment-Updated-March-2020.pdf

[64] https://novascotia.ca/just/regulations/regs/fcraquamgmt.htm#TOC2_7

[65] https://www.canlii.org/en/nb/laws/regu/nb-reg-91-158/latest/nb-reg-91-158.html

than 8,500 could escape without being reported). All sites in Maine are certified to the Global Seafood Assurances (GSA, formerly GAA) Best Aquaculture Practices which requires reporting to the certification body and to GSA if three or more escape events of 500 fish or more or a single event of 5,000 have occurred, but these data are also not publicly available.

Reported escapes have been highly variable in the four regions of Atlantic North America. For this assessment, escapes data were compiled from Morris et al. (2008) from 1994 to 2005, from DFO from 2010 to 2017[66] and from the Maine DMR from 1995 to date[67]. As of September 14th, 2021, the latest Canadian escapes data available from DFO are from 2017, and there were no Canadian data available from 2005 to 2009. The Maine DMR data were also accessed in September 2021, for which the most recent reported escape was in 2003 (again noting the limitations in the reporting requirements). A search of seafood industry media for more recent reported escapes shows these data appear to be current (i.e., no reports of escapes from Maine salmon farms were found after 2003). These searches did show two more recent escapes of 2,500 fish in Newfoundland in 2018 and 1,000 fish in New Brunswick in 2019[68]. Figure 24 shows the compiled escape data for each region.

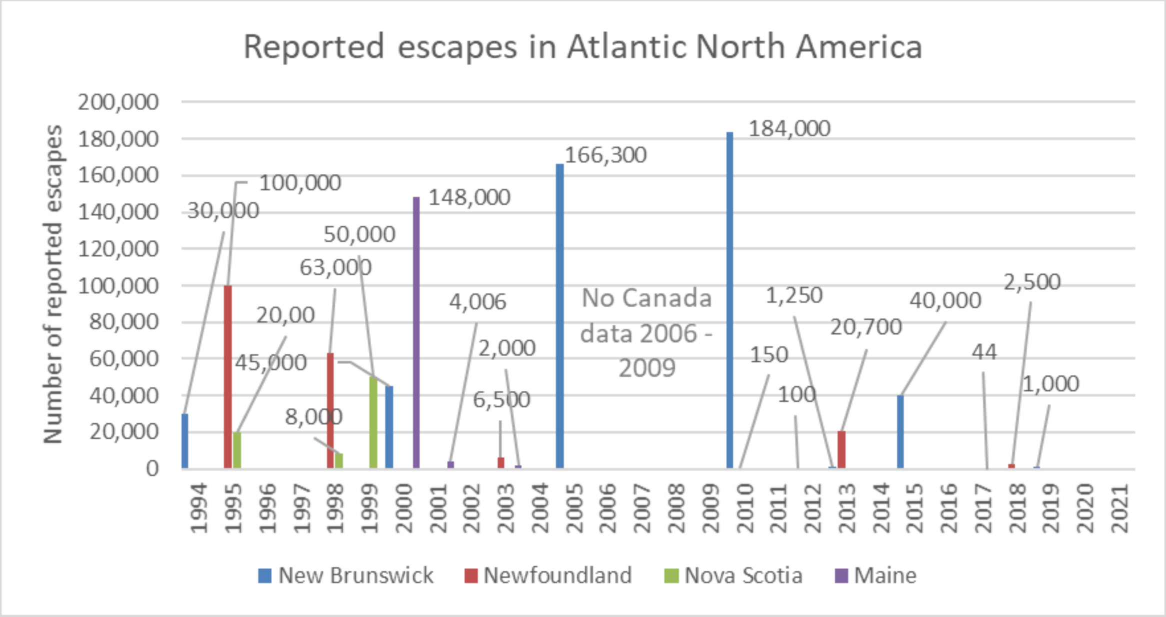

Figure 24: Escape data compiled from DFO, Maine DMR and media searches (see text above for references). Note where a range of escape numbers was listed, the median value was used here.

Morris et al. (2008) reported escapes were due to storms, handling errors, gear failures and boat crashes (which are all directly or indirectly due to human error), but vandalism was equal

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[66] https://www.dfo-mpo.gc.ca/aquaculture/protect-protege/escape-prevention-evasions-eng.html

[67] https://www.maine.gov/dmr/aquaculture/reports/documents/ReportedEscapesofFarmedAtlanticSalmoninMaine.pdf

[68] A third escape in June 2021 of 8,000 to 10,000 salmon was noted in Newfoundland in a landlocked freshwater lake, and has not been included in the escape data shown here.

to storm damage as a reported cause of escape from 1984 to 2005 (there are no recent media reports of vandalism in the Atlantic North America region). The 2018 Spring Report on salmon farming (OADC, 2018) noted the number of salmon reported to have escaped from farms along the Atlantic Coast remained high, partly as a result of the exposure of net pens to the effects of severe storms.

To illustrate the more recent regional reported escapes, Figure 25 shows the 10-year total reported escapes per region from 2011 to 2020 (note this does not include the large escapes in 2010) and also the average annual regional production over the same period[69]. Reported escapes during this period were zero in Maine and close to zero (44) in Nova Scotia but were substantial in New Brunswick and Newfoundland. While the scale of the industry and the number of sites in a region plays a role in the risk of escapes, a difference in performance (at least with regard to reported escapes) is apparent across the four regions.

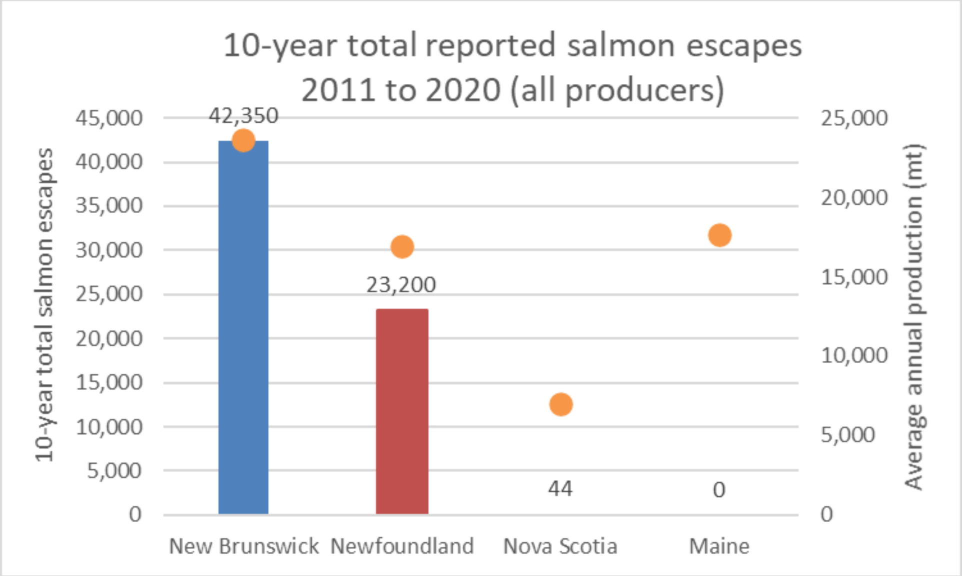

Figure 25: 10-year total reported escapes per region from 2011 to 2020 (values shown with data labels). Orange dots show average annual production in mt from 2011 to 2019 (secondary y-axis, with no data labels). Data from various sources as referenced in the text.

While large escape events are limited to a small number and small proportion of the salmon farms, it is considered that trickle losses can also be significant and potentially not detected or reported (Leggatt et al., 2010; Taranger et al., 2011). Escape statistics are usually based on reports by the farmers themselves and are likely to underestimate, significantly in some circumstances, the actual number of fish escaping from farms (Glover et al., 2017). For example, Sistiaga et al. (2020) noted the escape of small smolts through farm cage netting is a major challenge faced by the Norwegian salmon farming industry when the smolts placed in the net pens are smaller than the size estimated by the farmers, and this is considered here to present a similar risk in Atlantic North America.

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[69] Specifically, the average annual production from 2011 to 2019 given the lack of 2020 production data to date.

In Norway, where significant research has taken place, Skilbrei and Wennevik (2006) note small-scale undetected or unreported escape events may make up a large portion of the total escaped farmed fish, and a modelling analysis by Skilbrei et al. (2015) suggests that the total numbers of post-smolt and adult escapees have been two- to four-fold higher than the numbers reported to the authorities by farmers. ICES (2016) also supports the notion that the true number of escapees is likely to be significantly higher than reported figures. Therefore, with some inevitable uncertainty in specific escape numbers, evidence of escaped fish in the wild can also be considered, as discussed below.

Presence of escaped farmed salmon in the wild

Several studies in Atlantic North America and Norway have shown that escaped fish can disperse rapidly – within hours to days (e.g., Bungay et al., 2021; Dempster et al., 2018; Hamoutene et al. 2018; Skilbrei & Jørgensen, 2010; Skilbrei et al., 2010; Chittenden et al., 2011; Solem et al., 2013; Skilbrei, 2013; Skilbrei et al., 2014; Whoriskey et al., 2006). The dispersal characteristics vary considerably with the size/age of escaping fish, the location, and particularly the time of year, but beyond these immediate post-escape movements, the survival, migration, and ecological interactions of escaping salmon in the wild have also been shown to be complex and dependent on a similar suite of variables (Skilbrei, 2010; Hansen and Youngsson, 2010; Olsen and Skilbrei, 2010). In Norway, Aronsen et al. (2020) reported escaped farmed salmon caught in coastal waters and in fjords in Norway came from multiple escape events over several years, and approximately 50% of the escapees had spent one or more winters at sea after escape (with some spending up to 3 years at sea). The higher proportion of escapees captured on the coast compared to within fjords suggested there is a reservoir of immature farmed salmon in coastal waters, and individuals may enter rivers to spawn with wild salmon when they reach sexual maturity (Aronsen et al., 2020).

It is not known if the same phenomenon happens in Atlantic North America. For example, in contrast to Aronsen et al. (2020), in a simulated escape study in Newfoundland, Hamoutene et al. (2018) reported that migration to the open ocean (from the fjord-like Fortune Bay) was rarely observed in the size/age classes tagged in their study, and it was assumed that most individuals experienced natural mortality due to predation and starvation within Fortune Bay within a few weeks of release. Similar outcomes were seen by Whoriskey et al. (2006) from a simulated escape in Maine.

It is well established that mortality of escaping farmed fish is high; in addition to the Hamoutene et al. (2018) findings in Newfoundland, the review by Glover et al. (2017) suggested that most escaped salmon from marine farms do not return to freshwater. Observation of the empty stomachs in farmed escapees captured in coastal areas, in combination with the lack of change in fatty acid profile in escapees over time, indicated that escapees from marine cages often struggle to adapt to feeding on natural food items once they are in the sea (Glover et al., 2017). In some regions, seal predation is also suspected to cause mortality of escapees. In Maine, 56% of tagged salmon released in the winter died in the surrounding coastal region, as did 84% of those released in spring, probably the result of seal predation (Whoriskey et al., 2006). While the evidence indicates that survival to sexual maturity of feral escapes is very low and only a small proportion of escapees manage to survive and enter rivers, the number may still be numerically high due simply to the high number of escapes where they do occur.

It is also important to note that if escaped fish are able to reach spawning grounds and spawn with other farmed or wild counterparts, some male parr in their offspring are able to mature and successfully spawn[70]; however, while parr spawning may "fast track" introgression of farmed salmon in natural populations as they do not have to survive until adulthood to spawn, the actual impact and relative spawning success for male parr of farmed, hybrid and wild origin is uncertain, particularly as the tendency for parr maturation in farmed strains is lower than in wild populations (Glover et al., 2017).

Morris et al. (2008) reported escaped farmed salmon had been found in 54 of 62 rivers (87%) within a 300 km radius of the Atlantic North American aquaculture industry since 1984 (including 11 rivers that contain endangered salmon populations, discussed further in Factor 6.2). Extending the data of Morris et al. (2008), Keyser et al. (2018) documented 467 records from the 1980s to 2016 in 112 rivers, with a total of 9,236 escaped farmed salmon, primarily in rivers proximate to the aquaculture industry. While Keyser et al. (2018) noted that these records likely represent a minimum number of detections since identifying and quantifying escapes will depend on the location, timing, frequency, and extent of surveys carried out for this purpose, they also noted that reports of the presence of escaped farmed salmon are often not an unbiased sample, with opportunistic or targeted non-random sampling the norm. Similarly, the identification of farmed versus wild[71] salmon (in the wild) may have some element of error[72].

The results of Keyser et al. (2018 – supplemental information) shows the presence of farmed salmon is highly variable by river (i.e., many rivers have very few farmed salmon detected, while others occasionally have thousands) and is also highly variable by year (i.e., some rivers have escapes detected only in a few years of the 1980-2016 dataset, whereas other rivers have escaped farmed salmon almost every year). Figure 26 shows the numbers of escaped farmed salmon detected from the 1980s to 2016 as reported by Keyser et al. (2018), indicating that rivers in Passamaquoddy Bay in New Brunswick and rivers in southern Newfoundland generally had the highest numbers of escaped farmed salmon.

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[70] Farmed parr could also be present in rivers due to escapes from freshwater hatcheries.

[71] Note "wild" in this case includes wild spawned and hatchery raised restocked fish. Hatchery-raised fish for restocking may display some characteristics of farmed salmon e.g., fin damage.

[72] For example, the first use of DNA analysis to determine the source of salmon in the Magaguadavic River in 2017 identified two of seventeen presumptive escapes did not match farm genetics (J. Wiper, pers. comm., 2020). It is also plausible that the DNA analysis will identify presumptive wild fish as escapes.

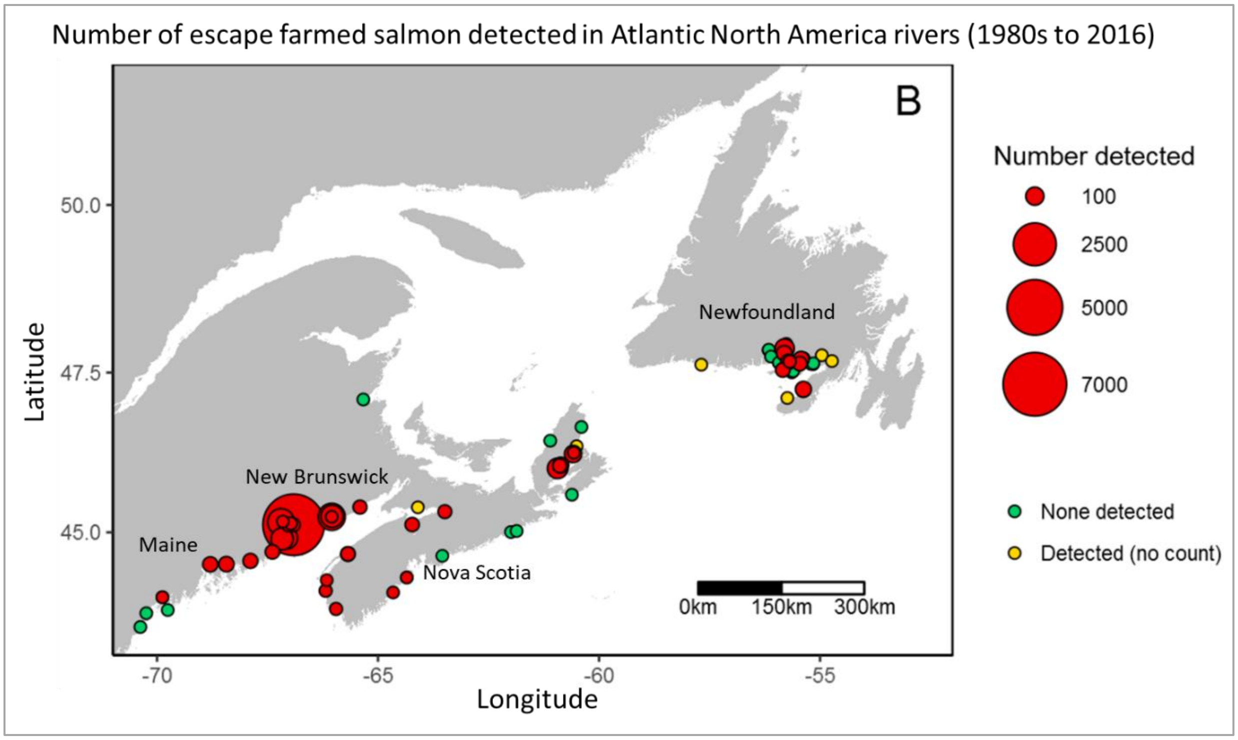

Figure 26: Number of farmed salmon detected in rivers in Atlantic North America from 1980 to 2016. Data from Morris et al. (2008) and Keyser et al. (2018 – supplemental information)

The average proportion of farmed salmon in the total count of salmon (i.e., wild + farmed) in the Keyser et al. dataset (i.e., from 1980 to 2016) is 10.1% in Maine, 22.5% in New Brunswick, 6.0% in Newfoundland and 6.2% in Nova Scotia, but it is important to interpret these data with caution; for example, the numbers detected are likely to vary by the capture method. The Keyser et al. (2018) dataset reported 13 different sampling methods which vary considerably by river and by region. For example, Maine and New Brunswick mostly used fishways and counting fences that count both (and potentially all[73]) wild and farmed salmon ascending rivers, whereas Newfoundland had many angler reports of farmed salmon and only a few counting fences. Nova Scotia had a wide variety of capture/sampling types, and the sampling was considered to be somewhat limited, particularly in the latter years of the Keyser et al. (2018) data.

With consideration of the temporal pattern of reported escapes in Figure 24 and the lower numbers of reported escapes in recent years, a second analysis of the Keyser et al. (2018) dataset from 2010 onwards shows much lower proportions of farmed salmon (despite declining wild salmon populations). Of all counted salmon, 0.04% were identified as farmed in Maine, 10.0% in New Brunswick, 0% in Nova Scotia; insufficient data existed to calculate a value for Newfoundland[74]. Data reported in the Annual Report of the US Atlantic Salmon Assessment Committee allows a further extension and/or confirmation of these data for Maine (Penobscot

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[73] Fishway traps are typically operated for approximately 6-7 months of the year (USASAC, 2020).

[74] With a dominance of angler reports of farmed salmon in Newfoundland, there is commonly no equivalent number of wild salmon with which to calculate the percentage of escaped farmed salmon.

River, Kennebec River and eastern Maine coastal rivers) with thirteen farmed fish captured in the last ten years, and only three fish in the six years from 2013 to 2020 with an average proportion over the last ten years (2010 to 2019) of 0.12% (USASAC, 2021). With consideration of the rivers in Passamaquoddy Bay in New Brunswick identified by Keyser et al. (2018) as having a high prevalence of farmed salmon, the numbers of farmed salmon have exceeded those of wild[75] salmon in 17 of the 20 years from 2000 to 2019 (again noting the numbers of wild fish have declined to very low levels).

Although potential genetic introgression is discussed in Factor 6.2, it is of relevance here to note the population simulations of Bradbury et al. (2020) which suggested that as the percentage of escapees within a population equals or exceeds 10%, both demographic decline and genetic change are expected, and the magnitude of these changes increases with increasing proportions of escapees present. This is similar to Norway's national monitoring program for escaped farmed salmon, which considers <4% of farmed salmon in the sampled population to be a low frequency of farmed escaped salmon, between 4% and 10% to be moderate, and >10% to be high (Aronsen et al., 2020). Using these values with the complete Keyser et al. dataset shows Maine and New Brunswick with a high proportion (>10%) and Newfoundland and Nova Scotia with a moderate proportion (<10%), but when considering the more recent data from 2010 onward, only New Brunswick had a high proportion (again noting the caution required with regard to variations in the sampling/capture methods).

Recaptures of escaped farmed salmon

As noted and referenced above, several studies in Atlantic North America and Norway have shown that escaped fish can disperse rapidly – within hours to days. Studies in Atlantic North America (Bungay et al., 2021, Hamoutene et al. 2018, and Whoriskey et al., 2006) conducted in Maine and Newfoundland found that surviving escapees dispersed rapidly (>1 km from the cage site within a few hours) although fish swimming patterns are mediated by fish size, season, and release location (Hamoutene et al., 2018; Bungay et al., 2021). While Hamoutene et al. (2018) showed that few fish left the larger bay system (Fortune Bay in Newfoundland – approx. 750 km^2), these studies concluded that recapture efforts would need to be immediate, and escapees were unlikely to be recaptured considering the rapid dispersal of the fish from the release site.

Each of the Atlantic North American regions is considered to have recapture protocols as part of their codes of containment and/or regulations; for example, Newfoundland's 2020 Code of Containment (Appendix 7) describes the "Measures for the recapture of escaped fish" including eligibility for a recapture license, the activation or trigger to determine if recapture efforts should be initiated, the recapture gear, use of the gear, and a broader recapture plan. Despite these protocols, salmon farming companies require permission from DFO as to when recapture efforts are permitted and their limitations, i.e., not all escape events are permitted to conduct recapture efforts.

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[75] "Wild" in this case includes wild spawned and hatchery raised stocked fish.

DFO includes some information on recaptures in their escape reporting data[76], but the 8-year dataset from 2010 to 2017 which includes 18 reported escape events or potential escape events shows only three had any recapture effort (noting again that DFO must give permission for recapture efforts to take place). Only one included the number of fish recaptured: 200 fish from an unknown escape number in 2015. Quotes attributed to a DFO spokesperson in a media report[77] following an escape of 2,000-3,000 fish in Newfoundland in 2018 mention the recapture of 400 fish or approximately 15-20%, and also note a recapture of 10% of a large escape in 2013. Given the practical challenges of recapturing escapes at sea, there is not sufficient evidence to show that recapture efforts lead to a consistent reduction in escape numbers.

A second opportunity to recapture escapees is provided by fishway traps, counting fences or other collection or capture devices used in rivers (i.e., after any fish that have survived predation and starvation at sea enter rivers, but before they reach spawning grounds). For example, after an escape of approximately 1,000 salmon from a farm in New Brunswick 2019, 62 presumptive escapees were captured by the ASF[78] at a live trap on the Magaguadavic River fishway (which discharges into the Passamaquoddy Bay in New Brunswick) and removed from the river (culled). Thus, fish that had escaped from marine growout net pen sites and succeeded in entering rivers were removed prior to any potential spawning. The detailed river data in Keyser et al. (2018) show fishway traps were the source of data in almost all Maine rivers, and the majority in New Brunswick. Fish traps are operated for approximately 6-7 months each year through the period of adult up-river migration, and any escaped farmed salmon (typically identified in the field by a scale analysis) are removed (culled) (USASAC, 2020; ASF, pers. comm., 2021).

As these devices are capable of capturing all salmon migrating up-river (wild salmon are subsequently released to continue upstream), they have the potential for a high recapture rate of escapees, even approaching 100%. For example, O'Reilly et al. (2006) reported that all escaped farmed salmon entering the Magaguadavic River have been removed at the fish ladder since 1996. However, while these recaptures prior to reaching the spawning grounds eliminate the potential genetic impacts of these fish, the number of rivers with traps in operation is uncertain. An analysis of the Maine rivers in USASAC (2020) indicates that while traps are located in many important rivers, not all are in operation every year, some operate on a visual count basis only (i.e., no removal of fish), some can be by-passed by the fish, and there are many rivers without them. In New Brunswick, the focus of available information is on the Passamaquoddy Bay, and while the case of the Magaguadavic River is noted above, it is not known how many other rivers in New Brunswick have operational traps. In Newfoundland and Nova Scotia, Keyser et al. (2018) noted fewer data sets from fish traps, and again it is not known how many rivers in these provinces have effective fish recapture devices but it is

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[76] https://www.dfo-mpo.gc.ca/aquaculture/protect-protege/escape-prevention-evasions-eng.html

[77] CBC News, Aug 16. 2018. About 400 escaped salmon recaptured in Hermitage Bay. https://www.cbc.ca/news/canada/newfoundland-labrador/salmon-escape-hermitage-bay-cooke-aquaculture-1.4787269

[78] https://www.asf.ca/news-and-magazine/in-the-field/more-escapes-arrive-at-magaguadavic-fishway

considered here to be low. With limited evidence of their widespread and/or routine use, there is not sufficient evidence with which to justify a recapture adjustment.

Conclusions: Factor 6.1 – Escape Risk

The net pen production system is inherently vulnerable to escapes, despite the presence in all regions of best management practices for design, construction, and management in the form of codes of containment. Reporting requirements vary by region, but the available data indicate reported escapes in Maine and Nova Scotia have been close to zero in the last ten years, while there have been substantial reported escapes in New Brunswick and Newfoundland (approximately 42,000 and 23,000 in total respectively). The true escape numbers may be higher (due to unreported or undetected losses), but the number of fish reaching spawning grounds is the primary concern. The extended data collection by Keyser et al. (2018) showed the capture of escaped salmon in 112 Atlantic North American rivers, primarily those proximate to the aquaculture industry, and the highest numbers of escaped farmed salmon were generally found in the rivers in Passamaquoddy Bay in New Brunswick and in southern Newfoundland. More specifically, the detection of escaped fish in the wild is highly variable by river and by year. In well-studied rivers that have effective fish trapping devices such as the Magaguadavic in New Brunswick (flowing into Passamaquoddy Bay), the number of escaped fish has outnumbered wild fish in 17 of the last 20 years, but in general, the numbers of escaped farmed salmon detected in rivers have decreased over time (as have the numbers of returning wild salmon). Since 2010, New Brunswick has had a moderate-high average prevalence of farmed salmon (10% of salmon captured in rivers were identified as farm escapes), while Maine and Nova Scotia have had close to zero or zero detections of escaped fish. The scores for Factor 6.1 are as follows:

- Maine: reported escapes have been low combined with only occasional detection of low numbers of escapes in rivers for the last ten years. The production system is still inherently vulnerable. Some rivers have effective recapture methods, but many do not, and the score for Factor 6.1 – Escape risk is 6 out of 10.
- New Brunswick: reported escapes have been high, the production system is still inherently vulnerable, and escapees are frequently detected in rivers. While some rivers have effective recapture methods, many do not. The score for Factor 6.1 – Escape risk is 2 out of 10.
- Newfoundland: Escape numbers have been moderate with infrequent detection of large numbers or moderately frequent detection of low numbers of escapees in the wild. The production system is still inherently vulnerable, with few demonstrable opportunities to recapture significant amounts of fish in rivers. The score for Factor 6.1 for Newfoundland is 2 out of 10.
- Nova Scotia: Maine: reported escapes have been low, with only occasional detection of low numbers of escapes in rivers, but recent and ongoing monitoring appear limited. The production system is still inherently vulnerable, with few demonstrable opportunities to

recapture significant amounts of fish in rivers. The score for Factor 6.1 – Escape risk is 4 out of 10.

Factor 6.2. Competitive and Genetic Interactions

Figure 27 shows a map of the North American Atlantic salmon populations grouped into seventeen Distinct Population Segments separated by the sections of coast into which their home rivers drain. The salmon farming industry is located in close proximity to the natal rivers of some of these populations (Population Segments 4, 14, 16, and 17 in Figure 27).

Figure 27: Map of North American Atlantic salmon populations. Colors are to facilitate the distinction of population segments. Map copied and modified from https://www.asf.ca/about-atlantic-salmon/state-of-populations

Genetic status of farmed stocks

The first Atlantic salmon breeding programs in Atlantic North America were aimed at salmon ranching in New Brunswick, and used broodstock fish from many rivers (Glebe, 1998). Although used in the first salmon farms in the region, these strains were abandoned due to disease in the broodstocks; subsequently, aquaculture strains were developed solely from broodstock from the St. John River (SJR) (which starts in Maine and enters the ocean in the Outer Bay of Fundy in New Brunswick) and have been used since then (Glebe, 1998). These SJR strains have also been used in Nova Scotia and Newfoundland (Wringe et al., 2018).

The same SJR strains were initially used in Maine farms in the early 1980s but were used in conjunction with local stocks (from the Penobscot River) and smaller numbers of European origin eggs from Scotland, Iceland, and Finland from 1989 (Glebe, 1998, DFO, 2018). The Scottish imports were from Landcatch, which used the Norwegian Mowi strain, and further imports of Norwegian and Icelandic strains occurred in 1997 (Glebe, 1998).

Since 2003/4, all fish stocked in Maine were required to be of North American strain (J. Wiper, pers. comm., 2020), and all production in Atlantic North America now uses strains of salmon that originated in the region. Broodstock in Maine are reported to be at least ten generations removed from wild populations (S Belle, pers. com.; J Lewis, pers. com.), and because of these extensive breeding programs, the fish in current production are considered to be genetically distinct from the wild populations in all rivers into which they may migrate.

It is of relevance to note the planned stocking in 2022[79] of new farms in Newfoundland (in Placentia Bay) with triploid all-female salmon with a production capacity of 30,000 mt. In the event of a future escape of these fish, the direct risks of genetic introgression would be minimal.

Relative proportions of escaped and wild salmon in rivers (and spawning grounds)

Although already discussed in Factor 6.1, the relative proportion of escaped farmed salmon in wild populations is a key factor in genetic introgression. The population simulations of Bradbury et al. (2020) suggested that as the percentage of escapees within a population equals or exceeds 10%, both demographic decline and genetic change are expected, and the magnitude of these changes increases with increasing proportions of escapees present. This is consistent with studies in Norway (Taranger et al., 2015) that concluded there was a high risk of genetic change when there is a 10% incidence of escaped farmed salmon within the total population of wild salmon returning to a river (there was no or low risk of genetic change with 4% incidence of escaped farmed salmon, and a moderate risk of genetic change with 4–10%). It must be noted that “genetic change” is challenging to quantify, and also cannot yet be unequivocally paired with any quantifiable decline in population size or viability.

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[79] https://www.fishfarmingexpert.com/article/grieg-postpones-first-stocking-in-newfoundland-as-precaution-against-isa/

The data presented above (primarily from Keyser et al., 2018) show the numbers of escaped fish caught in rivers are highly variable by river and year (and by sampling effort) in most regions of Atlantic North America. The potential relative proportions of farmed salmon among wild populations (which is also dependent on the associated numbers of wild salmon) is also likely to be highly variable. In Maine, the numbers of farmed salmon in rivers have consistently been low (Figure 26) and they are removed from the river before reaching the spawning grounds. In New Brunswick, the proportion of escaped farmed salmon in rivers has been high, and exacerbated by the very low numbers of wild fish. In many important rivers, the escaped fish are removed. In Newfoundland and Nova Scotia, the numbers of escapees detected in rivers have generally been low (also see Figure 26 - with the exception of specific events such as the large 2013 escape of mature fish) but the proportion of escapees among wild fish may also be significant given the declines in wild salmon populations described in the following section.

While escape numbers are important, the primary factor affecting the proportion of escapees among spawning wild populations (in addition to the size of the wild populations) is the mortality of escapees prior to reaching the spawning grounds. As discussed in Factor 6.1, it is well established that mortality of escaping farmed fish is high. The global review by Glover et al. (2017) suggested that most escaped salmon from marine farms do not return to freshwater, and in contrast to the Norwegian example showing a reservoir of immature farmed salmon in coastal waters from which individuals may enter rivers to spawn when they reach sexual maturity (Aronsen et al., 2020), the examples from Atlantic North America also show high mortality (Hamoutene et al., 2018; Whoriskey et al., 2006). Following the recent escape of 48,834 adult farmed salmon in Scotland in 2020, Fisheries Management Scotland (FMS) estimated that (a minimum of) 3,000 farmed salmon entered Scottish rivers following this escape event, indicating approximately 94% mortality prior to entering rivers.

<u>Evidence of hybridization, genetic introgression, and quantifiable impacts</u>
Bradbury et al. (2020) summarize the general situation as follows (referencing multiple studies, of which those relevant to Atlantic North America are: Wringe et al., 2019, 2018; Keyser et al., 2018; Sylvester et al., 2019, 2018):

> Genetic interactions (i.e., hybridization) between wild and escaped Atlantic salmon from aquaculture operations have been documented across the natural range of the species where the two co-occur. Escaped farmed Atlantic salmon regularly occur in both Europe and Atlantic Canada and have been commonly found in rivers at distances of up to 200 km from the nearest aquaculture site, although distant occurrences at sea have also been reported. As a consequence, hybridization between wild and domestic salmon can be both spatially extensive and represent a significant proportion of a population's annual production. Both experimental and field studies have demonstrated decreased survival of hybrids in the wild and suggest that wild population declines and genetic changes are the likely outcomes of hybridization and introgression. As a result, genetic interactions with escaped farmed salmon have been identified as a significant threat to the persistence and stability of wild Atlantic salmon populations.

It must be emphasized that Bradbury et al.'s summary here is very broad. With specific regard to Atlantic North America, Bradbury et al. (2020) states hybridization with wild individuals have been observed throughout the region, referencing O'Reilly et al. (2006), DFO (2018), Wringe et al. (2018), and Sylvester et al. (2018). These references warrant further review here. O'Reilly et al. (2006) studied escaped smolts in the Magaguadavic River and provided no evidence of their breeding (and therefore introgression) with wild salmon. DFO (2018) reviewed the Inner Bay of Fundy Atlantic Salmon Live Gene Bank and Supplementation Programs, and noted evidence of small amounts of European farmed salmon genetic material including in their founder populations collected in the late 1990s. The nature of the European genetic traits indicated wholly European salmon were involved, and indeed European origin eggs were sourced from Scotland, Iceland, and Finland from 1989 and further imports of Norwegian and Icelandic strains occurred in 1997 (Glebe, 1998; Clegg et al. 2004). DFO (2018) noted the frequency of detection of short European-type alleles in samples from the Bay of Fundy area increased markedly in and around 1998-2000, however these detections were in juvenile salmon (escaped from hatcheries), and there is therefore no specific evidence of prior or subsequent introgression. Nevertheless, regardless of the specific origin, DFO (2018) considered a fairly large proportion (approximately 10 to 25%) of 'in river' (as opposed to hatchery) produced Big Salmon River smolt may exhibit some level of European farmed salmon ancestry. In contrast, no European-type alleles have been identified in thousands of salmon surveyed from dozens of rivers along the east coast of Nova Scotia (O'Reilly et al., 2006).

The Wringe et al. (2018) research referenced by Bradbury is a specific study demonstrating hybridization with wild salmon populations in Newfoundland after a large escape in 2013. The escape provided ideal conditions for hybridization, with approximately 20,000 sexually mature farmed Atlantic salmon escaping just prior to the natural spawning period and in close proximity to wild salmon-bearing rivers. Hybrid salmon (i.e., progeny resulting from spawning between a wild salmon and an escaped farmed salmon) were found in 17 of the 18 rivers studied in Newfoundland in 2014, and feral juveniles (i.e., offspring of two escaped salmon) were found in 13 rivers. Wringe et al. (2018) therefore considered their finding to be clear landscape-scale evidence of interbreeding between wild and escaped Atlantic salmon resulting from a single escape event. They considered the impacts of the escape event to be substantial and region wide, and while the proportion of hybrid fish declined significantly after a single year of selection in the wild, the continued presence of F2 and backcross individuals indicate introgression was occurring.

The specific impacts of these examples of hybridization and introgression (e.g., in the Inner Bay of Fundy and in Newfoundland) and their temporal longevity are as-yet unclear. Spawning between farmed and wild salmon may result in reduced genetic integrity of the wild population and, under pressure from continual invasion, a loss of overall population fitness, but the degree of genetic impact on wild populations due to invasion is often population-specific and may be highly dependent on the selective pressures acting on invading individuals and their progeny (Sylvester et al., 2019).

The DFO review of the Live Gene Bank demonstrates the persistence of non-local (including European) genes in Inner Bay of Fundy wild salmon populations, but also noted the frequencies of European-type alleles declines sharply with each generational backcross of hybrids to North American salmon. The reduction or loss of such introgression over time has also been associated with reductions in relative hybrid survivorship (Sylvester et al., 2019). In their study of the 2013 escape event in Newfoundland, Wringe et al. (2018) noted the hybrid class composition of young-of-the-year sampled in 2015 revealed an almost complete absence of feral individuals and declines in the prevalence of most hybrid classes. They considered this loss of feral and hybrid individuals over time to be consistent with expected selection against these individuals in the wild. Sylvester et al. (2019) also note that although domestic-wild hybrid offspring have shown reduced fitness in lab and field experiments, consequential impacts on population abundance and genetic integrity remain difficult to predict in the field, in part because the strength of selection against domestic offspring is often unknown and context-dependent.

Further, Sylvester et al. (2018) noted that within-river distribution of hybrid parr was strongly associated with the migration effort required to reach spawning sites; the hybrid proportion decreased significantly with increased elevation, geographic distance, and the presence of obstructions. This supports the hypothesis that the distribution of escaped farmed Atlantic salmon can be restricted by migratory challenges, which result in the reduction of hybrid individuals in upstream spawning sites relative to downstream locations. These context-specific variables complicate the ability to quantify impacts at the population level, and Keyser et al. (2018) note that despite continued evidence of genetic impacts on wild salmon populations, the ability to predict population-level risks to inform management efforts remains limited.

Overall, the evidence from the Live Gene Bank and the study of Wringe et al. (2018) show genetic introgression has occurred in Atlantic North America. As discussed below, the status of many wild salmon populations in Atlantic North America is of concern, yet it is clear that the potential impacts of farmed salmon escapes are population-specific and context-specific, varying according to a complex suite of factors. The contribution of genetic introgression (if any) to the historic and recent declines of wild Atlantic salmon populations remains unclear.

Status of wild populations

Wild salmon populations in North America (and elsewhere) have been in long-term decline (Dadswell et al., 2021). By 1970 (two decades prior to significant farmed salmon production), the species' production capacity had been reduced to 32% of its estimated original productivity (VanderZwaag et al., 2011). Long-term declines were due to overfishing, dams, habitat damage, pollution, and acid rain[80]; due to the risk of population collapse, commercial fishing was closed in the US in 1949[81] and in eastern Canada in 1984 (Dadswell et al., 2021). Historically, exploitation by humans probably caused the greatest mortality to adults from most Atlantic salmon stocks; prior to 1950 most fisheries were confined to coastal regions, estuaries, and

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[80] Salmon populations in Nova Scotia were particularly affected by acid rain (Clair and Hindar, 2005).

[81] https://www.fisheries.noaa.gov/species/atlantic-salmon-protected

rivers, and although fisheries often captured as much as 50–90% of returning adults, adult return abundance remained sustainable because of high recruitment from annual freshwater cohorts. After 1950, open ocean exploitation by drift fisheries that could track and follow the movement of migrating salmonids with continuous exploitation resulted in a rapid decline of many stocks and led to international efforts to regulate and finally close most of these fisheries in the mid-1980s (Dadswell et al., 2021).

Despite these closures, adult returns to river and hatchery stocks with no obvious local impacts have also declined or collapsed since 1985; the estimated abundance of North American one sea-winter Atlantic salmon declined 85% between approximately 1980 to 1990, with a 90% decline of two sea-winter salmon over the same period, and the decline in adult return abundance to numerous North Atlantic stocks has continued through the 2000s and up to present (Dadswell et al., 2021). While salmon farming was developing rapidly in Norway in the 1980s and early 90s, production in the nascent industry in Atlantic North America was minimal. Figure 28 shows the recent decline in the pre-fishery abundance[82] of North American Atlantic two-sea winter salmon at sea[83] and also shows the later timeframe of aquaculture development in the region.

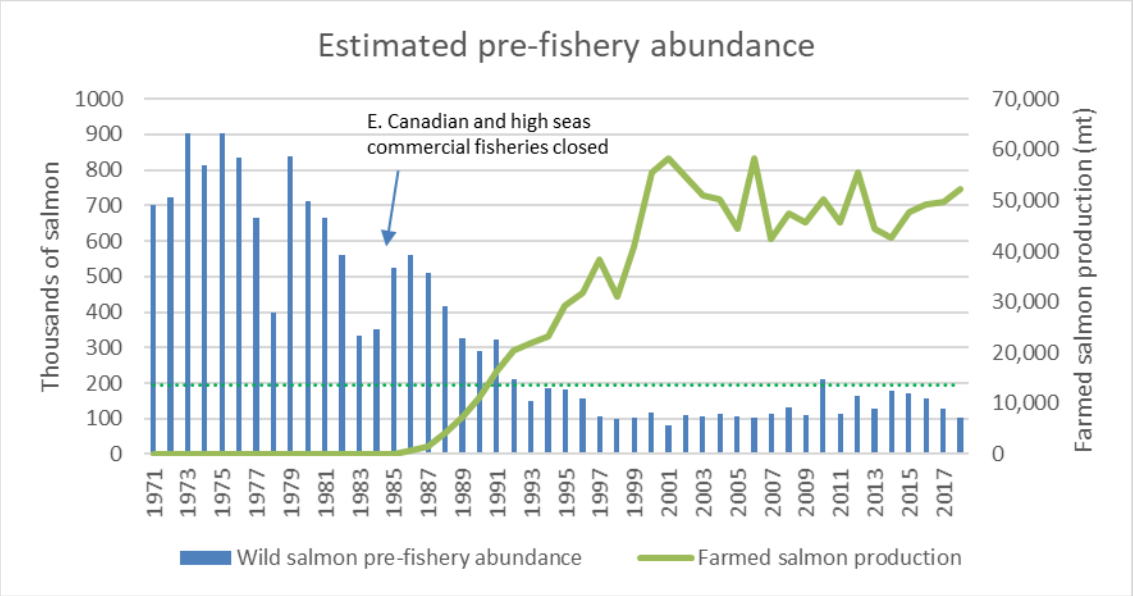

Figure 28: Pre-fishery abundance of North American two-sea winter Atlantic salmon (blue bars) with the minimum conservation limit in North American rivers shown by the dotted green line. Note that by 1970, the productivity of Atlantic salmon had already been reduced to one-third of its estimated original productivity. The solid green line shows Atlantic North American farmed salmon production in mt. Image context and caption taken from ASF (2020) with the data taken directly from the referenced source (ICES, 2020). North American farmed salmon production data from FAO FishStatJ.

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[82] Pre-fishery abundance (PFA) is a measure of abundance at sea before any harvest takes place in a given year.

[83] The ASF notes this graph does not capture abundance of all types of adult Atlantic salmon but indicates a general trend.

As a result of these declines and despite substantial restocking efforts, the Gulf of Maine Distinct Population Segment (DPS) is listed as endangered under the US Endangered Species Act (NOAA, 2020). Many Canadian populations have an at-risk status according to the Canadian Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and/or the Species at Risk Act (SARA) (ASF, 2020). Table 6 shows the conservation status of the seventeen groups of wild salmon populations (designatable units according to COSEWIC) mapped in Figure 27. The populations closest to the aquaculture industry are 4, 14, 16 in Canada and 17 (Maine in the US).

Table 5: Status of 17 North American wild salmon designatable units according to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), Canada's Species at Risk Act (SARA) and the US Endangered Species Act (ESA). Groups closest to salmon farming areas are highlighted in grey. Particular conservation concerns are highlighted in bold. Data from the Atlantic Salmon Federation accessed November 2020.

Population Segment	COSEWIC/ESA Status	SARA Status
1. Nunavik (Quebec salmon zone Q11)	Data deficient	No status
2. Labrador	Not at risk	No status
3. Northeast Newfoundland	Not at risk	No status
4. South Newfoundland	**Threatened**	No status
5. Southwest Newfoundland	Not at risk	No status
6. Northwest Newfoundland	Not at risk	No status
7. Quebec Eastern North Shore	**Special concern**	No status
8. Quebec Western North Shore	**Special concern**	No status
9. Anticosti Island Population	**Endangered**	No status
10. Inner St. Lawrence Population	**Special concern**	No status
11. Lake Ontario Population	**Extinct**	No status
12. Gaspe-Southern Gulf of St. Lawrence Population	**Threatened**	No status
13. Eastern Cape Breton	**Endangered**	No status
14. Nova Scotia Southern Upland	**Endangered**	No status
15. Inner Bay of Fundy	**Endangered**	**Endangered**
16. Outer Bay of Fundy	**Endangered**	No status
17. Gulf of Maine Population	**ESA: Endangered**	

Conclusions: Factor 6.2 – Competitive and Genetic Interactions

The domesticated strains of Atlantic salmon used as broodstock are genetically distinct from wild populations. Specific examples (particularly the large escape of 20,000 mature salmon close to rivers hosting wild salmon and at spawning time) have led to demonstrable genetic introgression in wild salmon populations, but the longevity of the altered genetics and their actual impact to wild salmon populations remains challenging to quantify. Wild salmon populations declined dramatically prior to the introduction of salmon farming, and despite intensive efforts to limit anthropogenic impacts, most populations throughout Atlantic North

America have remained at risk, including many that are endangered. This presents clear concern for impact and highlights the need for strong escapes management.

The greatest concern for impact is in rivers, where escapees could spawn with (or interfere in the spawning of) wild salmon. The numbers of escaped farmed salmon in rivers is highly variable geographically and temporally, and due to the low numbers of remaining wild salmon, the proportion of escapees within rivers can be relatively high in some cases. However, data from river monitoring and fish capture efforts demonstrate that, over the past decade, the number and proportion of escapees amongst all salmon migrating up-river is typically very low, further substantiating local and international research showing very high mortality of escapees. There is currently no evidence that the significant declines in wild salmon have been driven by farm escapes, and the documented mortality of escapees limits the present-day potential impact. Though introgression may occur, its impact is not considered likely to affect the population status of wild Atlantic salmon. As such, the final score for Factor 6.2 is 4 out of 10 for all regions.

Conclusions and Final Score

Best management practices to prevent escapes, such as Codes of Containment, are in place in every region in Atlantic North America and they have been effective in reducing the number of escapes over time. However, net pen systems are inherently vulnerable to both large-scale and small-scale fish escapes, and data show that escapes do still occur in the Atlantic North American industry, albeit with regional variation. Farms in Maine have not reported an escape since 2003, and farms in Nova Scotia have reported only 44 escaped fish in the past ten years. New Brunswick and Newfoundland have each reported many thousands of escaped fish over this time period. Escapees have been shown to disperse rapidly and recapture at sea is unlikely, but a second recapture opportunity occurs in rivers. The number of escaped fish entering rivers in the four regions is highly variable by river and by year, and while fish taps in some rivers allow the recapture and removal of (potentially all) escapees, the extent of their presence and operation across all rivers in the region is not known.

Although the industry in Atlantic North America has largely relied on local broodstocks, farmed Atlantic salmon are genetically distinct from their wild counterparts. Hybridization between escaped and wild salmon and genetic introgression have been demonstrated, particularly after a large escape of mature fish in Newfoundland. While the presence of hybrid offspring declines rapidly, determining the longevity of the introgression and quantifying the impact to affected populations remain challenging. Wild salmon populations in the North Atlantic have been in long-term decline (for many decades prior to salmon farming's introduction) and continue to decline in areas with and without salmon farms; nevertheless, several wild salmon populations in the vicinity of the salmon farming industry are of special concern, threatened, or endangered, and any contributions to their further decline or inhibitions of their recovery are a concern.

In Maine, there have been no reported escapes since 2003, very few escaped fish have been detected in rivers, and capture devices in important rivers allow their removal. The production system remains vulnerable, and escapees could potentially enter rivers in areas without recapture devices. The final score for Criterion 6 – Escapes for Maine is 4 out of 10. In New Brunswick, escape numbers have been high and escapees are detected in rivers, and though capture devices in important rivers allow their removal, escapees could enter rivers in areas with vulnerable populations in the Inner Bay of Fundy. The final score for Criterion 6 – Escapes for New Brunswick is 3 out of 10. In Newfoundland, escape numbers have been high and while typical numbers of escapees in rivers are moderate, there are fewer opportunities for recapture and studies of specific escape events have demonstrated genetic introgression in many rivers. The final score for Criterion 6 – Escapes for Newfoundland is 3 out of 10. In Nova Scotia, the number of reported escapes is very low and there have been few escaped fish detected in rivers, but recent and ongoing monitoring appear limited. There are fewer opportunities for recapture in rivers in Nova Scotia and escapees could potentially enter rivers in areas without recapture devices. The final score for Criterion 6 – Escapes for Nova Scotia is 4 out of 10.

Criterion 7: Disease; Pathogen and Parasite Interactions

Impact, unit of sustainability and principle

- Impact: Amplification of local pathogens and parasites on fish farms and their transmission or retransmission to local wild species that share the same water body.
- Unit of sustainability: Wild populations susceptible to elevated levels of pathogens and parasites.
- Principle: Preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasite

Criterion 7 Summary

Maine and Nova Scotia

C7 Disease parameters		**Score**
Evidence or risk-based assessment	Risk	
C7 Disease Final Score (0-10)		**4**
Critical	No	Yellow

New Brunswick

C7 Disease parameters		**Score**
Evidence or risk-based assessment	Risk	
C7 Disease Final Score (0-10)		**0**
Critical	No	Red

Newfoundland

C7 Disease parameters		**Score**
Evidence or risk-based assessment	Risk	
C7 Disease Final Score (0-10)		**2**
Critical	No	Red

Brief Summary

Large amounts of research and publicly available fish health and mortality data in other areas (particularly British Columbia and Norway) note the concern regarding the potential transfer of pathogens and parasites from salmon farms to wild salmonids, but there is very little information available in Atlantic North America. While many disease-related management and monitoring measures are in place, few data are available, and the open net pen system remains vulnerable. The ongoing occurrence of mortality events in Atlantic North American farms (as reported by industry media) highlights the likelihood that some diseases occur or are secondary factors in these events. Nevertheless, the potential for salmon farms to act as a reservoir for transmission of pathogens to wild fish (i.e., of types and numbers of pathogens that they wouldn't naturally encounter) remains uncertain. While recent research, particularly in British Columbia, continues to develop rapidly on many fronts and is making many associations between farm viruses and wild salmon, there have been few robust conclusions on demonstrable impacts.

A similar situation exists for sea lice. Large publicly available datasets from routine monitoring and research in the eastern Atlantic (Norway) and western Canada (British Columbia) demonstrate it is likely that there will be substantial mortality of wild salmon in some areas in some years. The limited available data in Atlantic North America indicate sea lice levels on farms are high in New Brunswick, including in some areas each year during the juvenile salmon outmigration period, but are likely low in Maine and Nova Scotia. Despite the welcome start of (minimal) data publication in Newfoundland, lice levels here remain largely unknown. Atlantic salmon are one of the most susceptible salmonid species to sea lice and sub-lethal impacts and increased risk of predation may also be important.

The analysis here has been limited to a simplistic overview, particularly given the limited data in the region. It highlights the ongoing uncertainty in the potential for wild Atlantic salmon to be infected with pathogens and parasites that they would not naturally experience, the uncertainty in the impact of any such infections, and in the potential cumulative impacts of pathogens and parasites from farms. The applicability of the research in other regions to Atlantic North America is also uncertain. Given the status of wild salmon populations in the Atlantic (see Criterion 6 – Escapes), the uncertainties driven by the lack of data largely define the need for a precautionary approach. For all regions, the potential impacts of viral or bacterial pathogens remains unknown, but in New Brunswick, lice levels on average are often high in at least one BMA each year during out-migration, with likely very high levels in individual farms, and the final score for Criterion 7 – Disease is 0 out of 10. In Newfoundland, lice levels remain largely uncertain and given the established pathogen and parasite transfer risk, the final score for Criterion 7 – Disease is 2 out of 10. For Nova Scotia and Maine, sea lice count data availability are also limited, but when combined with the pesticide use data, they indicate lice levels are low and the simple open nature of the production systems results in a final score for Criterion 7 – Disease of 4 out of 10 (all scores are allocated using the Seafood Watch risk assessment).

Justification of Rating

Without a robust understanding of how on-farm disease impacts wild organisms (i.e., Criterion 1 score of 2.5 out of 10 for the disease category), the Seafood Watch Risk-Based Assessment methodology was utilized.

The open nature of net pen salmon farms means farmed fish are vulnerable to infection by pathogens from the surrounding waterbody, from wild fish, or from other natural infection routes, and can act as a temporally unnatural reservoir for a variety of pathogens and parasites that have the potential to be transmitted or re-transmitted to wild resident organisms, including native salmon species (Hammell et al., 2009).

Acknowledging that pathogen detection alone is insufficient to allow inferences about the health and fitness of wild fish and requires the context of host susceptibility, virulence of pathogen strains, and environmental conditions (Jia et al., 2020), the expansion of salmon aquaculture has brought conservation concerns into regions where the areas occupied by salmon farms are important for wild salmon (e.g., Peacock et al., 2014). This Disease Criterion has two sections: first, bacterial and viral pathogens, and second, parasitic sea lice.

Bacterial and viral pathogens

Bacterial and viral pathogens on fish farms

Farmed salmon smolts are typically largely absent of marine pathogens when transferred from freshwater hatcheries to marine net pens but are immediately exposed to background levels of bacteria and viruses upon entry. In contrast to the Canadian Province of British Columbia, for which DFO publishes data on fish health events, average monthly mortality by health zone, carcass classifications, and site-level data on the causes of mortality events and contributing factors[84,85], there are no readily available similar data for the eastern Canadian provinces or for Maine. It can simplistically be concluded that bacterial diseases are present on farms based on the occasional use of antimicrobials, and also that the decline in antimicrobial use from 2012 to 2018 implies a decline in those pathogens, but in reality, there are minimal publicly available data with which to understand pathogen dynamics on salmon farms in Atlantic North America.

Seafood media reports show fish health events and mass mortalities do occur[86],[87] and even in cases where a disease is not the primary cause, it may exacerbate the mortality (the example provided in the footnote was potentially due to low oxygen levels, but fish health data from British Columbia show compromised gill health due to disease or parasites is often a contributing factor to high mortality in these situations).

There are four federally reportable aquatic animal diseases in Canada listed by the Canadian Food Inspection Agency (CFIA)[88] of relevance to Atlantic salmon, all of which are viral in nature:

- Infectious salmon anemia virus (ISA)
- Viral hemorrhagic septicemia virus (VHS)
- Infectious pancreatic necrosis virus (IPN)
- Infectious hematopoietic necrosis (IHN)

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[84] More information and the DFO fish health event data are available at: https://open.canada.ca/data/en/dataset/deefd1d7-7184-44c7-83aa-ec0db91aad27

[85] http://www.dfo-mpo.gc.ca/aquaculture/bc-aquaculture-cb-eng.html

[86] Recent example of 450,000 fish mortality event caused by low oxygen levels: https://www.undercurrentnews.com/2021/09/21/mowi-multiplies-salmon-mortality-numbers-in-newfoundland-by-nearly-five/

[87] Recent example of mortality event, https://www.undercurrentnews.com/2021/04/12/newfoundlands-farmed-salmon-mortality-rate-improves-to-still-high-20/

[88] https://inspection.canada.ca/animal-health/aquatic-animals/diseases/reportable-diseases/eng/1322940971192/1322941111904

Of these, only ISA has been detected on salmon farms in Atlantic Canadian provinces in recent years (CFIA data dating back to 2012). ISA exists in pathogenic and non-pathogenic strains, and both the number of total cases and the proportion of pathogenic strains have increased in recent years (Figure 29 – noting the 2021 data are to August only). It is noted that ISA cases prior to 2012 may have been higher, but CFIA data are only available after 2012.

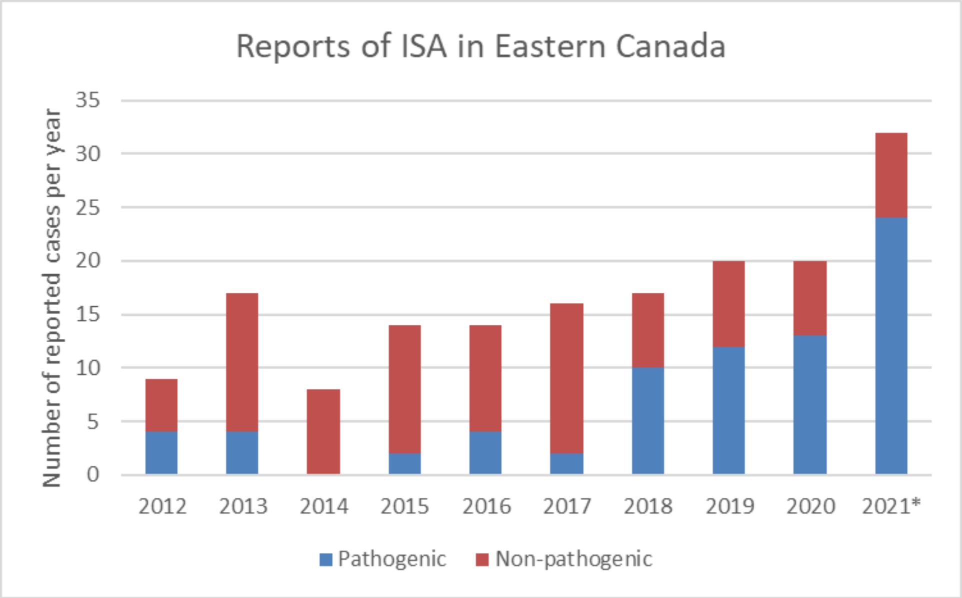

Figure 29: Reported cases of pathogenic and non-pathogenic infectious salmon anemia in salmon farms in Atlantic Canadian provinces from 2012 to *August 2021. Data from CFIA.

There are many measures in place to monitor and control for ISA. For example, each of the three Canadian provinces assessed here runs an ISA Control and Management Program, and in the US, the Animal and Plant Health Inspection Service (APHIS) of the US Department of Agriculture runs an ISA sampling program in Maine[89]. Considering the proximity of Maine and New Brunswick, New Brunswick also has an agreement with APHIS and Maine Department of Marine Resources on ISA management and surveillance. The control and management measures typically involve regular (e.g., monthly) site visits and fish sampling (for a suite of bacterial and viral pathogens), control and containment plans, movement controls, harvest boat certification, and other biosecurity measures (New Brunswick Department of Agriculture, Agriculture and Fisheries, pers. comm., 2021).

While the number of reported cases of ISA in the three Canadian provinces was 20 in 2020 (Figure 29), according to APHIS, there have been no confirmed ISA-positive net pens in Maine since 2006 (although two were categorized as “suspect” in 2020 and subsequently harvested). The reason for this difference between the two neighboring regions may be related to the relative scales of the industries, but the entire Canadian Atlantic Ocean (covering all the salmon

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[89] https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/animal-disease-information/aquaculture/isa-reports

farming provinces) is designation by CFIA as “infected” for ISA virus (and for two strains of VHS and IPN, but not for IHN).

Bacteria and viruses are ubiquitous in seawater[90] (Bergh et al., 1989) and farmed salmon are associated with a wide variety of bacteria and viruses (e.g., in recent publications: Bateman et al., 2021a,b; Shea et al., 2020; Mordecai et al., 2019, 2021a,b). Salmon farms are also associated with elevated pathogen environmental DNA (eDNA) suggesting that salmon farms serve as a reservoir for a number of (potentially) infectious agents (Shea et al., 2020).

In British Columbia, nine assessments were conducted by DFO of the risk to Fraser River sockeye salmon from the transfer of (nine individual) bacterial and viral pathogens from Atlantic salmon farms in the Discovery Islands area of BC[91]. While caution must be used in considering any direct relevance of these western Canada risk assessments to the Atlantic coast, some aspects of the methodology are useful as a framework for discussion. For example, in the “farm infection” component of the DFO risk assessments, the likelihood that farmed Atlantic salmon infected with each of the nine pathogens were present on one or more farms varied from highly unlikely (e.g., for the bacteria *Yersinia ruckeri*i) to extremely likely (e.g., for Piscine reovirus-1; PRV).

Salmon farms as reservoirs of pathogens

Wild fish (and farmed fish) are exposed to pathogens and parasites from a number of sources, but the focus here is on the potential for salmon farms to represent an unnatural additional reservoir. Using the DFO risk assessment methodology again as a framework, after the “farm infection” assessment discussed above, the “release assessment” determined the likelihood that a pathogen would be released from an infected Atlantic salmon farm located in an environment accessible to wild salmon (via infected farmed Atlantic salmon or via mechanical vectors such as personnel, wildlife, farm equipment or vessels). For all nine pathogens (three viruses and six bacteria) the assessment outcome was that the release of pathogens was expected and/or extremely likely. That is, it is extremely likely that the pathogens would be released from a net pen Atlantic salmon farm were it to contain infected fish. Although the DFO risk assessments only considered nine pathogens from farms only in the Discovery Islands in British Columbia, it is assumed here that net pen Atlantic salmon farms in general represent a reservoir of a variety of bacterial and viral pathogens which will be released into environments that are at times shared with wild fish. The potential impacts to those wild fish (if any) are considered in the next sections.

Exposure, infection, and disease in wild fish

With regard to their study of the Northwest Atlantic and eastern Canadian rivers, Teffer et al. (2020) and references therein provide the following background:

> Infectious agents such as viruses, bacteria, and other microparasites are ubiquitous in aquatic and marine environments yet their diversity among wild fish hosts remains

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[90] For example, there are approximately 10 million viruses per ml of seawater (Bergh et al., 1989)

[91] https://www.dfo-mpo.gc.ca/cohen/iles-discovery-islands-eng.html

> largely undescribed. Most information on fish disease has been derived from aquaculture settings where fish are more easily observed in later stages of disease, but extrapolation of this information to wild fishes may be misleading as conditions experienced by cultured fish differ greatly from wild fish.
>
> Many wild Atlantic salmon stocks come into contact with aquaculture facilities during seaward or spawning migrations, which may result in infectious agent exchange between farmed and wild fish. Despite recent advances in our understanding of the diversity of infectious agents hosted by salmon on Canada's west coast our knowledge of infectious agents affecting wild Atlantic salmon on the east coast remains scant.

For reference, Grefsrud et al. (2021b) provide a theoretical scenario in Figure 30 showing how migrating salmon may be affected after passing through an area of infection such as a farm, and they also caution that a) the presence of a pathogen does not mean infection, b) infection does not mean the development of disease or the spread of infection, and c) illness does not mean death.

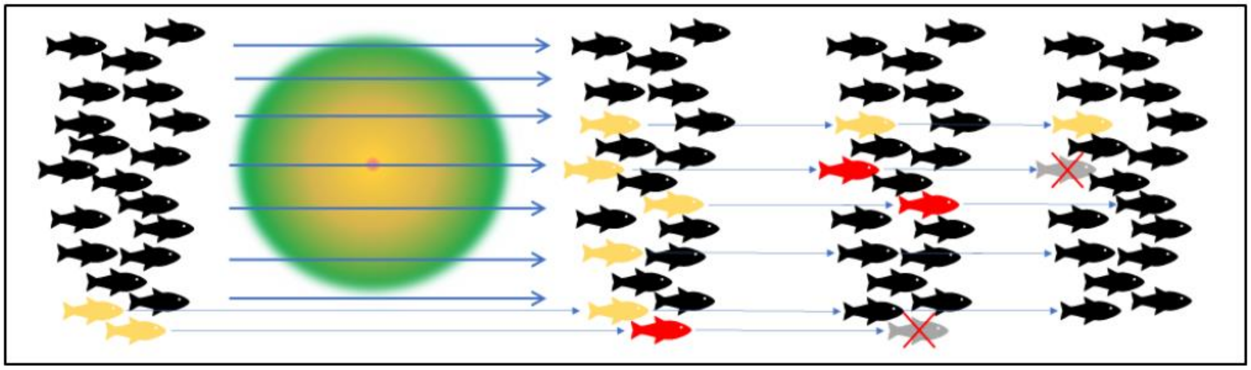

Figure 30: A theoretical scenario of migrating salmon smolts or sea trout in a fjord passing through areas with infection from farming. In such an area the exposure varies a lot. Upon exposure, some individuals may become infected (yellow fish). Some infected individuals may become ill (red fish). Some sick fish may die (grey fish), some may recover, and some may become chronically infected (carriers). Some of the wild fish may be naturally infected regardless of farming, and some of them may also become ill and die. Image copied from Grefsrud et al. (2021b).

Once more referring to the DFO's nine risk assessments, the "infection assessment" determined the likelihood that susceptible wild fish would be exposed to the pathogen at a dose and for a period of time sufficient to cause infection and disease (on the assumption that susceptible fish have been exposed to the pathogen released from a farm). Thus, the overall "likelihood" that wild fish become infected and diseased by pathogens attributable to Atlantic salmon farms depends on the sequential likelihoods of disease, release, exposure, and infection. In the specific case of the Fraser River sockeye salmon and the farms in the Discovery Islands, the combined likelihood outcomes (i.e., farm infection, release, exposure, and infection) for the nine pathogens were highly variable, ranging from extremely unlikely (e.g., for IHN virus) to very likely (for PRV).

Teffer et al. (2020) made the first quantitative molecular screening of dozens of infectious agents in wild and escaped Atlantic salmon in offshore feeding areas of the Northwest Atlantic Ocean and three Atlantic Canadian rivers. They identified fourteen agents in the tissues of sub-adult salmon collected in the Labrador Sea near Greenland or mature salmon in three Atlantic Canadian rivers, including five that (to their knowledge) had not been known to occur in Atlantic Canada (which included two bacteria (*Piscichlamydia salmonis* and *Syngnamydia salmonis*), one virus (Atlantic salmon calicivirus), one microsporidian (*P. theridion*), and one myxozoan parasite (*Paranucleospora pseudobranchicola*)).

With regard to the notifiable pathogen ISA, the virus has been detected in wild and cultured salmon in Atlantic Canada and the US, but most – if not all – detections in wild fish have shown no evidence of disease (including for intentionally-challenged hosts); therefore, it is assumed to be the non-pathogenic HRP0 strain that is affecting asymptomatic wild hosts (references in Teffer et al., 2020). CFIA's webpage "Facts about infectious salmon anaemia" (updated May 2020[92]) states ISA has been detected in wild salmon in Quebec but not in the rest of Canada. Teffer et al. (2020) note that it is not known whether wild fish have been affected by pathogenic strains of ISAv (which can develop spontaneously from the non-pathogenic strain) as the pathogenic strain causes acute disease and is therefore unlikely to be detected in sampling of wild fish. This is consistent with Miller et al. (2014), who note that as with any study of wild animals, it is also possible that heavily infected wild fish or those carrying highly pathogenic agents died or were predated prior to sampling.

Impacts to wild fish

The consequences of infection with pathogens are highly variable depending on the individual, the strain of the pathogen, and the circumstances. Assessing the impacts of pathogens to wild fish, which are challenging to monitor in the wild, is complex. Using the DFO risk assessment process again as a framework for discussion, the "consequence assessment" considers what happens if only one or a few fish are infected[93] or if there is significant infection and spread within the population. It considers the consequences to wild salmon abundance and diversity. Overall, the DFO risk assessment's likelihood/consequence combinations varied across the nine pathogens assessed (for example, while the consequences of a VHS infection were "moderate" for abundance and diversity, the likelihood of that happening was "extremely unlikely"), but the DFO assessments all concluded that the risk to the abundance and diversity of Fraser River sockeye salmon for each of the nine pathogens from Atlantic salmon farms in the Discovery Islands in British Columbia was "minimal".

In Atlantic North America, Teffer et al. (2020) note that our understanding of the mechanisms and frequency of infectious agent transmission among wild fishes is still in its infancy, especially

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[92] https://www.inspection.gc.ca/animal-health/aquatic-animals/diseases/reportable-diseases/isa/facts/eng/1327198930863/1327199219511

[93] It is important to note that the outcome of the "likelihood" assessment is in terms of the risk of a single fish being exposed and infected (a single wild sockeye salmon in this case) by the relevant pathogen. That is, it is "very likely" that a single Fraser River juvenile and a single Fraser River adult sockeye salmon will each be infected by PRV-1 from a salmon farm in the Discovery Islands in British Columbia.

for highly migratory and offshore marine hosts like Atlantic salmon and for pathogens that can cross continental borders via marine exchange. With consideration of this caveat, their study found no evidence to support aquaculture influence on wild adult infections, which varied relative to environmental conditions, life stage, and host origin.

In Norway, Madhun et al. (2021) produced the "Annual report on health monitoring of wild anadromous salmonids in Norway 2020" reporting the absence or low prevalence of viral infections in the tested migrating wild salmon smolt in 2020. Madhun et al. note this is consistent with previous findings in wild salmonids that showed no apparent relationship to the fish farming intensity or the frequency of on-farm disease outbreaks. Madhun et al. and other key reviews (e.g., Grefsrud et al., 2021a,b) conclude that wild salmon are exposed to a moderate to low infection pressure (of bacteria and viruses) from fish farming. This also agrees with Wallace et al.'s (2017) research in Scotland, concluding there is limited evidence for clinical disease in wild fish due to farm-origin pathogens, and they are likely to have had a minimal impact on Scottish wild fish.

Nevertheless, Madhun et al. (2021) caution that infection may lead to rapid disappearance, altered behavior, or biased sampling of the infected wild fish, and Norway's annual Fish Health Report (Sommerset et al., 2021) does acknowledge that the amplification of infectious agents in farmed stocks may have implications for wild stocks. Specific examples (e.g., Garseth et al., 2013) show the spread of viruses from salmon farms constitutes a risk of infection of unknown magnitude in the surrounding environment. Kibenge (2019) also emphasizes that there is a continuous emergence of viral diseases in aquaculture, and Grefsrud et al. (2021a,b) conclude that there continues to be moderate to high uncertainty with regard to the potential impact of viral and bacterial pathogens on wild Atlantic salmon due to knowledge gaps in the epidemiology of the various pathogens.

Beyond the DFO Risk Assessments

Beyond the narrow scope of the DFO risk assessments in British Columbia – that is, with consideration of the potential impacts of other pathogens (both singularly and cumulatively), potential impacts to other species of wild salmon and of other farming areas – the literature is extremely complex and developing rapidly on a number of fronts, particularly in British Columbia (e.g., Jia et al., 2020; Shea et al., 2020; Mordecai et al., 2019, 2021; Bateman et al., 2021a,b; Kibenge, 2019; Siah et al.,2020; Thakur et al., 2019; Polinski et al. 2020; Morton et al.,2017, 2020; Purcell et al.,2020; Zhang et al., 2019, 2021). These studies collectively articulate a complex scientific debate in British Columbia about the various aspects described above; that is, the presence of pathogens on farms, their transmission to wild salmon populations, and the subsequent impact (if any) to vulnerable populations considered essential to life by indigenous communities in British Columbia (e.g., Massey et al., 2021).

These studies make many associations between farm viruses and wild salmon but with as-yet few new robust conclusions, and while the research covers many relevant topics of relevance to eastern Canada or Maine, it is typically not possible to relate the results directly to the situation in the Atlantic Ocean. The inability to draw robust conclusions with regard to the impacts to wild salmon is perhaps best illustrated by Mordecai et al. (2021b) who note (emphasis added here) that "the risk of disease transmission from farmed to wild fish has increased, with potential to contribute to declines in wild fish populations, but the probability and magnitude of this transmission has not been determined". It therefore currently remains largely impossible to clearly differentiate between the speculation and justifiable precaution necessitated by the condition of wild Atlantic salmon populations, and the contrasting position broadly drawn from the DFO risk assessments and other studies that bacterial and viral pathogens from Atlantic salmon farms are of minimal concern to wild salmon.

Parasitic sea lice

Sea lice (*Lepeoptheirus salmonis* and *Caligus elongatus*) are ectoparasitic copepods that feed on the mucus, skin, and blood of host fish (Jones et al., 2012) and are a major production problem for salmon farms in all countries, resulting in losses of production (e.g., through reduced growth rates), increased susceptibility to secondary infections, direct animal welfare concerns, and costly treatments (that have their own welfare issues to the salmon and cleaner fish) (Grefsrud et al., 2021a; Sommerset et al., 2020). In addition, wild salmonids can be infected by lice discharged from net pen salmon farms, and many studies across salmon farming regions indicate substantial impacts are expected in some years (Shephard and Gargan, 2020). In the well-studied situation in Norway, for example, sea lice are currently considered to be the biggest (and expanding) threat to wild salmon populations (Thorstad et al., 2020; Grefsrud et al., 2021a,b; Sommerset et al., 2020).

Sea lice on salmon farms

Frazer et al. (2012) note that sea lice were not a concern to salmon farmers in the early 1990's, but as the industry developed, sea lice soon became the major cause of fish mortality and economic loss to the aquaculture industry in eastern Canada and Maine. Medcalf et al. (2021) noted that salmon farms in Atlantic Canada have much higher louse abundances than those in Pacific Canada or Europe, but as discussed below, the numbers are likely to be geographically and temporally variable across the provinces (and Maine) assessed here.

There is currently minimal public reporting of sea lice counts in the Atlantic North America region (unlike, for example, Canada's western province of British Columbia, for which DFO publishes detailed site-level monthly-average lice counts), but some data are available from other sources. In New Brunswick, aggregated sea lice data are presented annually in a graphic format for each of the Bay Management Areas (BMAs) by the Atlantic Canada Fish Farmers Association (ACFFA)[94]. In May 2021, the two operational companies in Newfoundland started publishing a monthly single data point for the average adult female *L. salmonis*[95] sea lice levels across all sites within the Newfoundland Aquaculture Industry Association (NAIA)[96]. The NAIA data published according to the Newfoundland and Labrador Aquaculture Policy and

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[94] https://www.atlanticfishfarmers.com/sea-lice-reports

[95] The NIAA data does not specify the species or development stage of the reported sea lice counts, but they were confirmed to represent adult female *L. salmonis* lice (J. Wiper, pers. comm., 2021)

[96] https://naia.ca/index.php/media/public-reporting

Procedures Manual (DFLR, 2019), while welcome, are minimal; this single data point per company per month representing the average monthly sea lice levels for each company's sites in Newfoundland (approximately 19 active sites in total in 2020) is likely to include a wide variation between counts and sites. Finally, mean monthly sea lice counts for 2020 from Maine and Nova Scotia were provided by the dominant (and only) producer in these regions (J. Wiper, pers. comm., 2021). In addition to these data, the quantities or frequencies of sea lice treatments along with expert personal communications can also be used (cautiously) as an indirect indicator of sea lice burdens on farms.

For Nova Scotia and Maine, the mean monthly counts of adult *L. salmonis* lice in 2020 are shown in Figure 31 (from approximately 12,600 fish in Nova Scotia, and 14,000 in Maine). There were no samples taken in March in Nova Scotia or Maine, nor in Nova Scotia in February due to low water temperatures. Lice levels in Maine in January were high (average of 12.4 lice per fish across all sites sampled) but were much lower during late April to early June which is the presumptive wild salmon out migration period (DFO, 2014). Sea lice levels in Nova Scotia in 2020 were very low in all months.

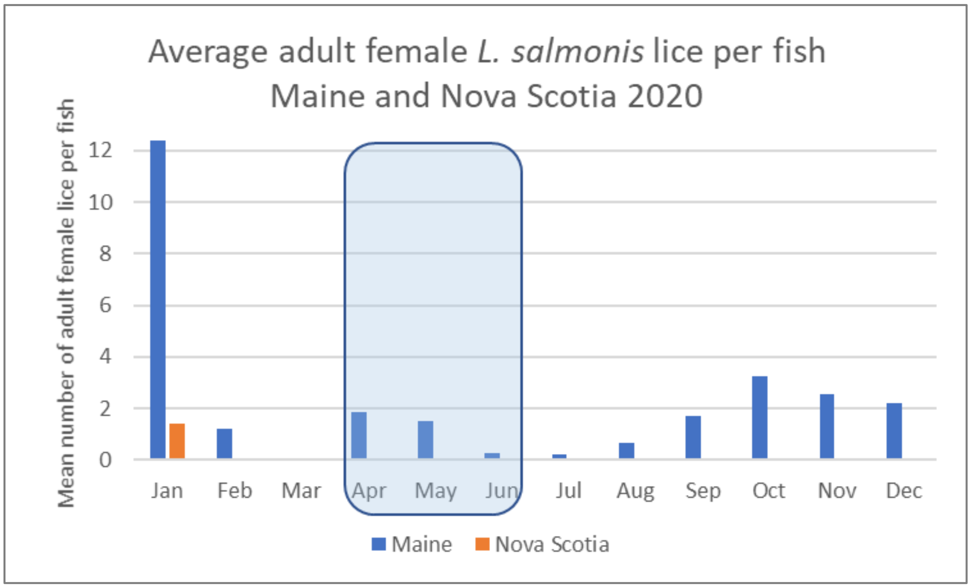

Figure 31: Mean monthly adult female L. salmonis sea lice counts in Maine (blue bars) and Nova Scotia (red bars) in 2020. Data from the only producer in these two regions (J. Wiper, pers. comm., 2021).

In New Brunswick, salmon producers are obliged to regularly report their sea lice levels and treatment data in Fish-iTrends (Elghafghuf et al., 2020), a web-based data entry portal established in 2010 by the Atlantic Canada Fish Farmers Association (ACFFA), the province of New Brunswick, and the Atlantic Veterinary College-Centre for Aquatic Health Science[97]. Unfortunately, site-specific data are not available to the public, but aggregated data are presented annually in a graphic format for each of the Bay Management Areas (BMAs) by the ACFFA.

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[97] Fish Farming Expert; Feb 12, 2015. https://www.fishfarmingexpert.com/article/tracking-lice-in-real-time/#:~:text=Fish%2DiTrends%20is%20a%20web,infectious%20loads%2C%20and%20treatment%20response.

Figure 32 shows the (most recent) 2020 sea lice count data from all New Brunswick BMAs. While the details are hard to see, the data are characterized by highly variable counts in different BMAs at different times of year (noting that annual variations are influenced by the production and fallow cycles, where recently stocked young fish typically have lower lice levels than second year fish), but sea lice are generally at their lowest levels in June and July. According to the Atlantic Canada Fish Farmers Association (ACFFA, 2021), strategic sea lice spring treatments begin in April and/or May, where required, to ensure that low sea lice abundance is maintained to minimize the risk to out-migrating wild salmon. ACFFA (2021) also note that historically, sea lice populations on salmon farms can be very low from January to June, but the levels of lice in Figure 32 demonstrate this is not always the case, with BMA-1 having high average counts exceeding twenty adult female lice per farmed fish. By the end of the outmigration period, the counts had declined to approximately 5 adult female lice per farmed fish. In BMA-2A, significant lice levels of approximately 2 to 5 adult lice per fish occurred during the outmigration period.

These lice count data aggregated across all sites per BMA likely hide a high site-to-site variability and much higher lice (and lower) levels than the average in some cases, but it must also be emphasized that these lice counts of adult female fish do not necessarily reflect the infection pressure experienced by wild out-migrating salmon, for which the relevant aspect is the number of infective copepodid lice stages present. While laboratory studies show the production and survival of these infective stages reduces at lower water temperatures[98] (Hamre et al., 2019; Dalvin et al., 2020), and may be almost zero below 5 °C, the evidence of periods of rapid increases in the counts of adult lice throughout the year in New Brunswick (Figure 32) strongly indicates that infective stages are present during the outmigration period.

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[98] A note here that Medcalf et al. (2021) suggest that the combined stressors associated with ocean warming and increasing sea lice in coastal salmon aquaculture can compromise wild salmon fitness through the impairment of vital organs.

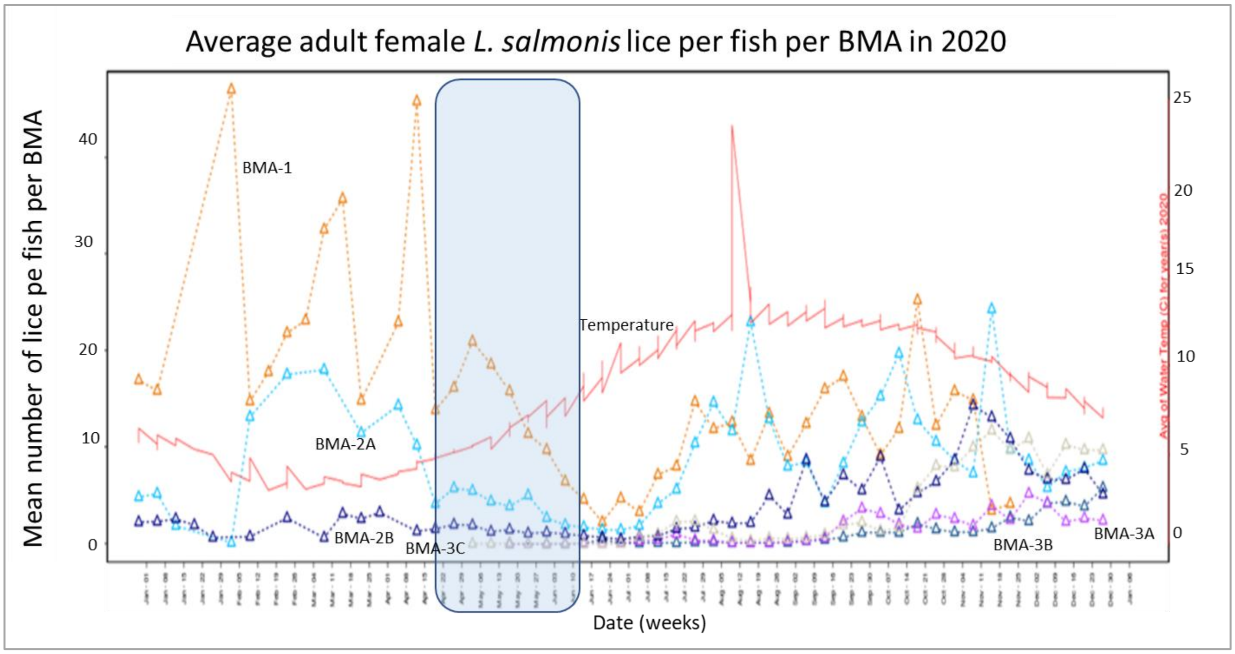

Figure 32: Mean numbers of adult female *L. salmonis* sea lice on farmed fish in the active (stocked) BMAs in New Brunswick in 2020. A map of the BMAs is provided in Figure 11. The x-axis labels show weekly dates of sea lice counts from January 1st at the left to December 31st at the right end. The shaded box shows the approximate wild salmon outmigration period from late April to early June. The thin red line shows sea surface temperature against the secondary y-axis. Image copied (and edited to add clearer labels) from ACCFA (2021).

Figure 33 presents similar data (aggregated across all sites in all BMAs) for each of the years 2015 to 2020, where each lien represents a single year. This shows a similar pattern with lice levels at their lowest in June and July, but with average lice levels across all sites in all BMAs in late April through May varying between approximately three and ten lice per fish, with considerable annual variability. All annual data since 2009 are available from ACFFA[99].

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[99] https://www.atlanticfishfarmers.com/sea-lice-reports

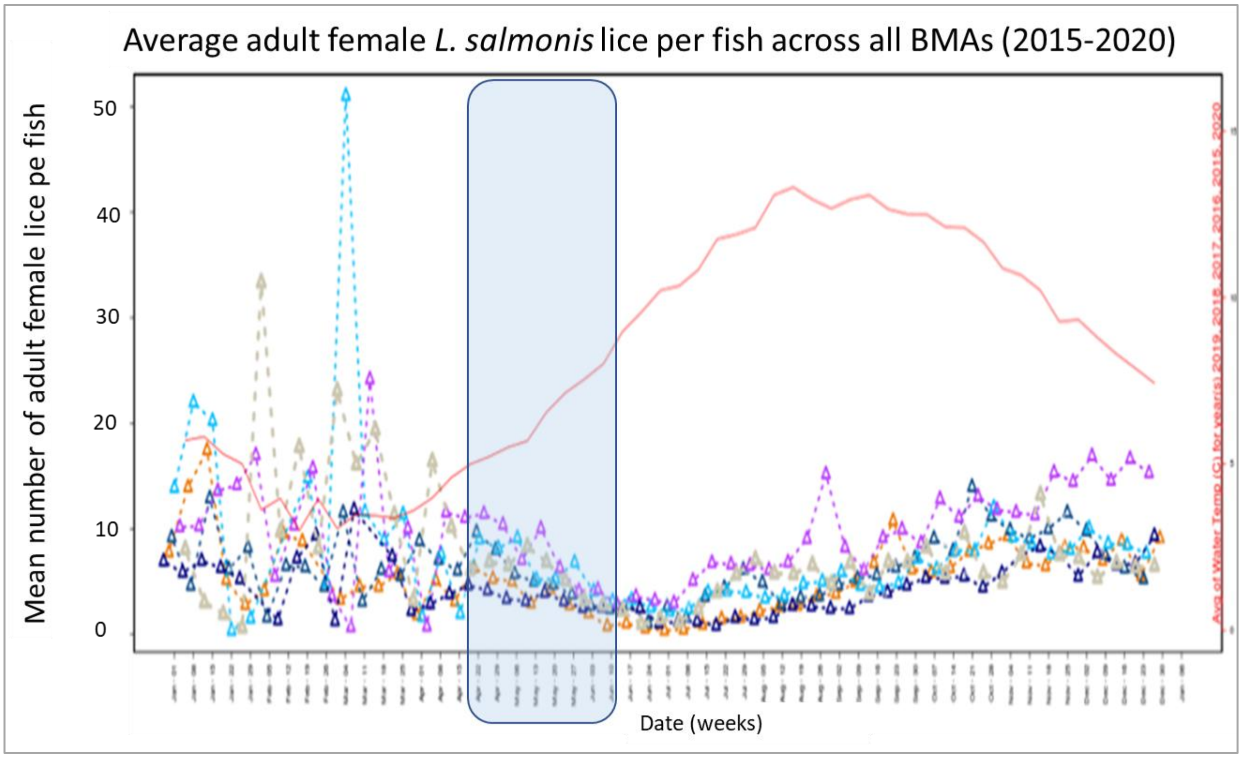

Figure 33: Average annual adult female lice per fish across all BMAs in all years 2015-2012. Each line represents a single year (not labelled for clarity). The x-axis labels show weekly dates of sea lice counts from January 1st at the left to December 31st at the right end. The shaded box shows the approximate wild salmon outmigration period from late April to early June. Image copied (and edited to add clearer labels) from ACCFA (2021)

For Newfoundland, the available NAIA data[100] show low lice levels with the average lice count for each company from May to August 2021 of 0.02 and 1.4 lice per fish. The low levels and/or the variability may reflect differences in the age of the fish (recently stocked smolts typically have lower lice levels). Criterion 4 – Chemical Use shows pesticide use has been high in Newfoundland (although recently largely replaced by non-chemical methods) and is indicative of the presence of significant sea lice infections. As noted above, there appear to be no readily available public sea lice count data from farms in Maine or Nova Scotia but given the single producer operating in both these regions, the provided sea lice count data for 2020 indicate mostly low levels, particularly during the outmigration period. In addition, Criterion 4 – Chemical Use shows pesticide use to control sea lice has been very low in both regions, with only a single treatment in 2014 in Nova Scotia, and minor amounts in Maine declining to zero since 2018. With the potential use of mechanical (i.e., non-chemical) treatments, these data are not considered conclusive of low lice levels, but a representative from the operating company noted that sea lice (*L. salmonis*) are largely non-existent in Nova Scotia (J. Wiper, pers. comm., 2021).

With regard to regulatory limits on sea lice numbers, treatment thresholds, or other limits on lice numbers, an industry representative (J. Wiper, pers. comm., 2020) stated that Nova Scotia

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[100] https://naia.ca/index.php/media/public-reporting

Aquaculture Management Regulations required salmon farms in the province to establish a sea lice treatment threshold (see Table 7) as part of the Farm Management Plan (FMP). While this is not directly disputed, the FMP template does not appear to be publicly available, and there is no apparent mention of sea lice limits in the Nova Scotia Aquaculture Management Regulations nor in the FMP minimum compliance requirements[101]. In New Brunswick, Sea Lice Management Plans are required to be submitted to the province each year prior to the season which must include a set target threshold (J. Wiper, pers. comm., 2021).

Table 6: Excerpt from Farm Management Plan template for Nova Scotia sites which outlines industry-determined sea lice treatment thresholds. Provided by J. Wiper, pers. comm., (2020). Note there is no mention of these lice levels in the Nova Scotia Farm Management Plan minimum compliance requirements.

April, May, June	July, August, September	October, November, December
Lice levels equal or greater than 0.5 adult female louse on average, for the site.	Lice levels equal or greater than 1.0 adult female louse on average for the site.	Lice levels equal or greater than 0.5 adult female louse on average, for the site.

It is currently clear from the 2019 New Brunswick sea lice data reported by the ACFFA (Figures 32 and 33 above) that not all Canadian provinces are following similar limits, although New Brunswick is also undergoing regulatory changes with a new Aquaculture Act and associated Regulations expected by the end of 2021[102] (J. Wiper, pers. comm., 2020). For comparison, in Norway, the lice limit is 0.2 adult female lice per farmed fish during the outmigration period (Karlsen et al., 2020). In British Columbia, the treatment threshold is three motile lice per fish (adult and subadult lice) during outmigration (note this is a treatment threshold and lice numbers may exceed it in reality)[103], and in Scotland, the Code of Good Practice[104] sets a treatment threshold of 0.5 adult female lice per fish from February to June and 1.0 lice per fish at other times of year (the regulatory limits under Scotland's Fish Health Inspectorate Sea Lice Policy[105] are complex, but substantially higher).

Impacts of sea lice on wild salmon

Figures 32 and 33 above show high levels of adult lice on farmed fish are present in some Canadian BMAs in New Brunswick and given the caveats regarding numbers of adult lice and the infection pressure of copepodids (which is affected by temperature and salinity), out-migrating wild Atlantic salmon smolts are likely to experience substantial sea lice infection pressures in some areas in some years. This supports an earlier review by Chang et al. (2011b), who noted the potential for sea lice transfer from farmed salmon to wild salmon migrating out

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[101] The FMP states: "Sea lice treatments applied according to Farm Management Plan" https://novascotia.ca/fish/aquaculture/aquaculture-management/?wbdisable=true

[102] The updated New Brunswick Aquaculture Act received Royal Assent in Dec 2019 and regulations are currently being developed. The new Act and regulations will both be proclaimed at the same time and is expected before the end of 2021.

[103] https://www.dfo-mpo.gc.ca/about-notre-sujet/publications/infographics-infographies/documents/sea-lice-pou-eng.pdf

[104] https://www.scottishsalmon.co.uk/code-of-good-practice

[105] https://www.gov.scot/publications/fish-health-inspectorate-sea-lice-information/

of the Magaguadavic and St. Croix rivers in New Brunswick would be high, especially if there are high sea lice numbers on salmon farms located near wild salmon migration routes.

It is notable that the nine DFO assessments of the risk to Fraser River sockeye salmon from the transfer of pathogens from Atlantic salmon farms in the Discovery Islands in British Columbia did not include an assessment of sea lice, and similar studies do not appear to be available in Atlantic North America. With considerable similarity to the methods used by DFO for the other pathogens, the Norwegian Institute of Marine Research annually considers the "risk associated with mortality of migrating post-smolt salmon (Atlantic salmon – *Salmo salar*) as a result of salmon lice discharges from salmon farms" (Grefsrud et al., 2021a). This considers two primary factors: A) Wild fish are infected by sea lice, and B) The wild fish's tolerance to sea lice. Factor A has three sub-factors of 1) The environmental conditions for lice, 2) Emissions of salmon lice larvae from farms, and 3) Overlap between wild fish and sea lice in space and time (see Figure 34).

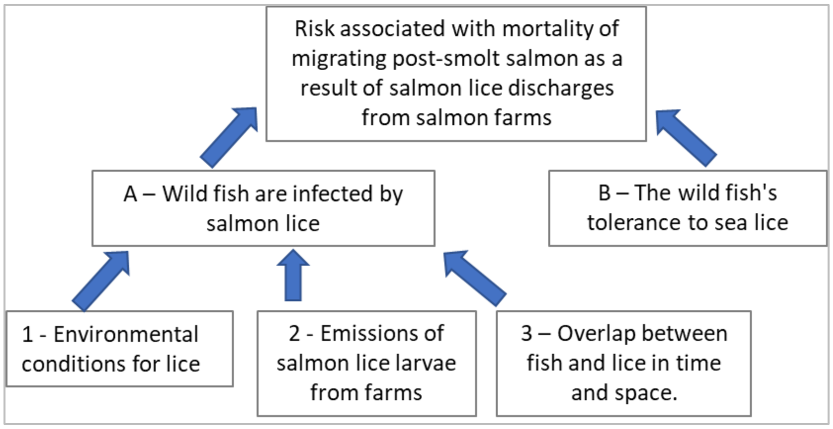

Figure 34: Factors and subfactors of the Norwegian Institute for Marine Research's annual risk assessment for sea lice impacts resulting from salmon farms. Translated from Grefsrud et al. (2021).

The Norwegian risk assessment is supported by large amounts of data on the lice levels on farms, in coastal waters, and on wild fish, and is conducted for each of Norway's 13 production areas. Attempting to repeat this type of risk assessment in Atlantic North America is beyond the scope of this Seafood Watch assessment, except to superficially note that each of the factors and subfactors will be highly variable. For example, environmental conditions for lice are generally considered suitable in the northwest Atlantic (as evidenced by the numbers of lice on farms and wild fish during the outmigration period) but as lice survival and development is strongly associated with temperature and salinity, there will be considerable local and temporal variations in the infection pressure experienced by wild fish. The emissions of lice larvae from farms (assuming emissions of larvae are correlated with the numbers of lice on farms) has already been shown above to be highly variable both temporally and geographically. The overlap between fish and lice in space and time is somewhat implied by the focus of sea lice management on the April-June outmigration period, but there is likely to be variation in outmigration (and coastal residence) times between salmon from different rivers in Maine, New Brunswick, Nova Scotia, and Newfoundland. The infection of wild fish by lice from salmon farms (if any) is therefore likely to be highly variable.

With regard to Atlantic salmon's tolerance to sea lice (Factor B in Figure 34) Braden et al. (2020) describe over 30 years of research on louse biology, control, host responses and the host-parasite relationship that has provided a plethora of information on the intricacies of host resistance and parasite adaptation. Figure 35 shows an image copied from Braden et al. (2020) showing susceptibility of the main salmonid species, with Atlantic salmon being the most susceptible, along with the Pacific Sockeye salmon.

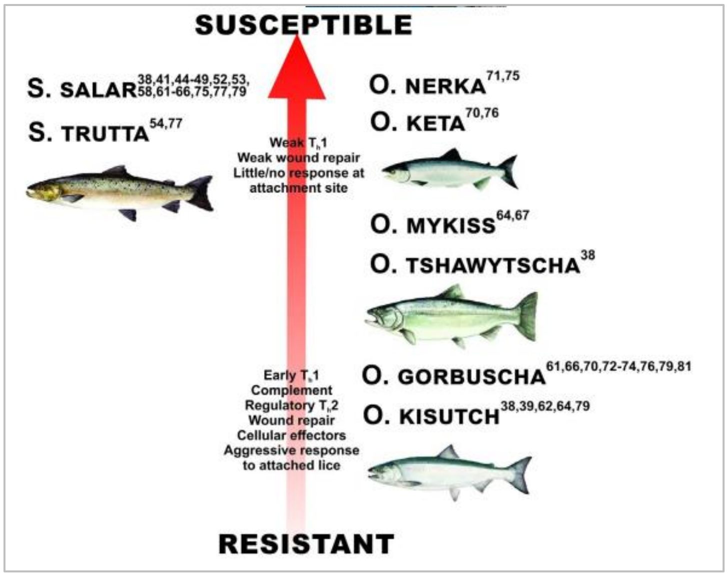

Figure 35: Overview of the susceptibility/resistance of Pacific (and Atlantic) salmonid species to sea lice. Image copied from Braden et al. (2020), and numbers refer to references quoted by Braden et al.

With consideration of the scale of lice infections necessary to negatively impact wild Atlantic salmon smolts, Vollset et al. (2019) simplistically[106] categorized mortality estimates of wild Atlantic salmon (in Norway) into four levels based on the number of sea lice per gram of fish weight (e.g., if a 50 gram smolt has five lice, it has 0.1 lice per gram of fish weight) such that:

- 100% of individuals with >0.3 lice per gram of fish weight will die.
- 50% of individuals with 0.2-0.3 lice per gram of fish weight will die.
- 20% of individuals with 0.1–0.2 lice per gram of fish weight will die.
- 0% of individuals with <0.1 lice per gram of fish weight will die.

NRC (2004) reported wild salmon post smolts in Maine enter the ocean at a size of 13 to 23 cm fork length, and most often 16 to 20 cm. Taking 18 cm as an average and using an Atlantic salmon length-weight relationship from Kane (1988), the lice loads listed above from Vollset et al. (2019) indicate that less than approximately 7 lice per 18 cm fish would be non-lethal, and increasing numbers would be associated with the following estimated mortalities:

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[106] see Vollset et al., 2019, for a full review – in Norwegian

- 100% of individuals with >21.5 lice per fish will die.
- 50% of individuals with 14.3 to 21.5 lice per fish will die.
- 20% of individuals with 7.2 to 14.3 lice per gram of fish weight will die.
- 0% of individuals with 7.2 lice per fish will die.

Unfortunately (and again in stark contrast to western Canada where comprehensive monitoring of lice levels on out-migrating juvenile wild salmon is conducted in all major farming areas) no data could be found for counts of sea lice levels on wild Atlantic salmon smolts in the Atlantic North America region. There has also been limited investigation of the impacts of lice transfer and infection in the northwest Atlantic. Ten years ago, Aas et al. (2011) noted that while the dynamics and impacts of sea lice transmission between wild and farm salmon have been studied more extensively in other salmon-farming regions, similar research in Atlantic North America is somewhat limited. A literature search for more recent studies indicates this is still largely the case.

In Norway, sea lice impacts to wild salmon are considered so important that they are the single factor currently controlling the expansion of the industry through a "traffic light" system; e.g., Vollset et al. (2020), but the limited research that is available from Atlantic North America, although now somewhat dated, provides no evidence of a link between sea lice on farms and sea lice on wild fish, and suggests that the sea lice burdens observed on farmed salmon may not actually present as great a risk to their wild counterparts as has been posited.

In one study, Carr & Whoriskey (2004) found that between 1992 and 2002, sea lice numbers on adult salmon returning to the Magaguadavic River – in the middle of the New Brunswick salmon-farming industry – were generally low, even in years when farms were experiencing sea lice epidemics. And while this research did not assess sea lice burdens on out-migrating (and more susceptible) smolts, another study, from 2001 to 2003 did. Lacroix & Knox (2005) investigated sea lice presence on wild, hatchery-origin, and escaped post-smolts in the vicinity of salmon farms (Gulf of Maine and Bay of Fundy) and found no *L. salmonis* on any of the 398 fish captured, and only 2.4%, 4.4%, and 2.4% of surveyed fish hosted (the non salmon-specialist) *Caligus* sp. lice in 2001, 2002, and 2003, respectively, at a maximum intensity of 1 louse per fish. In addition, Lacroix & Knox (2005) found no lesions indicative of prior lice attachment on wild or hatchery-origin post-smolts, and discard the probability that lice-infected fish experienced mortality before they could be captured, citing Grimes and Jackson's (1996) findings that lice-induced mortality typically occurs >3 weeks after infection. Lacroix and Knox (2005) conclude: "The survey found no evidence to support the hypothesis that parasites or diseases found in salmon farms or hatcheries were affecting post-smolts leaving the Bay of Fundy," and "The excellent health of post-smolts captured in the Bay of Fundy and Gulf of Maine (e.g., no salmon lice, lesions or other pathologies, or bacterial or viral pathogens) indicated that their survival over the long term was probably not compromised by the diseases or parasites associated with salmon farms along their migration route." Bricknell et al. (2015) supported the findings by Lacroix and Knox (2005) by determining that "the overall risk and intensity of infection observed during the out-migrating smolt window was at levels representative of a sub clinical infection with no physiological impact on the fish."

In a 2011 NOAA/NMFS-authored Biological Opinion, it is stated that while "these examples of disease transfer from farmed to wild salmon in other countries clearly demonstrate the risk to the Gulf of Maine Distinct Population Segment (GoM DPS), transmission of disease from Maine salmon farms to the GoM DPS has not been detected" (NMFS 2011). Publications such as those by Chang et al. (2011c) and DFO (2014) confirm that available evidence to date suggests that large-scale transmission of disease (including sea lice) from farm to wild fish has not occurred in Atlantic Canada. In Jones et al.'s (2015) review, despite uncertainty, it was concluded that the risk of sea lice "spillback" to wild fish was "moderate" and that its pervasiveness into the population was "unlikely." Organizations such as the Atlantic Salmon Federation, which is typically critical of the aquaculture industry for impacts such as escapes and genetic introgression (see Criterion 6 – Escapes), does not have any strong statements (as of a September 2021 review) on sea lice impacts to wild salmon in the region.

Despite these aspects, it is also worth noting the findings of recent research in Norway in terms of the challenges in detecting impacts; for example, it is important to note that one of the main problems is that the effect of lice on wild salmonids is context-sensitive; that is, the effect of lice is directly correlated with the overall survival in the ocean, so that in years of poor survival the effect of lice is large, while in years of good survival the effect of lice is almost not measurable (Vollset et al., 2015, 2019b; Bøhn et al., 2020). Second, it is important to note that the impacts are highly variable by locality (e.g., individual rivers and fjords) and year, and Vollset et al. (2019) recognize the challenges of drawing conclusions over an entire production area. Similarly, Bøhn et al. (2020) highlight that timing is crucial. In years with little overlap between lice blooms (on salmon farms) and wild smolt migration, only minor effects can be expected; conversely, in years with a strong overlap in timing, serious mortality effects can be expected. Shephard and Gargan (2020) also noted that the calculated reduction in the returns of wild salmon due to sea lice varied according to the characteristics of the location and the variable dynamics described above, but these authors also identified a clear interaction between sea lice and climate change and showed that returns of one sea-winter salmon are strongly impaired when smolts exposed to low–moderate levels of lice infestation also experience warmer temperatures in the late summer–autumn period. They suggest that the well-understood impacts of sea lice are likely to be exacerbated by ocean warming.

With regard to the federal oversight of the spread of infectious diseases and parasites from farmed salmon, the 2018 Spring Report (OADC, 2020 – covering Canada only) found that while research was increasing, including on the effects of disease and parasite transmission to wild fish, longer term funding was biased toward the development of the salmon farming industry as opposed to researching potential impacts, and gaps in scientific research remain. The Spring Report found that although DFO and the CFIA had put in place some measures to mitigate the spread of infectious diseases and parasites from farmed salmon, key elements were missing (noting some have since been at least partially addressed by endeavors such as the DFO pathogen risk assessments referenced above).

In summary (with regard to sea lice), as the industry expanded in the 1990s, sea lice became the major cause of fish mortality and economic loss to the aquaculture industry in eastern Canada and Maine. While data on sea lice numbers on farms remain limited, the use of pesticides and the 2020 count data currently indicate low levels of lice in Maine and Nova Scotia. In contrast to other parts of Canada (British Columbia) and the north Atlantic (Norway) which have comprehensive monitoring programs for sea lice on farms and on juvenile wild salmon (plus abundant site-level public data on both) very little is known about potential infections of wild Atlantic salmon with lice from farms. The available data from New Brunswick shows high average lice levels on farms during the out-migration period of juvenile salmon, but the limited and often dated available studies show a low concern with regard to impacts to wild fish. By referring again to the risk factors used by Grefsrud et al. (2021a) in Norway, it can be seen that there are large variations across all factors, thereby implying that the impacts may be severe when all the factors align, but that there may be few circumstances where they actually do in reality (i.e., if there are large numbers of lice emitted by a farm and high survival of the lice larvae, at the same time as juveniles Atlantic salmon of a susceptible size are migrating through the infection zone).

Conclusions and Final Score

Large amounts of research and publicly available fish health and mortality data in other areas (particularly British Columbia and Norway) note the concern regarding the potential transfer of pathogens and parasites from salmon farms to wild salmonids, but there is very little information available in Atlantic North America. While many disease-related management and monitoring measures are in place, few data are available, and the open net pen system remains vulnerable. The ongoing occurrence of mortality events in Atlantic North American farms (as reported by industry media) highlights the likelihood that some diseases occur or are secondary factors in these events. Nevertheless, the potential for salmon farms to act as a reservoir for transmission of pathogens to wild fish (i.e., of types and numbers of pathogens that they would not naturally encounter) remains uncertain. While recent research, particularly in British Columbia, continues to develop rapidly on many fronts and is making many associations between farm viruses and wild salmon, there have been few robust conclusions on demonstrable impacts.

A similar situation exists for sea lice. Large publicly available datasets from routine monitoring and research in the eastern Atlantic (Norway) and western Canada (British Columbia) demonstrate it is likely that there will be substantial mortality of wild salmon in some areas in some years. The limited available data in Atlantic North America indicate sea lice levels on farms are high in New Brunswick, including in some areas each year during the juvenile salmon outmigration period, but are likely low in Maine and Nova Scotia. Despite the welcome start of (minimal) data publication in Newfoundland, lice levels here remain largely unknown. Atlantic salmon are one of the most susceptible salmonid species to sea lice and sub-lethal impacts and increased risk of predation may also be important.

The analysis here has been limited to a simplistic overview, particularly given the limited data in the region. It highlights the ongoing uncertainty in the potential for wild Atlantic salmon to be infected with pathogens and parasites that they would not naturally experience, the uncertainty in the impact of any such infections, and in the potential cumulative impacts of pathogens and parasites from farms. The applicability of the research in other regions to Atlantic North America is also uncertain. Given the status of wild salmon populations in the Atlantic (see Criterion 6 – Escapes), the uncertainties driven by the lack of data largely define the need for a precautionary approach, and without a robust understanding of how on-farm disease impacts wild fish, the Risk-Based Assessment method was used. For all regions, the potential impacts of viral or bacterial pathogens remains unknown, but in New Brunswick, lice levels on average are often high in at least one BMA each year during out-migration, with likely very high levels in individual farms, and the final score for Criterion 7 – Disease is 0 out of 10. In Newfoundland, lice levels remain largely uncertain and given the established pathogen and parasite transfer risk, the final score for Criterion 7 – Disease is 2 out of 10. For Nova Scotia and Maine, sea lice count data availability is also limited, but when combined with the pesticide use data, they indicate lice levels are low and the simple open nature of the production systems results in a final score for Criterion 7 – Disease of 4 out of 10.

Criterion 8X: Source of Stock – independence from wild fish stocks

Impact, unit of sustainability and principle

- Impact: The removal of fish from wild populations
- Unit of Sustainability: Wild fish populations
- Principle: using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 8X Summary

Maine, US and Atlantic Canada

C8X Source of Stock – Independence from wild fish stocks	**Value**	**Score**
Percent of production dependent on wild sources (%)	0.0	0
Use of ETP or SFW "Red" fishery sources	No	
Lowest score if multiple species farmed (0 to-10)		n/a
C8X Source of stock Final Score (0 to -10)		**-0**
Critical?	No	Green

Brief Summary

All Atlantic salmon raised in the US and Canada are sourced from hatchery-raised broodstock; the industry's production is considered to be independent of wild fisheries for both broodstock and juveniles. The industry has increasingly used cleaner fish as an alternative to chemical pesticide treatments, which requires a minor use of eggs from wild caught lumpfish (*Cyclopterus lumpus).* This species is listed as threatened by COSEWIC, but the quantities used represent less than 0.15% of the commercial catch and are intended to result in the development of domesticated. In addition, wild-caught wrasse have been used on a small number of sites, but this use is not currently considered to reach the scoring threshold in the Seafood Watch standard (i.e., the reliance of 10% of the region's farmed salmon production on their capture). Due to the small amounts of wild caught cleaner fish, the final numerical score for Criterion 8X – Source of Stock for all of Atlantic North America is a deduction of 0 out of -10 for all regions.

Justification of Rating

Atlantic salmon aquaculture has seen a multi-decadal establishment of breeding programs, aimed at selection for traits advantageous to farming (e.g., fast growth, disease resistance), which has been integral in the rapid growth of the industry (Asche et al., 2013; Heino et al., 2016). In Atlantic North America (as discussed in Criterion 6 – Escapes, Factor 6.2) farmed Atlantic salmon are also the result of selective breeding programs initiated in the 1980s and have been used for aquaculture since then (Glebe, 1998; Wringe et al., 2018). Therefore, due to the industry-wide use of domesticated broodstocks globally, 100% of salmon eggs, juveniles and smolts are considered to be independent of wild salmon populations.

As discussed in Criterion 4 – Chemical Use, cleaner fish (the lumpfish *Cyclopterus lumpus*) are used as an alternative to chemical pesticides. These are predominantly considered to be hatchery-raised (currently at facilities in the Memorial University of Newfoundland), but according to the Environmental Preview Report for a proposed hatchery in Newfoundland[107], in its early years of operation the hatchery will require the harvest of roe from wild fish (as does the current production at Memorial University). The demand (4 million eggs) will amount to an estimated 80 kg to be harvested from approximately 300 females, plus five males. According to the dominant producer (of farmed salmon) in Atlantic North America, the use of wild caught lumpfish is now further limited to smaller numbers of wild fish used to supplement the genetic diversity in the domesticated stock, as opposed to the direct use of wild-caught roe (J. Wiper, pers. comm., 2021).

For reference, the commercial lumpfish fishery is directed entirely at harvesting the roe from females for human consumption, and in Canada is exclusively pursued in Newfoundland by inshore small boat fishers. The species has declined 58% in abundance over the last 20 years; catches are recorded as the quantity of roe and have declined from a peak of over 2,000 mt annually from 1987-2002 to 79 mt annually from 2009-14. As of 2017, the species is listed as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC)[108] due to the declines in abundance. The use in aquaculture of a threatened species dictates a critical score in the Seafood Watch Aquaculture Standard, but in this case, the volume intended to be harvested for the development of domesticated broodstocks that will, as a priority, alleviate the need for wild capture, is small. The current use of wild caught roe is likely to be considerably less than the proposed 80 kg (i.e., prior to the establishment of the hatchery[109]), but this quantity of roe in full represents 0.15% of the ongoing Atlantic Canada commercial fisheries harvest (52,420 kg as of 2019, according to the above-referenced project report).

According to an industry representative, a single farm in New Brunswick was also stocked with wild-caught wrasse (*Tautogolabrus adspersus*, known locally as cunners) in 2019, but the use of this species has not continued and the focus (at least from the dominant producer) is on the development of lumpish production as described above. This small scale of use (even if proven to be from an unsustainable fishery), is considered to be less than the 10% scoring threshold for the percentage of farmed salmon production dependent on wild caught species in the Seafood Watch Aquaculture Standard.

Conclusions and Final Score

All Atlantic salmon raised in the US and Canada are sourced from hatchery-raised broodstock; the industry's production is considered to be independent of wild fisheries for both broodstock

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[107] https://www.gov.nl.ca/ecc/files/env-assessment-projects-y2020-2062-EPR.pdf

[108] https://wildlife-species.canada.ca/species-risk-registry/species/speciesDetails_e.cfm?sid=1365

[109] The hatchery does not yet appear to be operational - https://marbase.ca/lumpfish-hatchery/

and juveniles. The industry has increasingly used cleaner fish as an alternative to chemical pesticide treatments, which currently requires a minor use of eggs from wild caught lumpfish (*Cyclopterus lumpus*). This species is listed as threatened by COSEWIC, but the quantities currently used represent less than 0.15% of the commercial catch and are intended to result in the development of domesticated broodstock. In addition, wild-caught wrasse have been used on a small number of sites, but this use is not currently considered to reach the scoring threshold in the Seafood Watch Aquaculture Standard (i.e., the reliance of 10% of the region's farmed salmon production on their capture). Due to the small amounts of wild caught cleaner fish, the final numerical score for Criterion 8X – Source of Stock for all of Atlantic North America is a deduction of 0 out of -10 for all regions.

Criterion 9X: Wildlife Mortalities

Impact, unit of sustainability and principle

- Impact: Mortality of predators or other wildlife caused or contributed to by farming operations
- Unit of Sustainability: Wildlife or predator populations
- Principle: Preventing population-level impacts to predators or other species of wildlife attracted to farm sites.

This is an "exceptional" factor that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 9X Summary

Maine, US and Atlantic Canada

Risk-Based Assessment

C9X Wildlife Mortality parameters		**Score**
Single species wildlife mortality score		-2
System score if multiple species assessed together		n/a
C9X Wildlife Mortality Final Score (0 to -10)		**-2**
Critical?	No	Green

Brief Summary

Regulations and management practices for non-harmful exclusion of wildlife are in place and Canada is amending the Marine Mammal Regulations (effective January 2022) to match those of the US Marine Mammal Protection Act, which prohibits lethal control of marine mammals with the exception of incidences where human safety is endangered (i.e., Nuisance Seal Licenses will no longer be issued in Canada). Although there are no publicly available data with which to confirm the mortality numbers, lethal control is considered to only be used in exceptional cases that would not affect the population status of the affected species (noting that Atlantic Canada continues to have an annual commercial hunt of grey and harp seals). Accidental mortalities (e.g., entanglement) of seals, birds, and large fish (sharks or tuna) cannot be eliminated in the net pen system and without robust data, mortality numbers are unknown. However, with effective deterrents (primarily above- and below-water predator nets), mortality of these species is also considered limited to exceptional circumstances and highly unlikely to affect population health. Without a robust dataset to determine the impact of farm-wildlife interactions, the Risk-Based Assessment method was used, and the final score for Criterion 9X – Wildlife Mortalities for all of Atlantic North America is -2 out of -10.

Justification of Rating

The presence of farmed salmon in net pens at high density inevitably constitutes a powerful food attractant to opportunistic coastal marine mammals, seabirds, and fish that normally feed on native fish stocks (Sepulveda et al. 2015). As these predators can threaten production, they have sometimes been lethally controlled, but can also become entangled in nets and other farm infrastructure resulting in mortality. Entanglements are not restricted to predators; for example, a humpback whale was entangled in gill nets used to recapture salmon from a farm in Newfoundland following an escape of 2,000-3,000 salmon in 2018[110]. The whale was released alive.

At all salmon farm sites in Canada and the US, control measures are in place to limit the direct interaction of wildlife and farmed fish. Passive control measures include the employment of predator control nets which enclose each pen's primary fish containment net and pen-top bird netting to prevent predation of farm fish by birds. While bird netting remains in place for the duration of the growout cycle, predator nets may be temporarily removed for periods during the summer to allow for better water flow and the maintenance of adequate dissolved oxygen content (J Wiper, pers. com., 2020). In addition, non-lethal acoustic deterrent devices may be used to discourage birds from landing on net pens. Lethal control measures of marine mammals are prohibited in the US by the Marine Mammal Protection Act of 1972 (MMPA) (NOAA 2007). As a Category III fishery, marine aquaculture operators must report incidental 'takes' to NOAA (NOAA 2015b). Lethal control of predatory birds is regulated by the USDA Animal and Plant Health Inspection Service (APHIS) and must be preceded by a NMFS-issued permit (Gorenzel et al. 1994; USFWA 2013).

In the Atlantic Canadian provinces, DFO states (on a webpage updated October 22nd, 2020[111]) that marine mammal predator control is governed nationally by the Marine Mammal Regulations under the Fisheries Act, and a license can be obtained from the Minister to hunt nuisance animals (defined as a marine mammal that represents a danger to life and/or equipment) if deterrence efforts have not been successful. However, Canadian news media[112] reports nuisance seal licenses will no longer be issued by DFO (in order to comply with export requirements to the US under the Import Provisions of the Marine Mammal Protection Act, starting January 1, 2022). Canadian fish farmers had already voluntarily committed to end lethal seal control in 2018 with the exception of cases where human health is endangered[113].

DFO ran a consultation from July to October 2020 on the proposed amendments to the Marine Mammal Regulations, which would:

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[110] CBC News Aug 4th 2018. Humpback whale freed from net meant for escaped farm salmon in Hermitage Bay. https://www.cbc.ca/news/canada/newfoundland-labrador/whale-caught-gill-net-cooke-aquaculture-1.4784732

[111] https://www.dfo-mpo.gc.ca/aquaculture/protect-protege/removal-fish-retraits-poissons-eng.html

[112] CBC News - Canada to ban 'nuisance seals' killing to keep access to U.S. market. https://www.cbc.ca/news/canada/nova-scotia/canada-to-ban-so-called-nuisance-seals-killing-1.5633394

[113] CBC News July 2 2020. Canada to ban 'nuisance seals' killing to keep access to U.S. market. https://www.cbc.ca/news/canada/nova-scotia/canada-to-ban-so-called-nuisance-seals-killing-1.5633394

1 - Remove the authority of the Minister of Fisheries and Oceans to issue a Nuisance Seal License.

2 - Include an exemption to the prohibition on disturbing, including lethal removal, of marine mammals

  a) where there is an imminent threat to human health and safety
  b) where the humane dispatch of a marine mammal, including seals, is imminently necessary to avoid serious injury, additional injury, or death due to entanglement in fishing gear or debris.

These amendments are intended to align with the language in the US MMPA which is already in place for US salmon farms in Maine.

Although it is considered that marine mammal mortalities, and particularly those occurring under nuisance sea licenses, would be reported to the relevant authorities, and in the case of the Canadian Provinces, subsequently to DFO, there do not appear to be readily available statistics on seal mortalities (deliberate or accidental through entanglement) on aquaculture sites in Maine or Atlantic Canada (in contrast to western Canada in British Columbia). The 2018 Spring Report on salmon farming (AOG, 2018) stated that according to DFO, aquaculture had little interaction with marine mammals on the east coast due to the location of the fish pens in shallow water. As such, the Department did not collect data on marine mammal interactions with aquaculture. According to NOAA (2020), an average of 350 harbor seals per year were killed by human activity between 2013 to 2017, of which 338 were attributed to observed fishing boat mortalities. None were attributed to aquaculture.

According to Canadian Science Advisory Secretariat (CSAS, 2017), the Atlantic Northwest population of grey seals has been increasing since the 1960s, and while there is not a recent population estimate for harbor seals, the population is generally considered to be increasing[114] (NOAA, 2020).

Given the restrictions in place in the US, the voluntary prohibition of seal kills in Canadian farms, and the evolving Canadian regulations, mortality of seals – due to threats to human health and safety or accidental entanglements – are considered to be limited to exceptional circumstances. It is also of relevance to note that commercial seal hunts continue in Canada, for which the latest data available from DFO show 1,612 grey seals and 66,800 harp seals were killed in 2016[115]. Similarly, while deterrents are considered effective in minimizing bird entanglements, mortalities are considered somewhat inevitable, yet also limited to exceptional circumstances that are highly unlikely to have any population level impacts on the species affected. Data previously supplied showed small numbers of sharks and tuna were also killed (in

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[114] An unusual mortality event is currently occurring since 2018 where elevated numbers of harbor seal and gray seal mortalities have occurred in the region, likely due to Phocine distemper virus: https://www.fisheries.noaa.gov/new-england-mid-atlantic/marine-life-distress/2018-2020-pinniped-unusual-mortality-event-along

[115] https://www.dfo-mpo.gc.ca/fisheries-peches/seals-phoques/seal-stats-phoques-eng.html

2013), and while it is not known if these incidences continue to occur, the numbers (10 sharks and 4 tuna in 2013) are again considered here to represent exceptional cases.

Conclusions and Final Score

Regulations and management practices for non-harmful exclusion of wildlife are in place and Canada is amending the Marine Mammal Regulations (effective January 2022) to match those of the US Marine Mammal Protection Act to prohibit lethal control of marine mammals (seals) except in incidences where human safety is endangered. Although there are no data with which to confirm the numbers involved, lethal control is therefore considered to only be used in exceptional cases that would not affect the population status of the affected species (noting that Atlantic Canada continues to have an annual commercial hunt of grey and harp seals). Accidental mortalities (e.g., entanglement) of seals, birds, and large fish (sharks or tuna) cannot be eliminated in the net pen system, and without robust data, mortality numbers are unknown. However, with effective deterrents (primarily above- and below-water predator nets), mortalities are considered limited to exceptional circumstances and highly unlikely to affect the health of populations. The Risk-Based Assessment method was used, and the final score for Criterion 9X – Wildlife Mortalities for all of Atlantic North America is -2 out of -10.

Criterion 10X: Introduction of Secondary Species

Impact, unit of sustainability and principle

- Impact: Movement of live animals resulting in introduction of unintended species
- Unit of Sustainability: Wild native populations
- Principle: Avoiding the potential for the accidental introduction of secondary species or pathogens resulting from the shipment of animals.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score.

Criterion 10X Summary

Maine, US

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	36	6
Biosecurity score of the <u>source</u> of animal movements (0-10)		8
Biosecurity score of the farm <u>destination</u> of animal movements (0-10)		2
C10X Introduction of Secondary Species Final Score (0 to -10)		**-0.8**
Critical?	No	Green

New Brunswick

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	18	8
Biosecurity score of the <u>source</u> of animal movements (0-10)		8
Biosecurity score of the farm <u>destination</u> of animal movements (0-10)		2
C10X Introduction of Secondary Species Final Score (0 to -10)		**-0.8**
Critical?	No	Green

Newfoundland

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	25	7
Biosecurity score of the <u>source</u> of animal movements (0-10)		8
Biosecurity score of the farm <u>destination</u> of animal movements (0-10)		2
C10X Introduction of Secondary Species Final Score (0 to -10)		**-0.6**
Critical?	No	Green

Nova Scotia

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	65	3
Biosecurity score of the <u>source</u> of animal movements (0-10)		8
Biosecurity score of the farm <u>destination</u> of animal movements (0-10)		2
C10X Introduction of Secondary Species Final Score (0 to -10)		**-1.4**

Critical?	No	Green

Brief Summary

Data on introductions and transfers from DFO shows there are considerable movements of aquatic organisms, including farmed salmon and cleaner fish, occurring into all Canadian provinces from elsewhere (typically other provinces, but also internationally). There are no data to understand movements into Maine from other regions, so the average of Canadian movements is used as a proxy. Regulations regarding live fish movements in the US and Canada are available, particularly through the US Animal and Plant Health Inspection Service and following the Canadian Code on Introductions and Transfers of Aquatic Organisms (which includes a "parasite or fellow traveler" risk assessment process). The combination of the tank-based hatchery systems (considered the dominant source of live animal movements during the salmon production cycle, including for cleaner fish) and the regulatory requirements (including the Certificate of Fish Health Transfer and associated screening) are considered to offer high biosecurity and reduce the risk that a secondary organism will be unintentionally transported. The recent import of salmon eggs from Iceland to Newfoundland is considered to be minor, and also to come from a relatively biosecure source. Overall, the trans-waterbody movement of animals (of all aquatic species, and therefore including salmon and cleaner fish) is variable across the regions based on DFO movement data, and provide an estimated reliance of 18%, 25%, and 65% of production for New Brunswick, Newfoundland, and Nova Scotia respectively. Maine is considered to have, by proxy, 36% reliance on such movements. All movements originate at typically highly-biosecure facilities. The final numerical deduction for Criterion 10X – Introduction of Secondary Species for New Brunswick is -0.4 out of -10; for Newfoundland is -0.6 out of 10; for Nova Scotia is -1.4 out of 10, and for Maine is -0.8 out of 10.

Justification of Rating

According to the UN FAO (2012), the expanded and occasionally irresponsible global movements of live aquatic animals have been accompanied by the transboundary spread of a wide variety of pathogens. In some instances, these pathogens have caused serious damage to aquatic food productivity and resulted in pathogens becoming endemic in culture systems and the natural aquatic environment. The global salmon farming industry has suffered from the introduction of pathogens during the international movements of live animals, and transfers of live material is regarded as one of the most serious risk factors for spreading disease within the industry (Sommerset et al., 2021, referring to the Norwegian industry). While the impacts to production are well documented, the ecological impacts beyond the farm are less apparent.

In Canada, the National Code on Introductions and Transfers of Aquatic Organisms[116] guides the Introductions and Transfers Committees with the assessments of proposals to move aquatic organisms from one body of water or rearing facility to another. The code states it has established an objective decision-making framework and consistent national process for assessing and managing the potential ecological, disease and genetic risks associated with

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[116] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/it-code-eng.htm#7

intentionally moving live aquatic organisms into, between, or within Canadian watersheds and fish rearing facilities.

Of particular relevance here is the “Parasite or fellow traveler risk assessment process” (which is Part 2 of the Aquatic organism risk assessment, in Appendix 7). This follows a two-step process: Step 1 estimates the probability that a parasite or fellow traveler may be introduced along with the species proposed for introduction, and secondly estimates the probability that the parasite or fellow traveler will encounter susceptible organisms or suitable habitat; Step 2 determines the consequence of establishment of a parasite or fellow traveler on native species or aquaculture and ecological or genetic impacts in the ecosystem.

Factor 10Xa International or trans-waterbody animal shipments

Potential movements of live animals within the salmon farming industry include imports of eggs (ova), the transfer of smolts from freshwater hatcheries to marine sites, transfers of ongrowing salmon between marine sites, and movements to harvest facilities. In addition, cleaner fish are moved from hatcheries to net pen salmon farms (with some moved from wild fisheries to broodstock facilities). Salmon farms in Atlantic North America are supported by approximately 20 land-based facilities for the production of salmon (eggs, fry, parr, or smolts) and cleaner fish to be stocked in net pens. The majority are located in Canada, and the majority of those are in New Brunswick. Until recently, the exclusive use of North American strains of Atlantic salmon in the region (see Criterion 6 – Escapes, Factor 6.2) meant there were not considered to be any international imports of eggs (from countries other than the US), but in 2020 one company imported two batches of all-female, triploid European-origin Atlantic salmon from Iceland to Newfoundland. There is also considered to be some interprovincial movement in Canada and international movement of eggs and hatched fish to or from Maine.

DFO provides basic data on introductions and transfers by province or territory[117], most recently for 2019 (accessed September 2021), with aggregated data on the origin (e.g., within province, from another province, or from another country), the purpose (e.g., aquaculture, enhancement, research, etc.), and the type of aquatic of aquatic organisms (e.g., marine finfish, freshwater finfish, marine shellfish). While the Canadian Code on Introductions and Transfers of Aquatic Organisms guides the movement of aquatic organisms from one body of water or rearing facility to another, it doesn’t specifically define any boundaries or characteristics of different water bodies. For the purposes of this assessment, movements across provinces or between Canada and Maine are considered trans-waterbody movements, and the category of “marine finfish” is considered to include salmon and cleaner fish.

The 2019 reporting for New Brunswick (as an example) states: “most proposed movements into or within New Brunswick were for Atlantic Salmon”, but there were 125 approved applications for 103 different species, and it is not possible to robustly determine how many were Atlantic salmon for aquaculture from outside New Brunswick. Nevertheless, some assumptions can be made; for example, only 18% of the approved movements into New Brunswick originated in

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[117] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/rep-rap-eng.htm

another province or country, and this therefore represents the maximum for any single species such as Atlantic salmon. Similarly, in Newfoundland, 25% of movements were from outside the province, and 75% for Nova Scotia (72% of movements were for aquaculture, and 65% were for marine finfish, therefore the maximum possible percentage for salmon would be 65% if all marine finfish movements were salmon). Similar data could not be found for Maine. Although a crude estimate based on a single species, these figures are used here, and without data for Maine, the average of the three Canadian provinces (36%) is used. As such, the score for Factor 10Xa for New Brunswick is 8 out of 10, for Newfoundland is 7 out of 10, for Nova Scotia is 3 out of 10, and for Maine is 6 out of 10.

Factor 10Xb Biosecurity of source and destination

Source of live fish movements

The risk of introducing a secondary species during the transport of live animals can be associated with the characteristics of the production system (including biosecurity practices) and the measures in place to manage the inspection and/or approval requirements prior to transport. Lillehaug et al. (2015) describe the biosecurity aspects of the farmed salmon system and consider movements of fertilized eyed eggs from specialized broodfish producers to be of low risk as the eggs are disinfected immediately after fertilization and sometimes again before delivery (this applies to the recent imports into Newfoundland of eggs from Iceland). For fry and smolts, the important feature from a biosecurity perspective is the containment aspect where, for tank-based systems on land (and often inside physical structures), the primary biosecurity risk is the water source (Lillehaug et al., 2015). The risk may be reduced significantly by employing water disinfection systems such as UV light or ozone that reduce the infectious load substantially, but no water treatment systems have the capacity to eliminate microorganisms completely. Lillehaug et al. (2015) consider land-based smolt production systems can more or less be isolated in a biosecurity sense, but that the biosecurity risk varies according to the transmission characteristics of the different pathogens. For cleaner fish, the potential to disinfect eggs plus the physical biosecurity of tank-based hatcheries and nurseries, is considered similar to that of salmon.

In Canada, the CFIA is the federal lead for the delivery of the National Aquatic Animal Health Program (NAAHP) and DFO and provinces also have a role. The federal and provincial legislation and the relevant authorities and their commitments are listed in Appendix 1 of the National Code on Introductions and Transfers of Aquatic Organisms. Prior to movements the Atlantic Provinces require verification of fish health and a Pan-Atlantic finfish policy for these transfers was created, called the Certificate of Health for Transfer (COHFT). The COHFT outlines the required fish health procedures for transfer permission to be granted, the responsibilities of the facility designated veterinarian(s), the provincial veterinarian(s), and the facility owners. The COHFT also requires biosecurity audits performed at each hatchery each year, including annual fish health sampling and testing. While the COHFT is designed to meet provincial requirements, it also considers the CFIA requirements for the receipt of live eggs or finfish from outside the Atlantic Provinces (e.g., Maine). It is considered here that similar requirements are in place in the US under the Animal and Plant Health Inspection Service[118], for example with regard to US import permits, veterinary health certificates, and inspections[119].

Overall, the tank-based hatchery sources of live fish movements have the potential for high biosecurity, even if specific practices in the region are not known. With the additional regulatory requirements in the Code on Introductions and Transfers of Aquatic Organisms, the score for Factor 10Xb is 8 out of 10.

<u>Destination of live fish movements</u>
The destination of greatest concern, i.e., with the weakest biosecurity, is the marine growout net pen sites that receive smolt movements from freshwater hatcheries and smolt units (and cleaner fish). Despite the presence of biosecurity protocols at net pen sites, the direct connection between the net pen and the external environment means the opportunity to contain any secondary organisms unintentionally included in live fish movements is low. Therefore, the score for the destination of live fish movements is 2 out of 10.

Overall, the score for Factor 10Xb is driven by the higher biosecurity system. The tank-based hatcheries as the source for salmon or cleaner fish movements present the highest degree of biosecurity, and the final score for Factor 10Xb is 8 out of 10.

Conclusions and Final Score
Data on introductions and transfers from DFO show there are considerable movements of aquatic organisms, including farmed salmon and cleaner fish, occurring into all Canadian provinces from elsewhere (typically other provinces, but also internationally). There are no data to understand movements into Maine from other regions, so the average of Canadian movements is used as a proxy. Regulations regarding live fish movements in the US and Canada are available, particularly through the US Animal and Plant Health Inspection Service and following the Canadian Code on Introductions and Transfers of Aquatic Organisms (which includes a “parasite or fellow traveler” risk assessment process). The combination of the tank-based hatchery systems (considered the dominant source of live animal movements during the salmon production cycle, including for cleaner fish) and the regulatory requirements (including the Certificate of Fish Health Transfer and associated screening) are considered to offer high biosecurity and reduce the risk that a secondary organism will be unintentionally transported. The recent import of salmon eggs from Iceland to Newfoundland is considered to be minor, and also to come from a relatively biosecure source. Overall, the trans-waterbody movement of animals (of all aquatic species, and therefore including salmon and cleaner fish) is variable across the regions based on DFO movement data, and provide an estimated reliance of 18%, 25%, and 65% of production for New Brunswick, Newfoundland, and Nova Scotia respectively. Maine is considered to have, by proxy, 36% reliance on such movements. All movements

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[118] https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/monitoring-and-surveillance/sa_nahss/animal-health-monitoring-and-surveillance

[119] https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/animal-and-animal-product-import-information/imports/live-animal-imports

originate at typically highly-biosecure facilities. The final numerical deduction for Criterion 10X – Introduction of Secondary Species for New Brunswick is -0.4 out of -10; for Newfoundland is -0.6 out of 10; for Nova Scotia is -1.4 out of 10, and for Maine is -0.8 out of 10.

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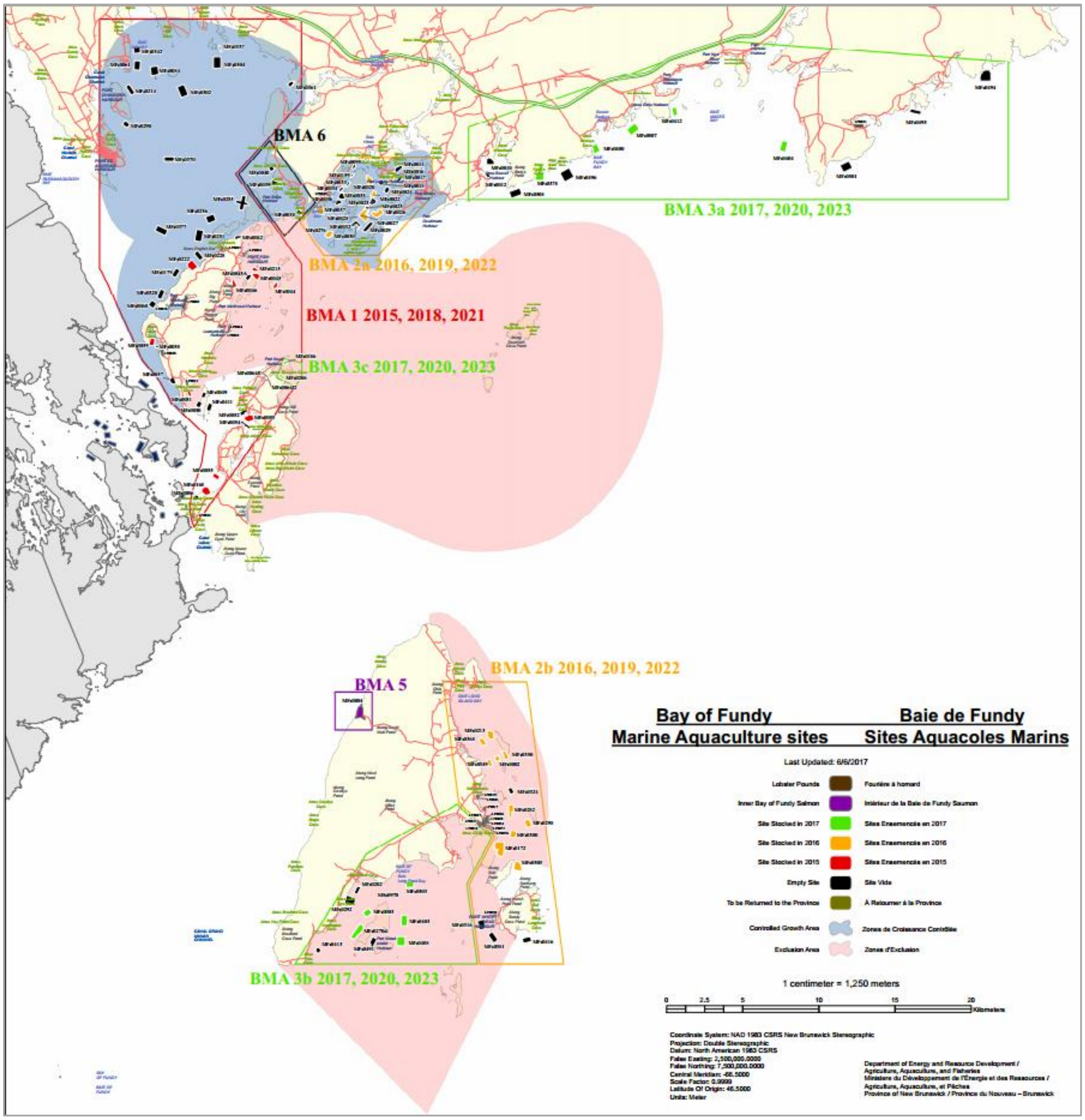
Appendix 1 – Map of Aquaculture Bay Management Areas



Appendix 2 – Data Points And All Scoring Calculations

This is a condensed version of the criteria and scoring sheet to provide access to all data points and calculations. See the Seafood Watch Aquaculture Criteria document for a full explanation of the criteria, calculations and scores.

All regions

Criterion 1: Data	
Data Category	**Data Quality**
Production	7.5
Management	7.5
Effluent	5.0
Habitat	5.0
Chemical Use	7.5
Feed	5.0
Escapes	7.5
Disease	2.5
Source of stock	7.5
Wildlife mortalities	5.0
Escape of secondary species	5.0
C1 Data Final Score (0-10)	**5.909**
	Yellow

All regions

Criterion 2: Effluent	
Effluent Evidence-Based Assessment	**Data and Scores**
C2 Effluent Final Score (0-10)	**4**
Critical?	NO

All regions

Criterion 3: Habitat	
F3.1. Habitat conversion and function	**Data and Scores**
F3.1 Score (0-10)	8
F3.2 – Management of farm-level and cumulative habitat impacts	
3.2a Content of habitat management measure	3
3.2b Enforcement of habitat management measures	4
3.2 Habitat management effectiveness	4.800
C3 Habitat Final Score (0-10)	**6.933**
Critical?	No

Maine and Nova Scotia

Criterion 4: Chemical Use	
Single species assessment	Data and Scores
Chemical use initial score (0-10)	8.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0-10)	**8.0**
Critical?	No

New Brunswick and Newfoundland

Criterion 4: Chemical Use	
Single species assessment	Data and Scores
Chemical use initial score (0-10)	2.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0-10)	**2.0**
Critical?	No

All regions

Criterion 5: Feed	
5.1 Wild Fish Use	
5.1a Forage Fish Efficiency Ratio (FFER)	**Data and Scores**
Fishmeal from whole fish, weighted inclusion level %	9.000
Fishmeal from byproducts, weighted inclusion %	6.000
Byproduct fishmeal inclusion (@ 5%)	0.300
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	7.500
Fish oil from byproducts, weighted inclusion %	2.500
Byproduct fish oil inclusion (@ 5%)	0.125
Fish oil yield value, weighted %	5.000
eFCR	1.300
FFER Fishmeal value	**0.537**
FFER Fish oil value	**1.983**
Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	5.000
Critical Source fisheries?	No
SFW "Red" Source fisheries?	No
FFER for red-rated fisheries	n/a
Critical (SFW Red and FFER >=1)?	No
Final Factor 5.1 Score	**2.820**

5.2 Net Protein Gain or Loss (%)	**Data and Scores**

Weighted total feed protein content	35.900
Protein INPUT kg/100kg harvest	46.670
Whole body harvested fish protein content	16.900
Net protein gain or loss	-63.788
Species-specific Factor 5.2 score	**3**
Critical (Score = 0)?	No
Critical (FFER>3 and 5.2 score <2)?	No

5.3 Feed Footprint	**Data and Scores**
CCI (kg CO2-eq kg-1 farmed seafood protein)	**18.935**
Contribution (%) from fishmeal from whole fish	4.299
Contribution (%) from fish oil from whole fish	2.866
Contribution (%) from fishmeal from byproducts	2.400
Contribution (%) from fish oil from byproducts	0.800
Contribution (%) from crop ingredients	79.041
Contribution (%) from land animal ingredients	10.594
Contribution (%) from other ingredients	0.000
Factor 5.3 score	**5**
C5 Final Feed Criterion Score	**3.410**
Critical?	**No**

Maine

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	6
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	6.000
F6.2 Invasiveness score	4
C6 Escape Final Score (0-10)	**4.0**
Critical?	No

Nova Scotia

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	4
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	4.000
F6.2 Invasiveness score	4
C6 Escape Final Score (0-10)	**4.0**
Critical?	No

New Brunswick and Newfoundland

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	2
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	2.000
F6.2 Invasiveness score	4
C6 Escape Final Score (0-10)	**3.0**
Critical?	No

Maine and Nova Scotia

Criterion 7: Disease	**Data and Scores**
Evidence-based or Risk-based assessment	Risk
Final C7 Disease Criterion score (0-10)	**4**
Critical?	No

New Brunswick

Criterion 7: Disease	**Data and Scores**
Evidence-based or Risk-based assessment	Risk
Final C7 Disease Criterion score (0-10)	**0**
Critical?	No

Newfoundland

Criterion 7: Disease	**Data and Scores**
Evidence-based or Risk-based assessment	Risk
Final C7 Disease Criterion score (0-10)	**2**
Critical?	No

All regions

Criterion 8X Source of Stock	**Data and Scores**
Percent of production dependent on wild sources (%)	0.0
Initial Source of Stock score (0-10)	0.0
Use of ETP or SFW "Red" fishery sources	No
Lowest score if multiple species farmed (0-10)	n/a
C8X Source of stock Final Score (0-10)	**0**
Critical?	No

All regions

Criterion 9X Wildlife Mortality parameters	**Data and Scores**
Single species wildlife mortality score	-2
System score if multiple species assessed together	n/a
C9X Wildlife Mortality Final Score	**-2**

Critical?	No

Maine

Criterion 10X: Introduction of Secondary Species	**Data and Scores**
Production reliant on transwaterbody movements (%)	36
Factor 10Xa score	6
Biosecurity of the source of movements (0-10)	8
Biosecurity of the farm destination of movements (0-10)	0
Species-specific score 10X score	-0.800
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**-0.800**
Critical?	n/a

New Brunswick

Criterion 10X: Introduction of Secondary Species	**Data and Scores**
Production reliant on transwaterbody movements (%)	18
Factor 10Xa score	8
Biosecurity of the source of movements (0-10)	8
Biosecurity of the farm destination of movements (0-10)	0
Species-specific score 10X score	-0.400
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**-0.400**
Critical?	n/a

Newfoundland

Criterion 10X: Introduction of Secondary Species	**Data and Scores**
Production reliant on transwaterbody movements (%)	25
Factor 10Xa score	7
Biosecurity of the source of movements (0-10)	8
Biosecurity of the farm destination of movements (0-10)	0
Species-specific score 10X score	-0.600
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**-0.600**
Critical?	n/a

Nova Scotia

Criterion 10X: Introduction of Secondary Species	**Data and Scores**
Production reliant on transwaterbody movements (%)	65
Factor 10Xa score	3
Biosecurity of the source of movements (0-10)	8

Biosecurity of the farm destination of movements (0-10)	0
Species-specific score 10X score	-1.400
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**-1.400**
Critical?	n/a