Monterey Bay Aquarium

Seafood Watch®

# Atlantic salmon

*Salmo salar*

Image © Monterey Bay Aquarium

## Atlantic North America

## (State of Maine, USA and Atlantic Canada)

## Marine Net Pens

January 14, 2016

Taylor Voorhees – Seafood Watch

# 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 Report. Each report 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." The detailed evaluation methodology is available upon request. In producing the Seafood Reports, 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 Seafood Reports 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 Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch® program at Monterey Bay Aquarium by calling 1-877-229-9990.

**Disclaimer**
Seafood Watch® strives to have all Seafood Reports reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science and aquaculture. Scientific review, however, does not constitute an endorsement of the Seafood Watch® program or its recommendations on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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# Guiding Principles

Seafood Watch™ defines sustainable seafood as originating from sources, whether fished[1] or farmed that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

The following **guiding principles** illustrate the qualities that aquaculture must possess to be considered sustainable by the Seafood Watch program:

Seafood Watch will:

- Support data transparency and therefore aquaculture producers or industries that make information and data on production practices and their impacts available to relevant stakeholders.
- Promote aquaculture production that minimizes or avoids the 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 beyond the immediate vicinity of the farm.
- Promote aquaculture production at locations, scales and intensities that cumulatively maintain the functionality of ecologically valuable habitats without unreasonably penalizing historic habitat damage.
- Promote aquaculture production that by design, management or regulation avoids the use and discharge of chemicals toxic to aquatic life, and/or effectively controls the frequency, risk of environmental impact and risk to human health of their use.
- Within the typically limited data availability, use understandable quantitative and relative indicators to recognize the global impacts of feed production and the efficiency of conversion of feed ingredients to farmed seafood.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild fish or shellfish populations through competition, habitat damage, genetic introgression, hybridization, spawning disruption, changes in trophic structure or other impacts associated with the escape of farmed fish or other unintentionally introduced species.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.
- Promote the use of eggs, larvae, or juvenile fish produced in hatcheries using domesticated broodstocks thereby avoiding the need for wild capture.
- Recognize that energy use varies greatly among different production systems and can be a major impact category for some aquaculture operations, and also recognize that improving practices for some criteria may lead to more energy-intensive production systems (e.g. promoting more energy-intensive closed recirculation systems).

[1] "Fish" is used throughout this document to refer to finfish, shellfish and other invertebrates.

Once a score and rank has been assigned to each criterion, an overall seafood recommendation is developed on additional evaluation guidelines. Criteria ranks 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

## State of Maine, US

| Criterion | Score (0-10) | Rank | Critical? |
|---|---|---|---|
| C1 Data | 7.50 | GREEN | |
| C2 Effluent | 5.00 | YELLOW | NO |
| C3 Habitat | 5.72 | YELLOW | NO |
| C4 Chemicals | 1.00 | RED | NO |
| C5 Feed | 6.59 | YELLOW | NO |
| C6 Escapes | 4.00 | YELLOW | NO |
| C7 Disease | 4.00 | YELLOW | NO |
| C8 Source | 10.00 | GREEN | |
| | | | |
| C9X Wildlife mortalities | -5.00 | YELLOW | NO |
| C10X Introduced species escape | -0.20 | GREEN | |
| **Total** | **38.60** | | |
| **Final score** | **4.83** | | |

OVERALL RANKING

| | |
|---|---|
| Final Score | 4.83 |
| Initial rank | YELLOW |
| Red criteria | 1 |
| Interim rank | YELLOW |
| Critical Criteria? | NO |

| FINAL RANK |
|---|
| **YELLOW** |

*Scoring note – scores range from zero to ten where zero indicates very poor performance and ten indicates the aquaculture operations have no significant impact. Color ranks: Red = 0 to 3.33, Yellow = 3.34 to 6.66, Green = 6.66 to 10. Criteria 9X and 10X are exceptional criteria, where 0 indicates no impact and a deduction of -10 reflects very poor performance. Two or more Red criteria trigger a Red final result.*

**Summary**

The final numerical score for Atlantic salmon (*Salmo salar*) produced in marine net pens in the state of Maine, United States (US) is 4.83 out of 10, which is in the Yellow range, and with only one Red criterion (Chemicals), the final ranking is Yellow and a recommendation of Good Alternative.

## Atlantic Canada

| Criterion | Score (0-10) | Rank | Critical? |
|---|---|---|---|
| C1 Data | 7.22 | GREEN | |
| C2 Effluent | 5.00 | YELLOW | NO |
| C3 Habitat | 5.72 | YELLOW | NO |
| C4 Chemicals | 1.00 | RED | NO |
| C5 Feed | 6.59 | YELLOW | NO |
| C6 Escapes | 2.00 | RED | NO |
| C7 Disease | 3.00 | RED | NO |
| C8 Source | 10.00 | GREEN | |
| | | | |
| C9X Wildlife mortalities | -5.00 | YELLOW | NO |
| C10X Introduced species escape | -0.20 | GREEN | |
| **Total** | **35.32** | | |
| **Final score** | **4.42** | | |

OVERALL RANKING

| | |
|---|---|
| Final Score | 4.42 |
| Initial rank | YELLOW |
| Red criteria | 3 |
| Interim rank | RED |
| Critical Criteria? | NO |

| FINAL RANK |
|---|
| **RED** |

*Scoring note – scores range from zero to ten where zero indicates very poor performance and ten indicates the aquaculture operations have no significant impact. Color ranks: Red = 0 to 3.33, Yellow = 3.34 to 6.66, Green = 6.66 to 10.  Criteria 9X and 10X are exceptional criteria, where 0 indicates no impact and a deduction of -10 reflects very poor performance. Two or more Red criteria trigger a Red final result.*

**Summary**

The final numerical score for Atlantic salmon (*Salmo salar*) produced in marine net pens in Atlantic Canada is 4.42 out of 10, which is in the Yellow range, but with three Red criteria (Chemicals, Escapes, and Disease), the final ranking is Red and a recommendation of Avoid.

# Executive Summary

Of the 2 million-plus tons (t) of global Atlantic salmon aquaculture production in 2013, 2.1% (approximately 44,000 t) was produced in Atlantic Canada and the United States. New Brunswick, Nova Scotia, and Newfoundland and Labrador are the salmon-producing provinces in Atlantic Canada (hereafter, *Canada*), and the former two contributed approximately 24,000 (52% of Atlantic North America's total) and 6,000 t (13%) respectively in 2014. Combined, this production was valued at approximately 215 million Canadian dollars (CAD). All Atlantic salmon aquaculture in the Atlantic United States (hereafter, *United States* or *US*) occurs in the state of Maine, where data show 18,600 t (40% of Atlantic North America's total) was produced in 2013, valued at USD 105 million. As of 2011, 60% of Atlantic salmon farmed in the Atlantic Canada region was exported to the United States, with approximately 7% staying in Atlantic Canada, and the remainder distributed throughout eastern Canada. Atlantic salmon aquaculture sites in Atlantic North America are dominantly owned and operated by a single corporation, with one additional notable producer. It may be sold as whole fish, fillets, smoked, or canned.

**Data.** The dominant producer of the region's industry was the provider of a large portion of the data and information used in this assessment (i.e., all data and information hereafter referred to as *industry-authored*, *industry-provided*, or similar). Where possible, it was supplemented and/or verified by data from independent entities (i.e., government agencies tasked with regulating and monitoring industry practice) and by data within peer-reviewed literature. Because salmon net pen aquaculture has been one of the most scientifically-researched and publically-discussed topics in marine science during the past 30 years, there is a significant volume of peer-reviewed literature from which data and information can be drawn. While other salmon-farming regions (i.e., Norway, British Columbia, Chile, United Kingdom, Ireland) are also well represented, there is indeed research, data, and information specific to Atlantic North America and the industry operating there. In the absence of site-specific information, or in an effort to assess the sustainability of the Atlantic North American industry against that of other salmon-farming regions, the literature concerning other salmon-farming regions has been consulted and cited. It is acknowledged that some gaps in information do exist, however overall, the confidence in the accuracy and comprehensiveness of the data and information used in the following assessment is relatively high. The final score for Criterion 1 – Data for Maine, US is 7.50 out of 10. In recognition of lower data confidence for the Escapes criterion, the final score for Criterion 1 – Data for Atlantic Canada is 7.22 out of 10.

**Effluent.** The Effluent criterion assesses the release of nutrients and particulate matter into the environment in which the farms are sited, and the physical, chemical, and biological implications of that release. While much of administered feed is consumed and subsequently retained in fish tissue (i.e., used for growth), there is a significant loss of carbon (C), nitrogen (N), and phosphorus (P) to the environment. Particulate organic C, N, and P are a result of both the percentage of feed that passes through the net pen unconsumed and fecal material. Upon or after their decent to the seafloor, solids particles may be consumed by other water column or benthic-dwelling organisms or dissolution begins; upon dissolving, nutrients are readily used by phytoplankton and macroalgae. Data show that while waste deposition and accumulation can be marked 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. The Effluent Criterion assesses the ecological impact of aquaculture operations *beyond* that of an 'allowable zone of effect,' and recent research in Atlantic North America has demonstrated and concluded that the minimal far-field impact observed on a site-by-site basis in other salmon-farming regions is indeed the case here. However, the reality of highly localized and heterogeneous impacts, and the aerial observation of the size, location, and concentration of salmon farms in areas of Atlantic North America, demonstrates the potential for localized impacts to overlap, ultimately causing or contributing to larger-scale, cumulative ecological impacts. The final numerical score for Criterion 2 – Effluent for all of Atlantic North America is 5 out of 10.

**Habitat.** Floating net pens have little direct impact to the physical nature of the habitat, rather, the most significant impacts result from the discharge and deposition of nutrient-rich feeds and fish waste, and their consequent encouragement of shifts in the chemical composition and biological community under and surrounding the farms. Data from Atlantic North America illustrates that *a)* there has been no industry-wide trend in sulfide deposition over the last 12 years, and *b)* the industry is generally performing well when compared to the sediment classification thresholds set forth by regulatory governances, such as the Maine Department of Environmental Protection and in the Environmental Monitoring Program for the Marine Finfish Cage Aquaculture Industry in New Brunswick. The percentage of farm sites in New Brunswick that remained oxic, and therefore resulted in "low environmental effects" to the surrounding benthos, between 2002 and 2014 ranged from 70–96%. Hypoxic sites did occur in every year, though the majority were classified as Hypoxic A, and therefore "may (have been) causing adverse environmental effects." In seven of the years, a small number of sites that were either Hypoxic C (i.e., "are causing adverse conditions") or Anoxic (i.e., "causing severe damage to the marine habitat") were reported. This demonstrates that localized and occasionally-severe ecological impacts do occur as a result of salmon farming, and ongoing monitoring is imperative to ensure these impacts remain a small percentage of the industry total. In both Maine and Canada, the siting and licensing process for new farm sites includes an Environmental Impact Assessment-like exercise, and farms are generally sited according to ecological principals. However, salmon farms in Atlantic North America are located in habitat that is of high ecological value. Maine-sited farms, for example, are located in and/or adjacent to water bodies deemed "critical habitat" for wild Atlantic salmon. The final score for Criterion 3 – Habitat for all of Atlantic North America is 5.72 out of 10.

**Chemical Use.** There are three significant concerns regarding the use of chemicals in Atlantic North American salmon farming. First, the recent use of antibiotics (in both total volume and per-ton of fish production) was markedly high, at nearly 23,000 kg of active substance and 412 g $t^{-1}$, in 2012, but short-term trend data (2013-2015) has indicated a reduction in antibiotic use by nearly two-thirds; administration in 2015 was 4,783 kg of active substance and 134 g $t^{-1}$. However, this use is significantly higher than most other salmon-farming regions of the world.

In addition, antibiotics deemed *Highly-* and *Critically Important to Human Health*, as defined by the World Health Organisation (WHO), are used. Second, the limited availability of registered pesticide therapeutants for the control of sea lice has resulted, at least twice, in the development of resistance to the few products permitted. Finally, in response to that resistance, a cypermethrin-based pesticide was used, illegally, at farm sites in New Brunswick; the application of cypermethrin in the marine environment is not permitted in Canada. Despite the use resulting in lobster mortalities in 2009, and the knowledge that ongoing government monitoring would be occurring, the product was used again in 2010. The three concerns result in a final score for Criterion 4 – Chemical Use for all of Atlantic North America is 1 out of 10.

**Feed.** The data used for assessment of Criterion 5 – Feed is complete for the growout cycle of the industry's 2012 year-class. The cycle-mean feed conversion ratio (FCR) is calculated to be 1.69. While fishmeal inclusion for the industry (6.43%) is markedly lower than that in other salmon-farming regions, fish oil inclusion (8.59%) is only marginally lower. The partial use of byproduct sources (24% of FM and 32% of FO) results in a moderate initial Fish In: Fish Out (FIFO) value of 1.97. Marine ingredients (herring, menhaden, anchovy) are sourced from fisheries in Atlantic Canada, Atlantic US and Gulf of Mexico, and Peru; these fisheries currently have no serious conservation concerns. The low fishmeal inclusion rate is most evident in calculating the protein budget, where it is supplemented by higher-than-average land animal byproduct use (42% of feed, supplying 70% of total protein), crop byproduct use (~10.5% of feed, ~3% of protein), and other crop ingredients (~24.5% of feed, ~16.5% of protein). The processing byproducts from the harvested salmon are used in cat food production. These aspects work in concert to achieve a net edible protein gain of 29.2%. Finally, the low marine ingredient dependence reduces the ocean area necessary to support the industry on a per-ton of production basis and the overall feed footprint. The final score for Criterion 5 – Feed for all of Atlantic North America is 6.59 out of 10.

**Escapes.** Escapes have been historically problematic for the salmon aquaculture industry. Improvements in net design and husbandry practices have resulted in a decreasing trend of escaped fish, but hundreds of thousands of salmon still escape from farms around the world every year. In all Atlantic North American salmon farming regions, Code of Containment protocols are in effect and elements generally include requirements for siting, system design, materials strength, maintenance and inspection, stock loss and recovery, and best practices for fish-handling procedures that typically increase the risk of escapement. While Codes are in place and similar in content for each region of the industry, their efficacy and enforcement differ markedly. In Maine, the Code is one part of a multi-faceted Containment Management System mandated by the Maine DEP Net Pen Aquaculture General Permit and has resulted in significantly-improved fish containment. Furthermore, the requirement to maintain a genetic database of hatchery families allows escaped fish to be traced back to the specific production site(s) from which they escaped. Maine-sited farms have not reported a breach of containment since 2003, and in only four years since 2003 were any farm-origin fish identified in rivers emptying into the Gulf of Maine; the 11-year average representation of farm fish among all adult returns is 0.24%. In all Canadian regions, Codes of Containment are self-regulated. Reportable escape events in Canada do still occur, and non-reported 'leakage' escapes is likely high, as farm fish representation in the Magaguadavic River over the same 11-year time period has averaged 70.3%.

Potential impacts that escapees may have on their wild counterparts primarily fall into ecological and genetic categories. The most significant competitive and/or disruptive ecological impacts that farm escapees have likely occur in coastal areas and in rivers. Potential genetic impacts are a result of introgression of farm fish gene complexes into those of wild fish. These interactions and their potential population-level effects are particularly significant in Atlantic North America where wild Atlantic salmon populations are a small fraction of their historic levels and are considered endangered in both the US and Canada; just a few hundred wild salmon return to all North American rivers annually. One study concluded: "*available data in eastern NA* (North America) *suggest that the potential risk of both genetic homogenization and a loss of local adaptation in NA wild Atlantic salmon populations due to introgression with farmed fish should be considered high*." In recognition of both this continued risk but greatly-improved fish containment by farms in Maine (as evidenced by the very low numbers of escapees identified in Maine rivers), the final numerical score for Criterion 6 – Escapes for Maine, US is 4 out of 10. Because of the ongoing risk of impact that fish escaping from Canadian-sited farms may have on their wild counterparts (as evidenced by the higher numbers of escapees in Canadian rivers), the final numerical score for Criterion 6 – Escapes for Atlantic Canada is 2 out of 10.

**Disease.** Fish grown in net pens are vulnerable to infection by pathogens and parasites in the environment, and as a result of the density with which farm fish are typically reared, the potential for pathogen and parasite amplification within the farm population is high. Both this increased pathogen load and the fact that farms may serve as unnatural temporal reservoirs for disease allow for the possibility for retransmission to wild fish. In the three years 2012-2014, bacterial kidney disease (BKD), sea lice, and "skin lesions" on farm fish had prescriptions written to treat them. Sea lice was the most prescribed-for condition, with an annual mean of 86 for an estimated 40 farm sites. Mean numbers of adult female sea lice per fish at New Brunswick-sited farms from 2009 to 2014 ranged seasonally from 0.1 to 17. Certain years and certain Bay Management Areas (BMAs), however, have experienced much higher means, sometimes approaching and/or exceeding 50-60 lice per fish. The annual mean number of lice per fish in Maine-sited farms between 2009 and 2015 ranged from 1.52-12.75, with a six-year mean of 5.5. No regulatory thresholds exist for sea lice loads in Atlantic North America, but these data show that sea lice loads exceed threshold goals set forth in the industry-authored Sea Lice Management and Treatment Plan. Infectious Salmon Anemia (ISA) is a highly virulent viral disease for which no treatment is applied and, in Canada, the presence of pathogenic ISA has been confirmed in 2012, 2013, and 2015. Monthly monitoring reports by the USDA, however, indicate that farms in Maine have been ISA-free since 2006. While there may be a high degree of concern that on-farm diseases could impact vulnerable wild salmon in Atlantic North America, the available evidence to date has shown that such transmission has not occurred. Both returning and outmigrating wild salmon have been found to have no or low levels of sea lice, wild non-salmonids appear to not typically host the louse species most commonly associated with ion-farm infections, and there have been no confirmed mortalities due to ISA in wild fish. With the recognition of a lower risk of ISA transmission, and an overall moderate degree of concern for impact to wild fish populations, the final numerical score for Criterion 7 – Disease for Maine, US is 4 out of 10. Because of ongoing incidence of pathogenic ISA in New Brunswick, and a marginally-higher degree of concern for impact to wild fish populations, the final numerical score for Criterion 7 – Disease for Atlantic Canada is 3 out of 10.

**Source of Stock.** 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 final numerical score for Criterion 8 – Source of Stock for all of Atlantic North America is 10 out of 10.

**Wildlife Interactions.** At all 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 tensioned predator control nets and pen-top bird netting. Active, non-lethal measures permitted include the use of acoustic deterrent devices, but their use is infrequent. Lethal action against predators or wildlife is prohibited. Interactions between wildlife and net pen operations do, however, occasionally result in mortality. In 2013, birds (18), sharks (10), seals (7), and tunas (4) each had direct interactions that resulted in mortality. Though mortalities are occasional, a lack of species-specificity for reported mortalities and the presence of endangered and/or threatened tuna and shark species presents a moderate concern. The final numerical deduction score for Criterion 9X – Wildlife Mortalities for all of Atlantic North America is -5 out of -10.

**Unintentional Species Introductions.** While the industry arguably operates within the same general waterbody, some international movement of eggs and/or live fish occurs between the US and Canada. Biosecurity at the source (hatcheries) is high with serial inspections to affirm the absence of diseases and pathogens of concern necessary for a facility to obtain a Fish Health Certificate. However, some facilities operate as flow-through systems and only mechanical filtration is used for effluent water treatment, ultimately having the potential to transfer unwanted organisms (e.g., pathogens) to the destination environment. The final score for Criterion 10X – Escape of Unintentionally Introduced Species for all of Atlantic North America is a deduction of -0.2 out of -10.

**Summary.** Marine net pen aquaculture of Atlantic salmon in the state of Maine, US achieves a final numerical score of 4.83 out of 10 and Seafood Watch recommendation of Good Alternative. Marine net pen aquaculture of Atlantic salmon in Atlantic Canada achieves a final numerical score of 4.42 out of 10, but with three criteria scoring below 3.3 (Chemical Use, Escapes, and Disease), the resulting Seafood Watch recommendation is an 'Avoid.'

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# Introduction

## Scope of the analysis and ensuing recommendation

**Species**
Atlantic salmon, *Salmo salar*

**Geographic Coverage**
Atlantic North America; State of Maine, United States (US) and Atlantic Canada

**Production Method(s)**
Marine net pens/cages

## Species Overview

**Brief Overview of the Species**
Atlantic salmon (hereafter, *salmon*) are native to the eastern (European) and western (North American) North Atlantic Ocean. As an anadromous species, 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' (FAO 2004; 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[2] 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 2-6 kg. Net pens are often circular, up to 150 meters (m) in diameter, and may extend 15-18 m deep from the surface (FAO 2004). 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.

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[2] 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)

**Production Statistics**

Of the 2 million-plus tons (t) of global Atlantic salmon aquaculture production in 2013 (FAO 2015), 2.1% (approximately 44,000 t) was produced in Atlantic Canada and the United States. New Brunswick, Nova Scotia, and Newfoundland and Labrador are the salmon-producing provinces in Atlantic Canada (hereafter, *Canada*), and provincial data show the former two contributed approximately 24,000 (52% of Atlantic North America's total) and 6,000 t (13%), respectively, in 2014 (DFO 2014a). Combined, this production was valued at approximately CAD 215 million (FAO 2015). Notably, production in New Brunswick fell in 2013 to less than 19,000 t (DFO 2014a). In Newfoundland and Labrador, Atlantic-salmon-only production could not be obtained, but total salmonid production (Atlantic salmon and steelhead trout) was 16,831 t in 2012, a market value of CAD 113 million. After a steadily increasing trend, Newfoundland and Labrador production in 2014 fell to less than 27% of its production a year earlier (NL DFA 2015). All salmon aquaculture in the Atlantic United States (hereafter, *United States* or *US*) occurs in the east-coast state of Maine, where 12,000 t (25% of Atlantic North America's total) were produced in 2012, valued at USD 78 million (M DMR 2015). FAO (2015) data indicates production in Maine is higher, and estimated at 18,600 t (42% of Atlantic North America's total) in 2014. Production data is synthesized in Figure 1 and detailed in Figure 2.

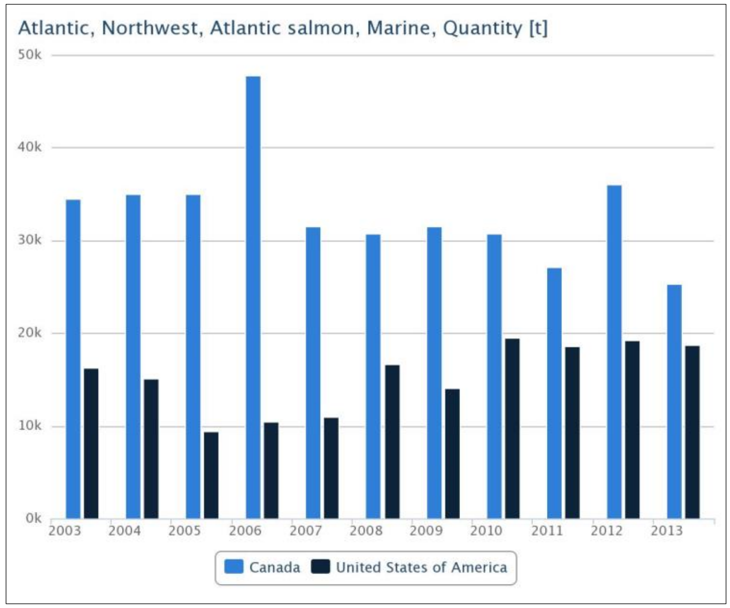


**Figure 1:** Atlantic salmon net pen aquaculture production in Atlantic North America from 2003 to 2013. Chart generated using FAO/Fish Stat and used directly as generated (FAO 2015).

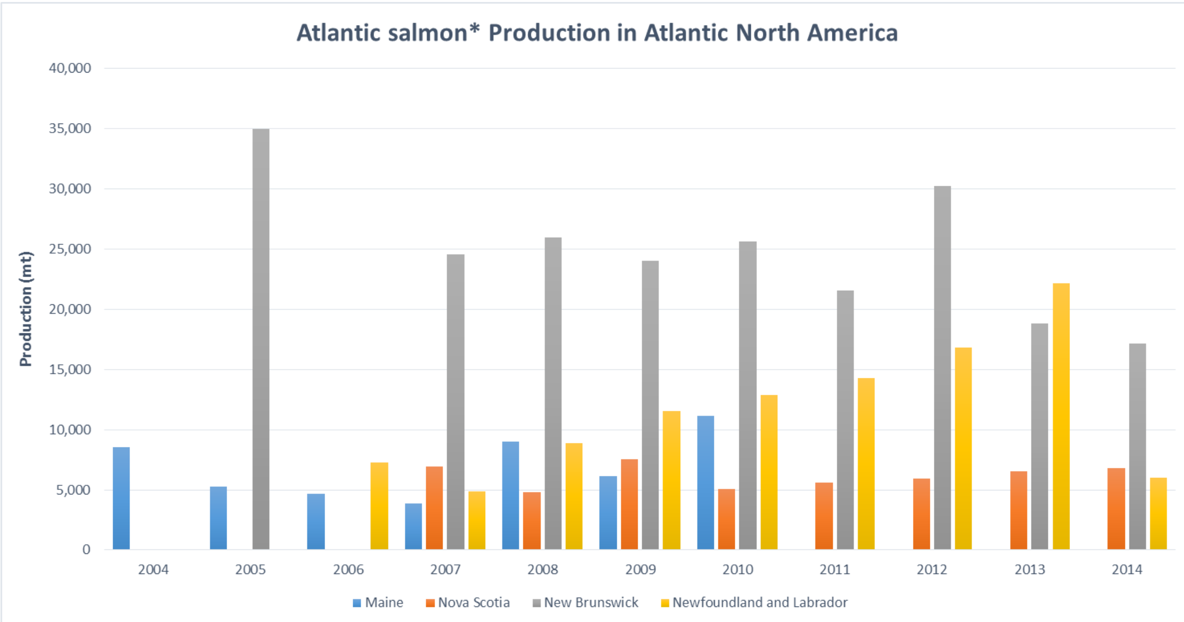


**Figure 2:** Atlantic salmon production in each of the four producing regions in Atlantic North America from 2004 to 2014. *Note:* No production representation of a region in a given year is a result of no data, not of no production. *Production in Newfoundland and Labrador represents Atlantic salmon and steelhead trout production; salmon-specific data could not be obtained. *All data from* DFO 2014b, NL DFA 2015, M DMR 2015, J Wiper, pers. com.

The non-dominant producer operates approximately 30% of farm sites in New Brunswick, and 50% of farm sites in Newfoundland (J Lewis, pers. com.); however, Atlantic salmon aquaculture sites in Atlantic North America are dominantly owned and operated by a single, vertically-integrated corporation, with divisions for farming operations, feed production, marketing, and transport. As of June 2015, this producer owned and operated a total of 149 sites across all regions of the Atlantic North American industry, of which 38 were active[3] (J Wiper, pers. com.). The regional breakdown was as follows: New Brunswick, 72 sites (22 active); Nova Scotia, 13 sites (4 active); Newfoundland and Labrador, 40 sites (6 active); Maine, 24 sites (6 active).

**Import and Export Sources and Statistics**

As of 2011, 60% of Atlantic salmon farmed in the Atlantic Canada region was exported to the United States, with approximately 7% staying in Atlantic Canada, and the remainder distributed throughout eastern Canada (ACFFA 2014a).

**Common and Market Names**

Atlantic salmon

| | |
|---|---|
| **Scientific Name** | *Salmo salar* |
| **Common Name** | Atlantic salmon |

[3] Active sites are those with fish currently in the water.

**Product Forms**
Whole fish, fillets, smoked, canned

# Analysis

## Scoring Guide

- With the exception of the exceptional criteria (9X and 10X), all scores result in a zero to ten final score for the criterion and the overall final rank. A zero score indicates poor performance, while a score of ten indicates high performance. In contrast, the two exceptional criteria result in negative scores from zero to minus ten, and in these cases zero indicates no negative impact.
- The full Seafood Watch Aquaculture Criteria that the following scores relate to are available on the Seafood Watch website. http://www.montereybayaquarium.org/cr/cr_seafoodwatch/content/media/MBA_SeafoodWatch_AquacultureCriteraMethodology.pdf
- The full data values and scoring calculations are available in Appendix 1.

## 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, nor enable businesses to be held accountable for their impacts.*
- *Sustainability unit: the ability to make a robust sustainability assessment.*
- *Principle: robust and up-to-date information on production practices and their impacts is available to relevant stakeholders.*

**Criterion 1 Summary**
**Maine, US**

| Data Category | Relevance (Y/N) | Data Quality | Score (0-10) |
|---|---|---|---|
| Industry or production statistics | Yes | 10 | 10 |
| Effluent | Yes | 7.5 | 7.5 |
| Locations/habitats | Yes | 10 | 10 |
| Chemical use | Yes | 7.5 | 7.5 |
| Feed | Yes | 7.5 | 7.5 |
| Escapes, animal movements | Yes | 7.5 | 7.5 |
| Disease | Yes | 5 | 5 |
| Source of stock | Yes | 10 | 10 |
| Predators and wildlife | Yes | 2.5 | 2.5 |
| Other – (e.g., GHG emissions) | No | Not relevant | n/a |
| **Total** | | | **67.5** |

| | | |
|---|---|---|
| **C1 Data Final Score** | **7.50** | **GREEN** |

**Atlantic Canada**

| Data Category | Relevance (Y/N) | Data Quality | Score (0-10) |
|---|---|---|---|
| Industry or production statistics | Yes | 10 | 10 |
| Effluent | Yes | 7.5 | 7.5 |
| Locations/habitats | Yes | 10 | 10 |
| Chemical use | Yes | 7.5 | 7.5 |
| Feed | Yes | 7.5 | 7.5 |
| Escapes, animal movements | Yes | 5 | 5 |
| Disease | Yes | 5 | 5 |
| Source of stock | Yes | 10 | 10 |
| Predators and wildlife | Yes | 2.5 | 2.5 |
| Other – (e.g., GHG emissions) | No | Not relevant | n/a |
| **Total** | | | **65** |

| | | |
|---|---|---|
| **C1 Data Final Score** | **7.22** | **GREEN** |

**Brief Summary**

The dominant producer of the region's industry was the provider of a large portion of the data and information used in this assessment (i.e., all data and information hereafter referred to as *industry-authored*, *industry-provided*, or similar). Where possible, it was supplemented and/or verified by data from independent entities (i.e., government agencies tasked with regulating and monitoring industry practice) and by data within peer-reviewed literature. Because salmon net pen aquaculture has been one of the most scientifically-researched and publically-discussed topics in marine science during the past 30 years, there is a significant volume of peer-reviewed literature from which data and information can be drawn. While other salmon-farming regions (i.e., Norway, British Columbia, Chile, United Kingdom, Ireland) are also well represented, there is indeed research, data, and information specific to Atlantic North America and the industry operating there. In the absence of site-specific information, or in an effort to assess the sustainability of the Atlantic North American industry against that of other salmon-farming regions, the literature concerning other salmon-farming regions has been consulted and cited. It is acknowledged that some gaps in information do exist, however, overall, the confidence in the accuracy and comprehensiveness of the data and information used in the following assessment is relatively high. The final score for Criterion 1 – Data for Maine, US is 7.50 out of 10. In recognition of lower data confidence for the Escapes criterion, the final score for Criterion 1 – Data for Atlantic Canada is 7.22 out of 10.

**Justification of Ranking**

Details regarding the Atlantic North American net pen Atlantic salmon farming industry, including the size, farm locations, production statistics, export markets, etc., are generally easily accessible and recent. The United Nations Food and Agriculture Organisation (FAO) has several resources (e.g., country fact sheets, species fact sheets, online data queries, etc.) to inform a relatively broad estimate, and government entities for each sub-region of the industry (i.e., Canada, New Brunswick, Nova Scotia, Newfoundland and Labrador, the United States, Maine) provide more detailed data and information on their respective websites. Annual production volumes, detailed farm site profiles, and site mapping documents are examples of information used to assess industry characteristics. Overall, confidence is high that the industry is well understood with respect to its total and relative production volumes, and the number and distribution of farm sites. The data score for the independent category of Production Data is 10 out of 10.

As the impact of waste discharge has been one of the publicly-critiqued aspects of salmon net pen aquaculture, there is a history of scientific study and peer-reviewed literature. The impacts have been shown to be highly variable and dependent on physical, chemical, and biological components unique to each region and specific location. For Criterion 2 – Effluent, recent peer-reviewed literature from several salmon-farming regions was used to assess the general status of far-field ecological impacts from salmon aquaculture. To ensure comparability, research conducted in southwestern New Brunswick, the most productive sub-region of the Canadian/US industry, was cited here. Confidence in the data's representation of the real far-field impacts of salmon farming is moderately high, but a greater volume of site-specific information would be supportive. The data score for Criterion 2 is 7.5 out of 10.

The types of data used for the assessment of Criterion 2 are also largely applicable for Criterion 3 – Habitat. In addition to the acquisition of peer-reviewed literature, which detail the processes of nutrient discharge and the ecological impacts of such, a large volume of raw environmental monitoring data specific to Atlantic North America was obtained from an industry representative and from Maine Department of Marine Resources (M DMR or DMR). Aggregated data for Canadian-sited farms are publicly available on provincial government websites or by public request. The regulatory agencies responsible for setting and enforcing environmental impact standards are identifiable and contactable. The regulations are publicly available on their respective websites. Furthermore, Environmental Monitoring Program guidelines, which detail the monitoring and reporting required by the industry, were obtained. As New Brunswick is the most productive Canadian province, data and information specific to the region were most heavily cited. Overall, the confidence in the quantity and quality of data to assess the real and potential impacts to the habitats in which farms are sited is high. The data score for Criterion 3 is 10 out of 10.

The assessment of Criterion 4 – Evidence or Risk of Chemical Use was supported in two ways. The actual use of chemicals during production by the industry was assessed using industry-provided data and data obtained from Maine DMR. Chemical use (antibiotics and anti-louse products) for 2012-2015 in Canada and Maine were presented together, but data were specific with regard to the chemicals used and their amount used per-annum. Without historical data, the long-term declining trend that has been documented in most other salmon-farming regions (particularly in antibiotic use) could not be verified to have occurred in Atlantic North America as well, but the data provided did allow for an accurate snapshot of recent and current use. Historical antibiotic use (2003-2014) at Maine-sited farms was obtained from Maine DMR. To compare performance of the industry against those in other salmon-farming regions, data from previous Seafood Watch salmon aquaculture assessments (i.e., Bridson 2014a, 2014b, 2014c, 2014d, 2014e) were queried, as these assessments have compiled and evaluated chemical use data in the same manner as was aimed for here. To evaluate the impact of such chemical use (especially that of resistance development), peer-reviewed literature was consulted and cited. While all data and information included here is relevant and thorough, the data score is prevented from achieving the highest score as a result of the absence of independent verification of some data and the absence of data detailing the use of antifouling/biocidal products. Therefore, the data score for Criterion 4 is 7.5 out of 10.

The data provided for Criterion 5 – Feed were high in detail. Though fishmeal and fish oil yield values and the protein content of whole, harvested fish were estimated (though, largely from widely-cited peer-reviewed literature), all other values used in the calculation of feed and protein efficiency, and the fisheries sourced to supply fish meal and oil were obtained directly from industry- and feed-manufacturer-authored documents. However, the absence of independent verification of this information and the limitation of data to a single year-class of production are gaps in allowing for a complete assessment of resource utilization for the Atlantic North American industry. The data score for Criterion 5 is 7.5 out of 10.

Criterion 6 – Escapes is multi-faceted, and the data required to make a robust assessment of its real and potential impacts are complex and many. The general risk of escapement from net pen systems was informed by a large body of both peer-reviewed and public-facing literature. A historical record (1984-2005) of reported escapes in both regions of the Atlantic North American industry was obtained from peer-reviewed literature, and those specific to Maine (beginning in 1995) are publicly available on the Maine DMR website. Escape data in Canada could not be obtained directly from the provincial government entities to which escapes are reported, but details of escapes reported by the industry were obtained from an industry representative. The numbers of farm-origin fish returning to Maine rivers was obtained from publically-available reports by the US Atlantic Salmon Assessment Committee, prepared for the North Atlantic Salmon Conservation Organization. The numbers of farm-origin fish returning to the Magaguadavic River were obtained from peer-reviewed literature and personal communication with a representative of the Atlantic Salmon Federation. Mitigation measures were supported by a body of literature demonstrating improvements in net design and integrity, and detailed industry-authored Code of Containment protocols. The differences in requirements between Maine-sited farms and Canadian-sited farms could be articulated through analysis of publically-available sources (e.g., Maine DEP Net Pen Aquaculture General Permit) and personal communication with representatives from US regulatory agencies (e.g., NOAA, NMFS) and international NGOs (e.g., Atlantic Salmon Federation). The assessment of the percentage of escaped farm-origin fish that are, or would be, recaptured or experience mortality was supported by an extensive body of peer-reviewed literature. Finally, the risk of ecological impact was informed by peer-reviewed literature that spans several decades, and considers many of the variables affecting competition for food, habitat, and breeding partners between escapees and wild fish, and the occurrence and impact of escapee genetic introgression into wild genotypes. And while these interactions are some of the most well-studied topics in aquaculture, much of this assessment was informed by research conducted in other salmon-farming regions. However, some key site-specific (i.e., focused on Atlantic North America) research has been conducted and is included here, in addition to the well documented and high vulnerability of wild Atlantic salmon. As the decline of wild Atlantic salmon is the result of many complex factors, the magnitude of contribution of escaped farm-origin fish to that decline is uncertain. For this reason, data confidence cannot be considered to be unequivocally high, but is as robust as the complexity of the situation allows. The data score for Criterion 6 for Maine, US is 7.5 out of 10. Because escape data is less robust for Canadian-sited farm sites, the data score for Criterion 6 for Atlantic Canada is 5 out of 10.

Data pertinent to Criterion 7 – Disease is moderate. Industry-provided data regarding the number of prescription therapeutants written allows for inferences of the types of disease conditions seen on the farms and their prevalence relative to one another, but even though data detailing typical dosages of these therapeutants exists in peer-reviewed literature and elsewhere, complexities in drug manufacturing and administration render any would-be estimates of the true pathogen load to not be robust. The prescription data reveal that sea lice is the most commonly-treated condition in Atlantic North America, and industry-provided data communicates the sea lice load on fish at New Brunswick- and Maine-sited farms from 2009 to 2014 and 2009 to 2015, respectively. These data are aggregated by Bay Management Area and state-wide, and do not allow for the determination of highly-localized differences in parasite load. Industry-authored sea lice management plans detail the measures taken to prevent, monitor, and treat sea lice infestations at both farm- and BMA-level scales. Infectious Salmon Anemia (ISA) is one of the most well-known and virulent pathogens affecting salmon aquaculture. Canadian government regulations require that incidences of ISA infection are reported; these reports are compiled and publicly available on federal and/or provincial websites. In addition, peer-reviewed literature and monthly United States Department of Agriculture (USDA) monitoring reports through August 2015 provide information on ISA occurrence in Maine. The transmission or retransmission of pathogens and parasites from farm fish to wild fish and its impacts have been one of the most historically debated topics in net pen aquaculture. However, there is a body of peer-reviewed literature that details the real and potential pathways and impacts of such transmission, and some of that literature was used and is cited in this assessment. Overall, there are gaps in both the prevalence of disease on Atlantic North American salmon farms and the impacts that diseases on farms have on wild salmon. However, some peer-reviewed data and data generated by ongoing research of disease transmission and dynamics in Atlantic North America were available for inclusion in this assessment. It is uncertain if the data presented here and the current understanding of disease transmission from farm to wild fish are fully understood. As a result, the data score for Criterion 7 is 5 out of 10.

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. According to the document, the industry's breeding program is currently in its fourth generation of selection, demonstrating a non-reliance on wild fish for use as broodstock or juveniles. Confidence is high in assessing Criterion 8 – Source of Stock; the data score for Criterion 8 is 10 out of 10.

There is only low-moderate data for the assessment of Criterion 9X – Wildlife and Predator Mortalities. Industry-authored Wildlife Interactions Plan documents were submitted which detail the measures taken to discourage the occurrence of interactions between wildlife and farm fish and the infrastructure in which they are grown, and an industry-authored statement communicated the number of interactions that resulted in mortality for birds, seals, sharks, and tunas in 2013. However, the reports of these interactions, which are required to be submitted to government regulators, could not be obtained for inclusion in the assessment, and it is therefore unknown if the mortalities reported for 2013 are indicative of the average annual number of mortalities resulting from the interaction between wildlife and aquaculture operations. The mortalities reported by the industry were not species-specific. The data score for Criterion 9X is 2.5 out of 10.

The quantity and quality of data for Criterion 10X – Escape of Unintentionally Introduced Species is considered high. Industry-authored biosecurity plans were submitted and government-authored regulations of domestic and international movements of live fish were publically available and consulted. Government-issued Fish Health Certificates, which certify the absence of a set of pathogenic organisms at broodstock and/or hatchery facilities and authorize them to ship fish inter-provincially or internationally, data regarding the percentage of fish which are shipped internationally, and effluent water filtration summaries for broodstock/hatchery facilities were all submitted by the industry to verify regulatory compliance and strict record keeping. All of these sources of information are positive drivers of confidence in a comprehensive and accurate assessment of this criterion. The data score for Criterion 10X is 10 out of 10.

**Conclusion**

As mentioned, the industry's dominant producer was the provider of a large portion of the data and information used in this assessment (i.e., all data and information referred to as *industry-authored*, *industry-provided*, or similar). Where possible, it was verified and/or supplemented by data from independent entities (i.e., government agencies tasked with regulating and monitoring industry practice) and by data within peer-reviewed literature. As salmon net pen aquaculture has been one of the most scientifically-researched and publically-discussed topics in marine science during the past 30 years, there is a significant volume of peer-reviewed literature from which data and information can be drawn. While some is specific to Atlantic North America and the industry operating there, other salmon-farming regions (i.e., Norway, British Columbia, Chile, United Kingdom) are also well represented; in the absence of site-specific information, or in an effort to assess the sustainability of the Atlantic North American industry against that of other salmon farming regions, such literature has been consulted and cited. It is acknowledged that gaps in information exist, however, overall, the confidence in the accuracy and comprehensiveness of the data and information used in the following assessment is relatively high.

The final numerical score for Criterion 1 – Data is 7.50 out of 10 for Maine, US and 7.22 for Atlantic Canada.

# Criterion 2: Effluents

***Impact, unit of sustainability and principle***

- *Impact: aquaculture species, production systems and management methods vary in the amount of waste produced and discharged per unit of production. The combined discharge of farms, groups of farms or industries contributes to local and regional nutrient loads.*
- *Sustainability unit: the carrying or assimilative capacity of the local and regional receiving waters beyond the farm or its allowable zone of effect.*
- *Principle: aquaculture operations 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 beyond the immediate vicinity of the farm.*

**Criterion 2 Summary**
**Maine, US and Atlantic Canada**

Effluent Evidence-Based Assessment

| | | |
|---|---|---|
| **C2 Effluent Final Score** | **5.00** | **YELLOW** |

**Brief Summary**

One of the most historically-debated critiques of salmon net pen aquaculture is the release of nutrients and particulate matter into the environment in which the farms are sited, and the physical, chemical, and biological implications of that release. While much of administered feed is consumed and subsequently retained in fish tissue (i.e., used for growth), there is a significant loss of carbon (C), nitrogen (N), and phosphorus (P) to the environment. Particulate organic C, N, and P are a result of both the percentage of feed that passes through the net pen unconsumed and fecal material. Upon or after their descent to the seafloor, solids particles may be consumed by other water column or benthic-dwelling organisms or dissolution begins; upon dissolving, nutrients are readily used by phytoplankton and macroalgae. Data show that while waste deposition and accumulation can be marked 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. The Effluent Criterion assesses the ecological impact of aquaculture operations beyond that of an 'allowable zone of effect,' and recent research in Atlantic North America has demonstrated and concluded that the minimal far-field impact observed on a site-by-site basis in other salmon-farming regions is indeed the case here. However, the reality of highly-localized and heterogeneous impacts, and the aerial observation of the size, location, and concentration of salmon farms in areas of Atlantic North America, demonstrates the potential for localized impacts to overlap, ultimately causing or contributing to larger-scale, cumulative ecological impacts. The final numerical score for Criterion 2 – Effluent for all of Atlantic North America is 5 out of 10.

**Justification of Ranking**

This criterion, Criterion 2 – Effluent, assesses the ecological impact of aquaculture operations *beyond* that of an 'allowable zone of effect' (approximately 30m from the net pens), whereas Criterion 3 – Habitat, assesses those impacts within such a zone. Regulatory agencies often have allowable-impact and monitoring standards that differ with respect to distance from farm infrastructure. In these cases, these zones may determine in which criterion certain data or information falls. In both Canada and Maine, allowable zones of effect are employed; in Maine for example, monitoring for 'far-field' impacts is conducted at 35 m, however benthic monitoring at Canadian sites has been conducted at distances of up to 200 m from the farm boundaries. As such, 35-m monitoring data is included in the assessment of Criterion 3 – Habitat, and the data from farther-field monitoring is used here, in Criterion 2 – Effluent.

As effluent data quality and availability is good (i.e., Criterion 1 score of 7.5 or 10 for the Effluent category), the Seafood Watch Evidence-Based Assessment was utilized.

One of the most historically-debated and popularized critiques of salmon net pen aquaculture is the release of nutrients and particulate matter into the environment in which the farms are sited, and the physical, chemical, and biological implications of that release. A volume of literature exists which articulates these concerns (e.g., Perez 2002, Whitmarsh et al. 2006, Redmond et al. 2010, Azevedo et al. 2011, Skriptsova & Miroshnikova 2011). As feed is supplied to farm fish, several in-series and in-parallel processes ensue. While much of administered feed is consumed and subsequently retained in fish tissue (i.e., used for growth), there is a significant loss of carbon (C), nitrogen (N), and phosphorus (P) to the environment (Wang et al. 2013). And though the salmon aquaculture industry has worked to make significant reductions in nutrient loss per unit of fish production (Bureau and Hua 2010), the losses do still, especially when considering the marked expansion of the industry, represent a point source of nutrient flux that may exceed the carrying capacity of the ecosystem in which farms are sited. Particulate organic C, N, and P are a result of both the percentage of feed that passes through the net pen unconsumed [one recent estimate of which is 3% (Wang et al. 2013)] and as fecal material (Silvert and Sowles 1996, Strain and Hargrave 2005, Wang et al. 2013).

The rate that these particulates settle is dynamic and complex, depending on factors such as particle size, water depth, current speed, and bathymetry, among others (see Silvert and Sowles 1996 for their benthic impact modeling work in New Brunswick). Upon or after their decent to the seafloor, solids particles may be consumed by other water column or benthic-dwelling organisms (Strain and Hargrave 2005, Wang et al. 2012), or dissolution begins. As these solids break apart, either during or after their fall to the benthos, the particulate C, N, and P become dissolved matter (Olsen and Olsen 2008), where they may be readily used as nutrients by phytoplankton and macroalgae (Troell et al. 2003, 2009). In addition, carbon is lost inorganically during fish respiration as $CO_2$ (Silvert and Sowles 1996; Wang et al. 2012, 2013).

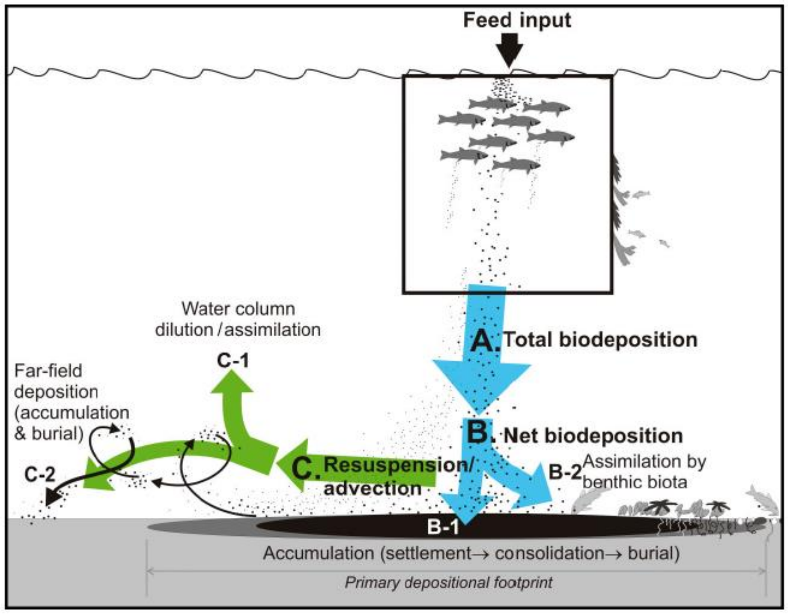


**Figure 3:** Summary of major pathways for salmon feed-derived bio-deposition. A: total biodeposition = all waste particulates produced by the farm (feed and feces, ignoring dissolved organic component). B: net bio-deposition includes the particulates that settle, accumulate and/or are used (assimilated) in the near-field or 'primary footprint'. C: resuspension and advection includes the fraction of A that is exported from the immediate vicinity by current. Image taken directly from Keeley et al. (2013).

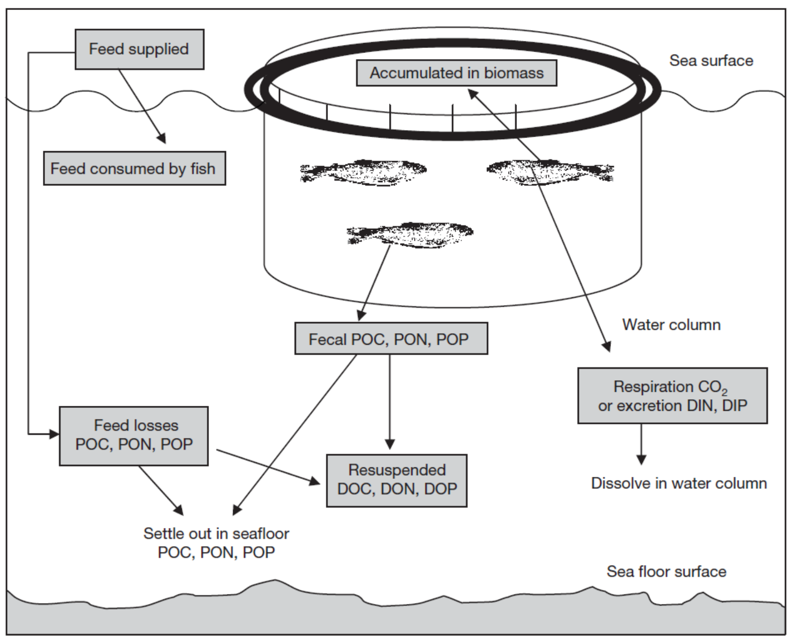


**Figure 4:** The flow and date of nutrient components from a salmon net pen system. POC: particulate organic carbon; PON: particulate organic nitrogen; POP: particulate organic phosphorus; DIN: dissolved inorganic nitrogen; DIP: dissolved inorganic phosphorus; DOC: dissolved organic carbon; DON: dissolved organic nitrogen; DOP: dissolved organic phosphorus. Image taken directly from Wang et al. (2012).

There have been several studies that have estimated and/or quantified the nutrient budget of salmon net pen aquaculture, but a recent study conducted in Norway (Wang et al. 2013) found the following:

Of the C, N, and P incorporated in administered feed,

- Approximately 38% of C, 43% of N, and 24% of P were retained as fish biomass;
- Approximately 62% of C, 57% of N, and 75% of P were lost to the environment;

- Approximately 19% of C, 15% of N, and 44% of P were released as particulates;
- Approximately 40% of C was respired as $CO_2$, and;
- Approximately 39% of N and 24% of P were excreted as dissolved inorganic nutrients.

Despite the potentially large loss of nutrients, data show that while deposition and accumulation can be marked 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 impacts assessed in this Effluent Criterion, most specifically in the benthos, are minimal (e.g., Brooks and Mahnken 2003; Mayor et al. 2010; Mayor and Solan 2011; Keeley et al. 2013; Price et al. 2015). In Scotland, for example, it has been shown that benthic impacts from salmon aquaculture operations may only extend 25-50 m from cage sites (Mayor et al. 2010), and can be only statistically detectable within 50 m of net pen arrays (Mayor and Solan 2011). While some studies (Brooks and Mahnken 2003, for example) have shown that (at times of peak production) impacts to benthic community structure can change not only in the immediate vicinity of farm sites but also at distances of more than 200 m, it was noted that siting in highly-depositional environments (i.e., shallow depth, poor current velocity, etc.) was a major factor in these observed impacts. In Atlantic North America, such siting may have been common in the industry's earlier years, but is unlikely to have occurred more recently (J Lewis, pers. com.).

In Atlantic North America, some research in southwestern New Brunswick has found that benthic and ecological impacts from aquaculture can be observed over an area much larger than the farm site footprint; for example, quantification of nutrient fluxes by Strain and Hargrave (2005) demonstrated that the salmon aquaculture industry is the largest source of "anthropogenic waste" (i.e., carbon, nitrogen, and phosphorus) in the region, and that fluxes due to farming operations can be greatly different than those due to natural processes. Additionally, Robinson (2005) documented algal mat growth in a Bay of Fundy intertidal area at a distance of 1 km from a farm site resulting from farm-point eutrophication. However, there is also a body of evidence that far-field and ecological impacts resulting from salmon farms in the region are minimal. The aforementioned study by Strain and Hargrave (2005) did conclude that dissolved oxygen concentrations were lower (up to 1.4 mg/L) only in the vicinity of farm sites, and that inlet-wide ecosystem effects were likely minimal. Research in Newfoundland found no differences in water column quality and minor, localized effects on the benthos (Tlusty et al. 2005). In both Blue Hill Bay, Maine (Sowles 2005) and three bays in New Brunswick (Harrison et al. 2005), no (near-field or far-field) increases in chlorophyll were found. Finally, more recent research in the area has demonstrated and concluded that the minimal ecological and far-field impact observed in other salmon-farming regions is indeed the case in Atlantic North America (e.g., Chang and Page 2011; Chang et al. 2011a, 2012).

Figure 5, taken directly from Chang et al. (2011a), is a contour plot of the seabed that shows the distribution and gradients of benthic sulfide concentrations at six salmon farms in southwestern New Brunswick. The plot confirms that the heavy sulfide deposition and accumulation often seen beneath net pens displays a rapid, declining gradient with distance. At these farm sites, sulfide concentrations of 0-750 µM (considered "Oxic A," the lowest concern for deleterious ecological impacts in the Canadian provincial Environmental Monitoring Program standards) are typically observed within 100-200 m of the net pen array; at five of the six sites presented in Figure 5, Oxic A-achieving sulfide concentrations were indeed found within the boundaries of net pen arrays.

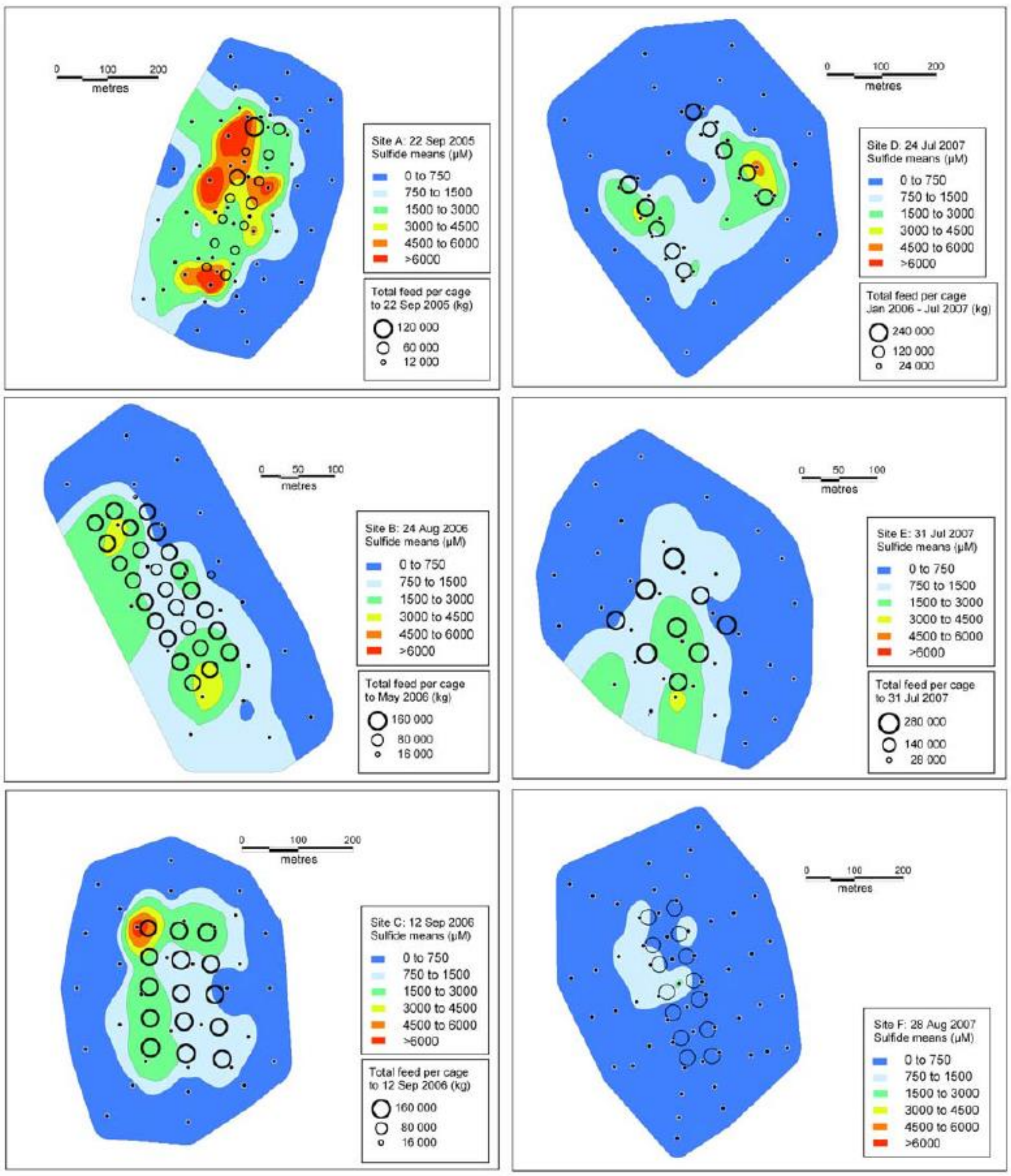


**Figure 5:** A contour plot showing mean benthic sulfide concentrations sampled during summer at six salmon farm sites in New Brunswick. Black dots on each plot indicate sampling location. Circles represent approximate cage location with the size of a given circle determined by the feed input to that cage. Site F was actively feeding, but feed input data was not available. Image from Chang et al. (2011a)**.**

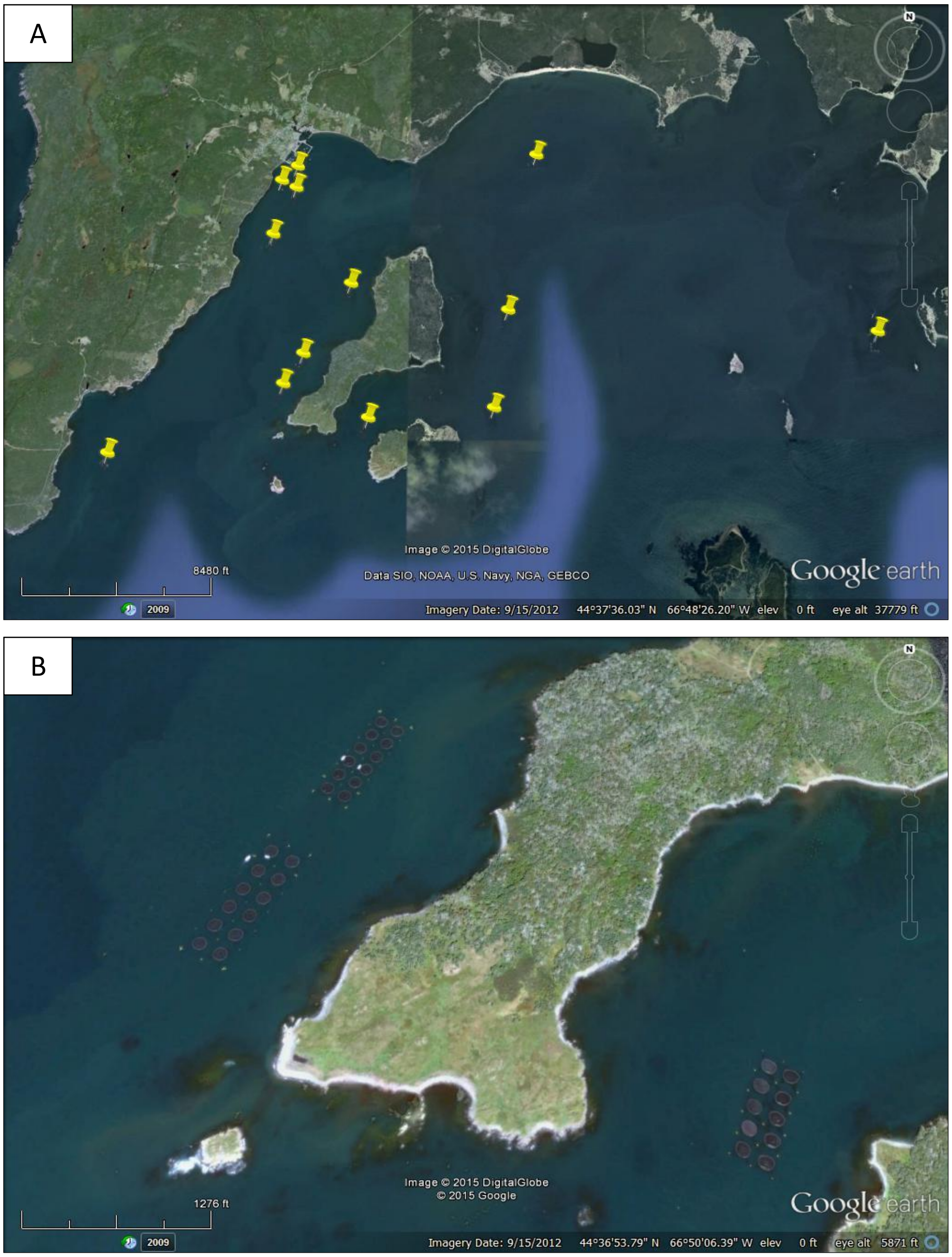


**Figure 6:** Aerial views of Atlantic salmon aquaculture farm sites in the Bay of Fundy near Grand Manan Island, New Brunswick, Canada. **(A)** The yellow pins indicate the location of individual net pen arrays, each considered by the industry and regulatory agencies to be distinguishable 'sites.' **(B)** Three net pen arrays can be seen in proximity to one another. Images from Google Earth.
***Note:*** An undetermined number of sites indicated may not have been active at the time of imaging.

However, the data presented in Figure 5, in Chang and Page (2011), Chang et al. (2011a), and Chang et al. (2012), do show the reality of highly-localized and heterogeneous impacts of salmon net pen aquaculture in the region. Furthermore, aerial observation of the size, location, and concentration of salmon farms in Atlantic North America is evidence of potential for localized impacts to overlap, ultimately causing or contributing to larger-scale, cumulative ecological impacts. Figure 6 illustrates this observation. In Image A (top) of an area of the south coast of Grand Manan Island, New Brunswick, each yellow pin represents the location of a net pen array; not every array is considered an independent site by the industry and by regulatory agencies. The proximity of sites, however, supports the potential for each site to play a contributing role in a cumulative ecological impact. In Image B (bottom), three net pen arrays (of two distinct farm sites) are shown in greater detail. Off the western shore of the island (Wood Island), one farm site is comprised of two net pen arrays, with 12 pens each, moored approximately 180 m apart. Given the complexity of impact potential, the contour plot constructed by Chang et al. (2011a), and the conclusions drawn by other authors cited here, this relatively short distance between net pen arrays could indeed lead to an aggregate impact.

**Conclusion**

Ultimately, the data show that while waste deposition and accumulation can be marked 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 the net pen array. Given the proximity of farm sites, however, there is the potential for the waste deposition and its associated physical, chemical, and biological impacts from individual net pen arrays to overlap with one another, resulting in a cumulate impact. The concern for ecosystem-scale impacts due to salmon aquaculture effluent is low-moderate to moderate.

The final numerical score for Criterion 2 – Effluent for all of Atlantic North America is 5 out of 10.

# 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.*
- *Sustainability unit: The ability to maintain the critical ecosystem services relevant to the habitat type.*
- *Principle: aquaculture operations are located at sites, scales and intensities that cumulatively maintain the functionality of ecologically valuable habitats.*

**Criterion 3 Summary**
**Maine, US and Atlantic Canada**

| Habitat parameters | Value | Score | |
|---|---|---|---|
| F3.1 Habitat conversion and function | | 7.00 | |
| F3.2a Content of habitat regulations | 2.25 | | |
| F3.2b Enforcement of habitat regulations | 3.50 | | |
| F3.2 Regulatory or management effectiveness score | | 3.15 | |
| **C3 Habitat Final Score** | | **5.72** | **YELLOW** |
| Critical? | NO | | |

**Brief Summary**

Floating net pens have little direct impact to the physical nature of the habitat, rather, the most significant impacts result from the discharge and deposition of nutrient-rich feeds and fish waste, and their consequent encouragement of shifts in the chemical composition and biological community under and surrounding the farms. Data from Atlantic North America illustrates that *a)* there has been no industry-wide trend in sulfide deposition over the last 12 years, and *b)* the industry is generally performing well when compared to the sediment classification thresholds set forth by regulatory governances, such as the Maine Department of Environmental Protection and in the Environmental Monitoring Program for the Marine Finfish Cage Aquaculture Industry in New Brunswick. The percentage of farm sites in New Brunswick (the most productive Canadian province) that remained oxic, and therefore resulted in "low environmental effects" to the surrounding benthos, between 2002 and 2014 ranged from 70–96%. Hypoxic sites did occur in every year, though the majority were classified as Hypoxic A, and therefore "may (have been) causing adverse environmental effects." In seven of the years, a small number of sites that were either Hypoxic C (i.e., "are causing adverse conditions") or Anoxic (i.e., "causing severe damage to the marine habitat") were reported. This demonstrates that localized and occasionally-severe ecological impacts do occur as a result of salmon farming, and ongoing monitoring is imperative to ensure these impacts remain a small percentage of the industry total. In both Maine and Canada, the siting and licensing process for new farm sites includes an Environmental Impact Assessment-like exercise, and farms are generally sited according to ecological principals. However, salmon farms in Atlantic North America are located in habitat that is of high ecological value. Maine-sited farms, for example, are located in and/or adjacent to water bodies deemed "critical habitat" for wild Atlantic salmon. The final score for Criterion 3 – Habitat for all of Atlantic North America is 5.72 out of 10.

**Justification of Ranking**

**Factor 3.1. Habitat Conversion and Function**

Many of the impacts described in Criterion 2 – Effluent are also applicable here in Criterion 3 – Habitat. While the floating net pens used to farm salmon have little direct impact to the physical nature of the habitat, impacts do result from the discharge and deposition of nutrient-rich feeds and fish waste, and their consequent encouragement of shifts in the chemical composition and biological community under and surrounding the farms. As such, Criterion 3 – Habitat, assesses the impact of these discharges and depositions and not the lesser impact of farm infrastructure implementation.

For the Atlantic North American industry, there are several sets of data that can be used to determine the extent to which the habitat occupied by salmon farms have been converted for that purpose and the functionality that the conversion and subsequent farming activities have maintained. One of the most commonly-used metrics for assessing the impact a net pen aquaculture operation has on the ecosystem in which it is sited is the concentration of sulfide in the benthos under and surrounding the farm site. A time series of benthic sulfide data, from 2002 to 2014, was submitted by an industry representative for inclusion into this assessment; the data set is inclusive of sites within New Brunswick and Nova Scotia, but based on the dominance of production (and thus, monitoring data) by New Brunswick, it is only these data that are used to represent Canadian-sited operations. Benthic sulfide data for Maine-sited farms were obtained from a representative of the Maine DMR.

Benthic sulfide data at farms in New Brunswick are summarized in Figure 7. For each year in the time series, the value presented is an average of all replicate samples for every site in the province; this is acknowledged to result in a heavy, likely imperfect, generalization of the impact the industry is having on the benthic environment in which it operates, but is nonetheless useful (and necessary) in achieving an industry-wide perspective. While the plotting of the highest and lowest observed sulfide concentrations illustrates the heterogeneity of localized impact, the plotting of the mean (blue line) illustrates that *a)* there has been no industry-wide trend in sulfide deposition over the last 12 years, and *b)* the industry is generally performing well when compared to the sediment classification thresholds set forth in the Environmental Monitoring Program for the Marine Finfish Cage Aquaculture Industry in New Brunswick, authored and governed by the New Brunswick Department of Environment and Local Government (NB DELG) (NB DELG 2012). Those thresholds aim to use the benthic sulfide concentration as a proxy for the overall health of the benthos, and are presented in Table 1.

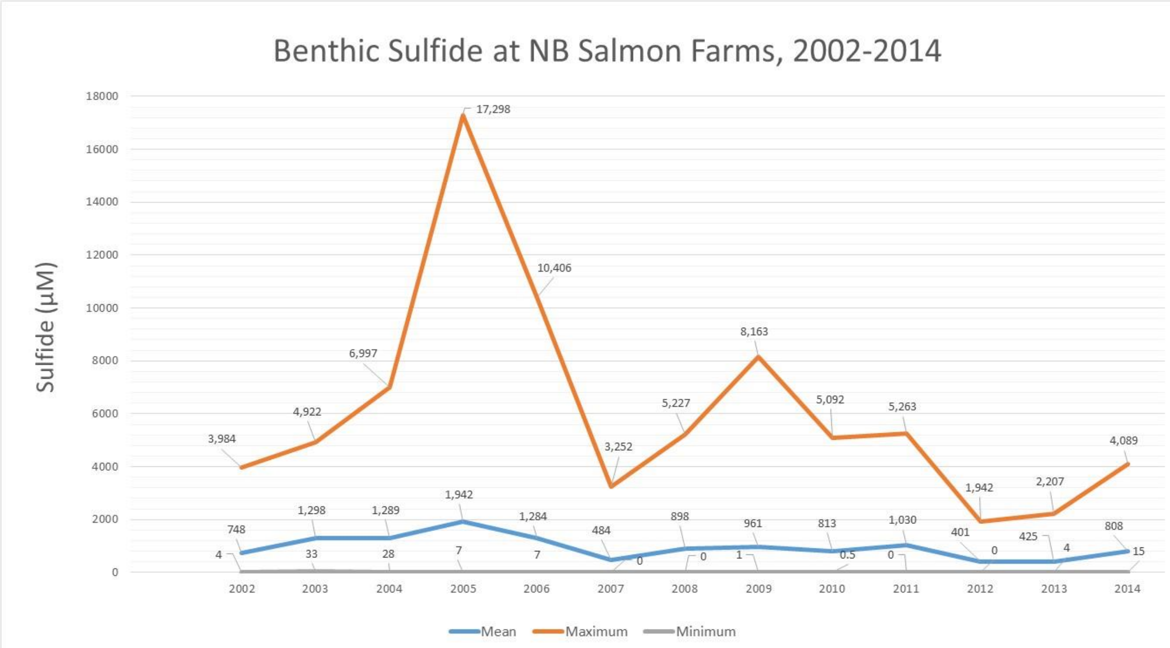


**Figure 7:** The mean (blue line), maximum (orange line), and minimum (grey line) measurements of benthic sulfide concentration beneath net pens in New Brunswick from 2002 to 2014. Oxic conditions are those with a sediment sulfide concentration of <1,500 µM. Graph produced using industry-supplied data.

According to the Environmental Monitoring Program, the sediment classifications displayed in Table 1 have the following ecological representations:

**Table 1:** The classification scheme for benthic sediment condition based on sulfide concentrations set forth in the Environmental Management Program for New Brunswick. Table taken from NB DELG 2012.

| Site Classification | | Sediment Sulfide Concentrations |
|---|---|---|
| Oxic | Oxic A | Sulfide = <750µM |
| | Oxic B | Sulfide = 750 to 1499 µM |
| Hypoxic | Hypoxic A | Sulfide = 1500 to 2999 µM |
| | Hypoxic B | Sulfide = 3000 to 4499 µM |
| | Hypoxic C | Sulfide = 4500 to 5999 µM |
| Anoxic | Anoxic | Sulfide ≥ 6000 µM |

- Oxic A and B: These sites may have low environmental effects on the marine sediments adjacent to the net pens.
- Hypoxic A: These sites may be causing adverse environmental effects to the marine sediments adjacent to the net pens.
- Hypoxic B: These sites are likely causing adverse environmental effects on the marine benthic sediments in the area adjacent to the net pens.
- Hypoxic C: These sites are causing adverse conditions in the marine sediments immediately adjacent to the net pens as a result of releases of organic material.
- Anoxic: These sites are causing severe damage to the marine habitat as a result of releases of organic material.

In only one year was the province-wide mean benthic sulfide concentration less than "oxic" (at 1,942 µM in 2005). In every year, however, a number of individual sites (6–28%) were slightly hypoxic (i.e., Hypoxic A), and in some years, a percentage of sites (2–10%) were either marginally- or markedly-hypoxic (i.e., Hypoxic B and C, respectively) or anoxic. Table 2 provides more detail than the summary in Figure 7 by showing the number of sites surveyed and the percentage of sites that fall within each of the six sediment health categories for each year between 2002 and 2014, as well as the mean for the time series. Figure 8 provides a more illustrative representation of this data.

**Table 2:** For each year from 2002 to 2014, the number of New Brunswick salmon farm locations (i.e., farm sites) sampled for benthic sulfide concentration and the per-year mean percentage of samples that can be placed in one of the six categories set forth in the New Brunswick Environmental Management Plan. The "MEAN" row at the bottom communicates the percentage of samples that fall within each category's parameters across all years of the time series. Table produced using industry-supplied data.

| | n | Oxic A | Oxic B | Hypoxic A | Hypoxic B | Hypoxic C | Anoxic |
|---|---|---|---|---|---|---|---|
| **2002** | 42 | 55 % | 33 % | 12 % | | | |
| **2003** | 43 | 51 % | 23 % | 28 % | | | |
| **2004** | 51 | 45 % | 39 % | 12 % | 2 % | | 2 % |
| **2005** | 59 | 36 % | 34 % | 22 % | | | 8 % |
| **2006** | 58 | 62 % | 17 % | 10 % | 2 % | 2 % | 7 % |
| **2007** | 50 | 84 % | 10 % | 6 % | 2 % | | |
| **2008** | 45 | 66 % | 7 % | 24 % | | 2 % | |
| **2009** | 39 | 64 % | 15 % | 18 % | | | 3 % |
| **2010** | 42 | 62 % | 17 % | 19 % | | 2 % | |
| **2011** | 48 | 65 % | 17 % | 6 % | 10 % | 2 % | |
| **2012** | 53 | 81 % | 15 % | 4 % | | | |
| **2013** | 45 | 80 % | 13 % | 7 % | | | |
| **2014** | 40 | 73 % | 13 % | 10 % | 8 % | | |
| **MEAN** | **47** | **63 %** | **19 %** | **14 %** | **1.8 %** | **0.6 %** | **1.5 %** |

The percentage of farm sites in New Brunswick that remained oxic, and therefore resulted in "low environmental effects" to the surrounding benthos, ranged from 70% (in 2005) to 96% (in 2012). As previously mentioned, hypoxic sites occurred in every year, though the majority were classified as Hypoxic A, and therefore "may (have been) causing adverse environmental effects." In four of the 13 years, no sites were categorized as less than Hypoxic A, but in seven of the other nine years, there were a percentage of sites that were either Hypoxic C (i.e., "are causing adverse conditions") or Anoxic (i.e., "causing severe damage to the marine habitat"). Collectively, the majority of sites (82%) remained oxic, with most of those able to be categorized as Oxic A, having a mean benthic sulfide concentration below 750 µM. Since 2012, 86–96% of all sites in New Brunswick have achieved oxic status. This demonstrates the generally-low benthic impact caused by New Brunswick salmon farming. However, a small but not unimportant percentage of sites have caused negative impacts to the benthic environment, including some which were categorized as Anoxic. This demonstrates the reality that localized and occasionally-severe ecological impacts do occur as a result of salmon farming, and ongoing monitoring and improved site management is imperative to ensure these impacts remain a small percentage of the industry total.

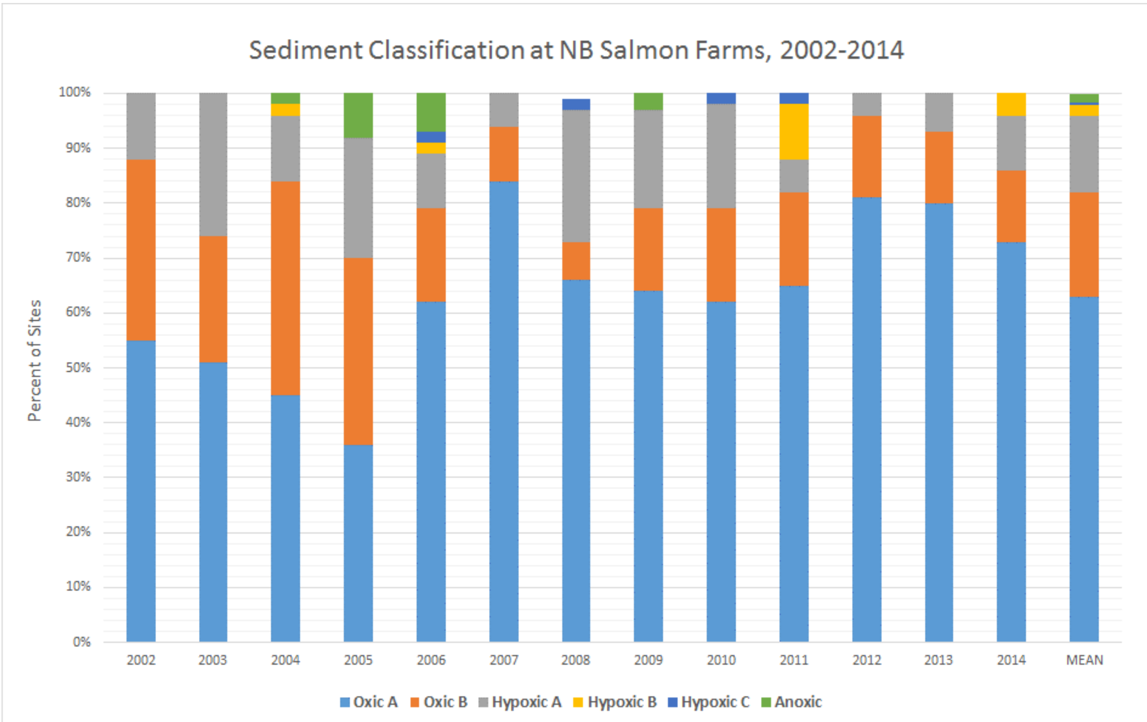


**Figure 8:** Percentage of salmon farming sites that fall within six categories outlined in the Environmental Management Program for the Marine Finfish Cage Aquaculture Industry in New Brunswick (NB DELG 2012) for each year in the time series 2002-2014. Chart produced using industry-supplied (and independently verified) data.

The dispersal gradient of sulfide accumulation beneath and surrounding salmon net pens is illustrated in a contour plot constructed by Chang et al. (2011a), which is seen as Figure 5 in Criterion 2 – Effluent (page 25). For each of the six sites included in the study, sulfide accumulation was found to remain in the general proximity of the net pens and disperse relatively rapidly with distance from the pen array. The most heavily-impacted, and sometimes anoxic sediment was found to be beneath the pen arrays. While impacts to the ecosystem beyond an Allowable Zone of Effect are addressed in Criterion 2 – Effluent, the inclusion of Chang et al.'s contour plots showing impacts over a wider area is also of relevance here in demonstrating that impacts to the benthos are often highly variable under and immediately surrounding net pens (Figure 5). While benthic environments at distances of 100-200 m from pen arrays (and sometimes even within pen arrays) may show ambient or negligibly-elevated sulfide content, Figure 5 demonstrates the necessity for recognizing the potential for cumulative impacts of many farm sites, of farm sites located in proximity to one another, and of farm sites located in areas with naturally-depositional or poorly-erosional water flow characteristics. In New Brunswick, the sulfide-metric impact is currently considered to be moderate.

Sulfide content is also used as a metric of the benthic impacts in Maine. There are differences in the monitoring programs between Canada and Maine which are discussed in more detail in section 3.2, but one similarity allows a broad comparison of the performance of Maine-sited farms and New Brunswick-sited farms. In Maine, a tiered monitoring system requires more specific and rigorous benthic monitoring if the mean sulfide concentration at a distance of 30 m from the edge of a net pen array exceeds 3,000 µM. Similarly, the New Brunswick Environmental Monitoring Program proposes that sulfide concentrations ≥ 3,000 µM (i.e., "Hypoxic B" or worse) either "are likely causing," "are causing," or "are causing severe" conditions/damage to the sediments beneath and surrounding net pens. There is, therefore, a degree of continuity between Maine and Canada of the sulfide load and its ecological significance.

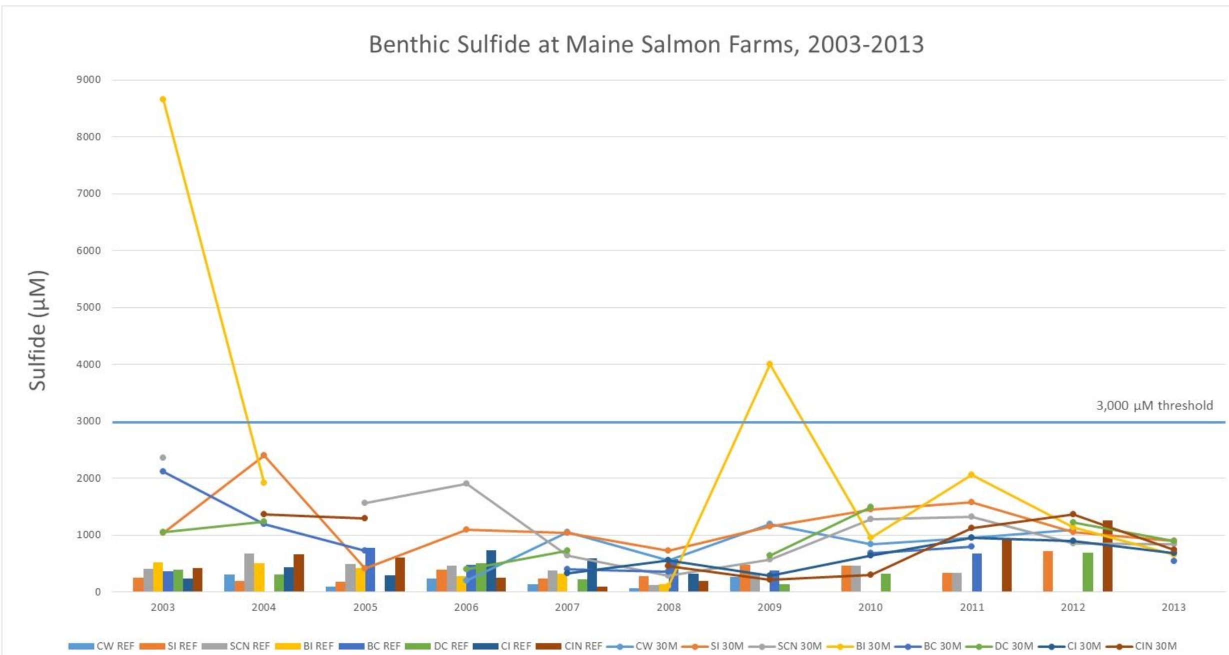


**Figure 9:** The mean benthic sulfide concentration at reference locations (bars) and at 35 m distance from the edge of net pen arrays (lines) at eight Maine-sited salmon farms, from 2003 to 2013. Also illustrated is the 3,000 µM threshold, exceedances of which require additional (species diversity and *Capitella* sp.) monitoring. Graph produced using industry- and Maine DMR-supplied data.

An eleven-year time series of the benthic sulfide concentration surrounding eight Maine-sited farms is represented in Figure 9. Overall, benthic sulfide at locations at a distance of 35 m from the edge of net pen arrays typically remained below 2,000 µM; of the six exceptions, three occurred at the same site (site "BI," yellow line), further demonstrating the localized variation of impacts. Two of these exceedances measured greater than 3,000 µM – the aforementioned threshold for additional monitoring. While performance in Maine was similar to that in New Brunswick, and performed well against the regulatory thresholds set forth in the General Permit by the Maine Department of Environmental Protection (DEP), it must be acknowledged that most sites indeed experience greater sulfide deposition – even outside the '30 m Mixing Zone' – than at reference locations (Figure 9).

Notably, however, the adequacy of sediment sulfide concentration as the sole (initial) proxy for ecological health has been questioned, including for Atlantic North America; a DFO review of aquaculture monitoring strategies identified macrofaunal community analysis, dissolved oxygen analysis, underwater video and photography, and others as suitable metrics, and concluded that "multiple measures of ecosystem status and change will usually be the most effective strategy for management of ecosystem effects of aquaculture" (DFO 2005). Despite this advice, sediment sulfide (in both Canada and Maine) remains the primary metric of ecological health and impact.

Overall, the impacts of salmon net pen aquaculture to the habitats in which it is sited are considered to be moderate, as the data suggests that these habitats generally, though not fully, continue to maintain functionality. Site fallowing is widely regarded as an effective strategy for aquaculture impact mitigation, and the fallowing requirements in Canada and restocking requirements in Maine (discussed below) likely play important roles in maintaining general ecosystem functionality. The numerical score for Factor 3.1 is 7 out of 10.

**Factor 3.2. Habitat and Farm Siting Management Effectiveness**

Factor 3.2 is a measure of the presence and effectiveness of regulatory or management controls appropriate to the scale of the industry. It is ultimately a measure of confidence that the cumulative impacts of farms sited in the habitats declared in Factor 3.1 are at appropriate spatial scales.

**Factor 3.2a. Regulatory or Management Effectiveness**

In both Canada and Maine, there is a permitting process for salmon farming operations. In Maine, farmers must acquire a General Permit for Net Pen Aquaculture, authored by the Maine Department of Environmental Protection (DEP) and last updated in April 2014 (DEP 2014). Canadian-sited farms must acquire licenses from their respective provincial governments, and inter-provincial differences do exist. All applications in both Maine and Canada are each reviewed by several agencies and are subject to public hearing and consultation.

There is some evidence that the location/siting/licensing process, the industry size and farm site concentration, and the strategy for expansion of the industry are based on ecological principles, the potential for cumulative impacts, and the maintenance of ecosystem functionality. For example, the Maine DEP General Permit states that:

> "Outside the designated Mixing Zones, discharges from the facility must not cause or contribute to conditions that are hazardous or toxic to aquatic life, or that would impair the uses designated by the classification of the receiving waters. Within the designated mixing zone, the discharge must not cause or contribute to conditions that are lethal to passing organisms indigenous to the receiving water."

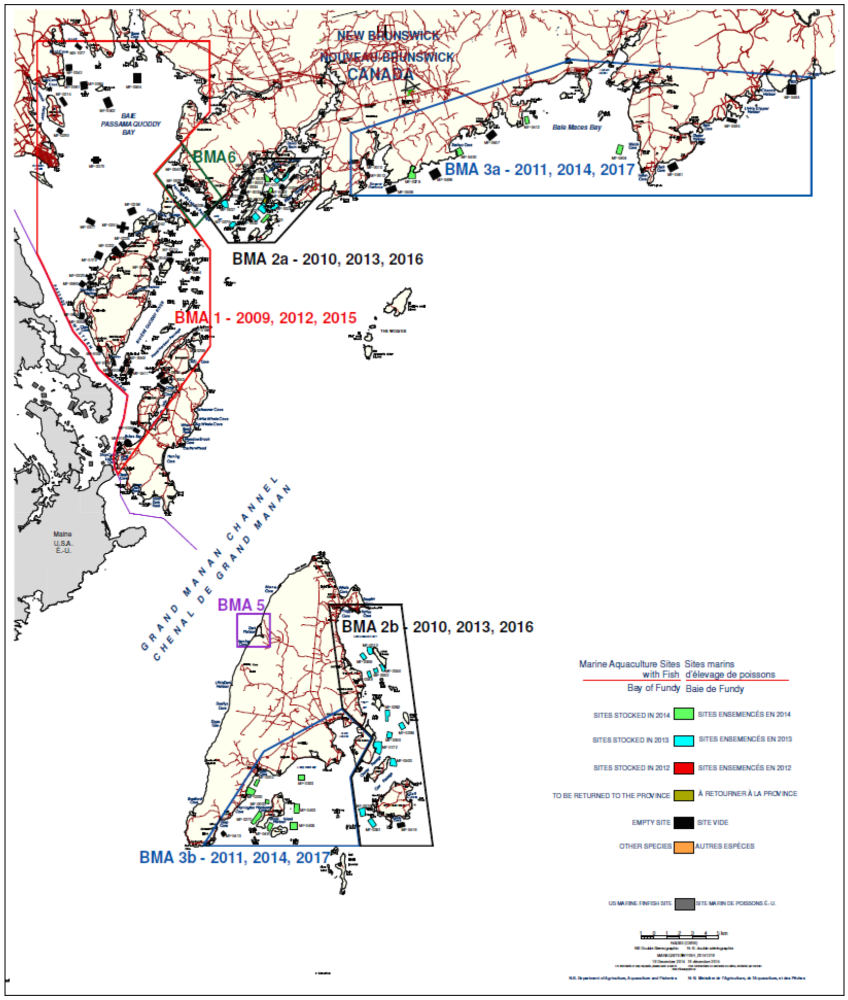


**Figure 10:** The New Brunswick Bay Management Areas (BMA), individual salmon farm sites, and the color-coded status of each site. Image produced by the New Brunswick Department of Agriculture, Aquaculture and Fisheries.

In theory, these stipulations should ensure that farm siting occurs in an ecologically responsible and sensitive manner, but no comprehensive zoning or master plans for either coastal Maine or Canada could be identified. In New Brunswick, farm sites are grouped within Aquaculture Bay Management Areas (ABMA or BMA) (Figure 10). These facilitate single-year-class stocking and fallowing regimes (discussed later in this section), but are not comprehensive ecosystem-based management plans which explicitly limit the total size, concentration, or cumulative impacts of the industry. But while an official, explicit ecosystem-based management regime is not apparent in either Canada or Maine, based on the generally-good cumulative environmental performance of salmon farms, assessed in Factor 3.1, there appears to be a generally-successful effort to limit the size, concentration, and expansion of the industry. However, the realities of localized impacts are indicative of the potential for future expansion to foster a more serious cumulative ecological impact. Furthermore, the aforementioned inadequacy of only using sediment sulfide concentration as a proxy for the overall health of the ecosystem in which farms are cited presents uncertainty and a risk that ecological impacts are not fully understood.

In both Maine and Canada, the siting and licensing process for new farm sites may include an Environmental Impact Assessment-like exercise, but differences do exist between regions. In Maine, an ‘Environmental Characterization and Baseline’ study approved by the Maine Department of Marine Resources (M DMR) must be conducted, and includes both benthic and water column characteristic investigation. In New Brunswick, the Application Guide for Marine Aquaculture states that the rigor and complexity of the pre-siting assessment is “determined by the type of aquaculture activity to be carried out at the site, or may be site specific." EIAs are explicitly required in Newfoundland, but are not in Nova Scotia.

However, salmon farms in Atlantic North America are located in habitat that is of high ecological value. Maine-sited farms, for example, are located in and/or adjacent to water bodies deemed "critical habitat" for wild Atlantic salmon, a classification conditioned by wild salmon's listing under the Endangered Species Act (US DOC 2009) by the National Oceanographic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), and United States Fish and Wildlife Service (USFWS). In Canada, the Species at Risk Act (SARA), under which several sub-populations of Atlantic salmon are listed, identifies the areas and habitats those sub-populations use; indeed, salmon farms are sited in these areas and salmon aquaculture is listed as one of the threats to the health and recovery of wild salmon (COSEWIC 2010). In addition to wild salmon, coastal Maine and Canada is inhabited, frequented, and valuable to several vertebrate and invertebrate marine organisms, and is the epicenter of an economically- and culturally-important commercial and recreational lobster fishery. Though few physical alterations to the habitat occur during the implementation or operation of salmon net pen aquaculture, it is the biological integrity of the areas in which farms are located that is threatened by their siting.

While "habitat restoration" is often thought of as the ability to regenerate a degraded habitat, the notion is applicable here in two primary ways. First, "restoration" of the habitat could be thought of as the cessation of salmon farming in the area to reduce and eliminate the direct threats that farm fish may have on their wild counterparts (e.g., disease transfer, genetic introgression, resource competition, etc.). Alternatively (or additionally), "restoration" could be thought of as a fallowing regime to allow the ecosystem to recover from any impacts caused by the growing cycle (e.g., deposition of excess nutrients and particulates, infiltration of chemical residues, disease incubation within the farm population, etc.). While no requirements for the full restoration of habitat exist in the policies or permits for either region of the industry, there is a fallowing regime in New Brunswick (NB DAAF 2015). All sites within a Bay Management Area must be simultaneously fallowed for two consecutive months prior to restocking, but *each* site must be fallowed for a minimum of four months following harvest (Chang & Page 2011). In theory, the habitat surrounding farm sites should be "restored" by the conclusion of the fallowing period (Carroll et al. 2003). One study of New Brunswick salmon farms concluded that fallowing for four or more months typically allowed benthic conditions to recover, but the variability of this recovery was highlighted by some sites demonstrating elevated sulfide concentrations 7-21 months after the commencement of the fallowing period (Chang and Page 2011). While no explicit fallowing period exists in the control measures for Maine-sited farms, the restocking of a net pen may be done only when it is demonstrated that the benthic sulfide concentration under that net pen is less than 4,000 µM (DEP 2015). When compared to the sediment classification scheme set forth in the New Brunswick EMP, this sulfide content still qualifies as "Hypoxic B," and is therefore not deemed to be restored. The success of habitat restoration efforts in either Canada or Maine, therefore, are considered to be moderate.

The numerical score for Factor 3.2a – Regulatory or Management Effectiveness is 2.25 out of 5 (detailed sub-scores are provided in Appendix 1).

**Factor 3.2b. Siting Regulatory or Management Effectiveness**
The authoritative bodies responsible for permitting, regulating, monitoring and enforcing salmon aquaculture in both Canada and Maine are generally identifiable and contactable. 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 Canada
    - http://www.ec.gc.ca/default.asp?lang=en&n=FD9B0E51-1
- Transport Canada
    - http://www.tc.gc.ca/eng/menu.htm
- New Brunswick Department of Agriculture, Aquaculture and Fisheries
    - http://www2.gnb.ca/content/gnb/en/departments/10/aquaculture.html
- Newfoundland and Labrador Department of Fisheries and Aquaculture
    - http://www.fishaq.gov.nl.ca/aquaculture/index.html
- Nova Scotia Department of Fisheries and Aquaculture
    - http://novascotia.ca/fish/aquaculture/

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
    - http://www.maine.gov/dep/water/wd/atlantic_salmon_aquaculture/index.html

Other entities in each region are involved in specific aspects of aquaculture operations, such as Health Canada for chemical-specific regulations and the US Environmental Protection Agency for wastewater discharge regulations, and their contributions are outlined or linked to from the aforementioned primary regulatory agencies.

As mentioned in 3.2a, proposals for new sites are evaluated individually and with consideration of how each might contribute to the industry's cumulative impact, but it appears that no comprehensive zoning or ecosystem-based management plans govern the farm siting or permitting process.

The transparency of siting regulations and management enforcement in Atlantic North America is generally good. 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 comment are in existence. In addition, the results of environmental monitoring are, in some cases, publicly available. In Canada, for example, the annual results of each province's Environmental Monitoring Program are summarized in a document which can be accessed on their respective websites. The results of environmental monitoring are not pre-emptively public, but may be acquired upon request. Comprehensive zoning plans are not evident in either region, but Bay Management Area information for New Brunswick-sited farms (including the years in which each BMA will be stocked with a new generation of fish) is publicly available.

There is evidence that many of the control measures set forth in policies, permits, and/or industry-authored Standard Operating Procedures are achieved. For example, the thresholds of benthic sulfide concentration in the areas surrounding net pen arrays are generally met. When exceeded, explicit violations of the permits in either region do not occur, but requirements exist for additional monitoring, auditing, staff training, and impacts research respective to each region. In Canada, these requirements are detailed and defined as the Tier 2 and Tier 3 monitoring curricula (NB DELG 2012; NS FAA 2014) and in Maine, the requirement is for an investigation of the community structure of benthic infauna surrounding the farm site in exceedance. There is evidence that these requirements are indeed undertaken in the event of initial non-compliance. However, it must be noted that the restrictions and limits defined in the control measures are not being achieved in their entirety. While limits for sulfide deposition, for example, may be generally met, there remain at all times a percentage of sites that exceed these limits. In addition, the industry is sited in habitats that are considered critical for the population-depressed wild Atlantic salmon. And, as is discussed in greater detail in Criterion 4 – Chemicals, there have been chemicals used that were not approved for application in the marine environment. In large part, the aquaculture regulations are defined, appropriate, and achieved. But, as the following excerpt from a DFO-authored Regulatory Impact Analysis document (DFO 2015a) communicates, there is nonetheless some concern that the adequacy and achievement of regulation is incomplete.

> "Overall, the environmental impacts of the aquaculture sector are well managed through the suite of federal and provincial regulations addressing aquaculture husbandry activities and the use of products to control diseases and pests. However, given the large number of regulators and the breadth of the regulatory requirements, the current regime can be cumbersome for aquaculture operators and confusing for Canadians who seek assurances that environmentally sustainable practices are required by law.
>
> A consequence of this complex regime is that regulatory gaps exist and, despite multiple legal requirements established by multiple regulators, a risk of negative environmental impacts, however negligible, remains."

The numerical score for Factor 3.2b – Siting Regulatory or Management Effectiveness is 3.5 out of 5 (detailed sub-scores are provided in Appendix 1).

Factors 3.2a and 3.2b are used to calculate a score of 3.15 out of 10 for Factor 3.2.

**Conclusion**

The habitats in which farming operations are sited maintain general functionality, and the efficacy of regulatory and management entities are mostly effective, with the exceptions that the industry is sited in critical habitat for severely population-depressed wild Atlantic salmon and there is no evidence of an ecosystem-based expansion plan which considers this. For all of Atlantic North America, factors 3.1 and 3.2 combine to give a final Criterion 3 – Habitat numerical score of 5.72 out of 10.

# Criterion 4: Evidence or Risk of Chemical Use

***Impact, unit of sustainability and principle***

- *Impact: Improper use of chemical treatments impacts non-target organisms and leads to production losses and human health concerns due to the development of chemical-resistant organisms.*
- *Sustainability unit: non-target organisms in the local or regional environment, presence of pathogens or parasites resistant to important treatments.*
- *Principle: aquaculture operations by design, management or regulation avoid the discharge of chemicals toxic to aquatic life, and/or effectively control the frequency, risk of environmental impact and risk to human health of their use.*

**Criterion 4 Summary**
**Maine, US and Atlantic Canada**

| Chemical Use parameters | Score | |
|---|---|---|
| C4 Chemical Use Score | **1.00** | |
| **C4 Chemical Use Final Score** | **1.00** | **RED** |
| Critical? | NO | |

**Brief Summary**

There are three significant concerns regarding the use of chemicals in Atlantic North American salmon farming. First, the recent use of antibiotics (in both total volume and per-ton of fish production) was markedly high, at nearly 23,000 kg of active substance and 412 g $t^{-1}$, in 2012, but short-term trend data (2013-2015) has indicated a reduction in antibiotic use by nearly two-thirds; administration in 2015 was 4,783 kg of active substance and 134 g $t^{-1}$. However, this use is significantly higher than most other salmon-farming regions of the world. In addition, antibiotics deemed *Highly*- and *Critically Important to Human Health*, as defined by the World Health Organisation (WHO), are used. Second, the limited availability of registered pesticide therapeutants for the control of sea lice has resulted, at least twice, in the development of resistance to the few products permitted. Finally, in response to that resistance, a cypermethrin-based pesticide was used, illegally, at farm sites in New Brunswick; the application of cypermethrin in the marine environment is not permitted in Canada. Despite the use resulting in lobster mortalities in 2009, and the knowledge that ongoing government monitoring would be occurring, the product was used again in 2010. The three concerns result in a final score for Criterion 4 – Chemical Use for all of Atlantic North America is 1 out of 10.

**Justification of Ranking**

Chemical use in salmon aquaculture has three general categories of purpose: antibiotic, which combat bacterial disease; antiparasitic, which, in the farmed salmon industry, are most commonly used to target sea lice; and antifouling, which inhibit marine growth on farm infrastructure (i.e., nets, pen moorings, etc.) (Burridge et al. 2010).

Health Canada regulates chemical therapeutants based on their mode of administration; when used as topical and bath treatments, therapeutants are considered pesticides, and when administered orally (either directly or incorporated in feed) or via injection, are considered drugs (Burridge and Van Geest 2014). 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 application of chemical therapeutants is conditioned by signage at the farm site alerting the public of their use, sediment monitoring for accumulated chemical residues for 7-30 days post-use, and the submission of a monthly drug use report, which includes the following, as amended from the Maine Net Pen Aquaculture General Permit:

1. The number of days of application
2. The drug or disease control chemical used
3. The concentration and total quantity used
4. The approximate number of fish and pens treated
5. The method of application
6. Condition treated

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).

Data obtained from an industry representative documented the industry-wide use of several chemicals in the calendar years of 2012, 2013, and 2014. Their use is discussed, according to the class to which they belong, in the following sections.

<u>Antibiotics</u>

There has been a steady, and typically marked, decline in antibiotic usage across many salmon-farming regions of the world, due in large part to the development of vaccines (Rust et al. 2014); the best example being Norway where antibiotic usage has fallen 95% in the past 20 years (Midtlyng et al. 2011) while total salmon production has increased more than 5.5-times during the same period (Rust et al 2014). The World Health Organisation (WHO) (2011) has cited this development as a "lesson on the importance of preventative medicine," that "is relevant to all food-animal production." And while many improvements in antibiotic use for salmon aquaculture have been made, there is still often significant concern for the type and the amount that *are* used and the effects that their use (and misuse) can have on the ecology of the environments in which farms are sited (Buschmann et al. 2012).

The most serious concern with regard to antibiotic use in aquaculture is the potential for bacteria to develop resistance to the drugs intended to control them (both *in* the animals fed antibiotics and in the environment in which those animals are grown), and that resistance being transmitted to human pathogens (Buschmann et al. 2012). The pathways for the realization of this potential (e.g., unconsumed medicated feed falling to the benthos, incompletely-absorbed residues being excreted by farm fish, persistence and leaching of residues into the benthos and water column, the development and selection for resistance genes, the mobility of those genes, etc.) are well documented, and a volume of literature detailing them can be found in research and reviews by Buschmann et al. (2012), Cabello et al. (2013), and Miranda (2012). In an investigation of antibiotic resistance in areas surrounding Chilean salmon farms, Shah et al. (2014) concluded that:

> "*High levels of AR* (antimicrobial resistance) *in marine sediments from aquaculture and nonaquaculture sites suggest that dispersion of the large amounts of antimicrobials used in Chilean salmon aquaculture has created selective pressure in areas of the marine environment far removed from the initial site of use of these agents*."

Industry-supplied data for chemical use from 2012 to 2015 included the administration of antibiotics (Figure 11). Though long-term industry-wide trend data (i.e., >5 years) for Atlantic North America could not be obtained, antibiotic use in 2013, 2014, and 2015 were each reduced by nearly two-thirds relative to use in 2012. The three-year average use of 2012-2014 was 12,867 kg of active chemical, administered in 1,637,960 kg of medicated feed. Including the less-granularly detailed data for 2015, the four-year average antibiotic use was 10,846 kg of active chemical. As seen in Figure 11, oxytetracycline (tradename Terramycin™) was the overwhelmingly-dominant antibiotic used; note that the y-axis is logarithmic. In the three years for which drug-specific data was available (2012, 2013, and 2014), oxytetracycline accounted for 98.33%, 92.65%, and 92.65%, respectively, of the total antibiotic administration. Florfenicol (tradename Aquaflor™), erythromycin, and tribrissen were each used in all three years, and penicillin was used, as a trial treatment, in 2012 only.

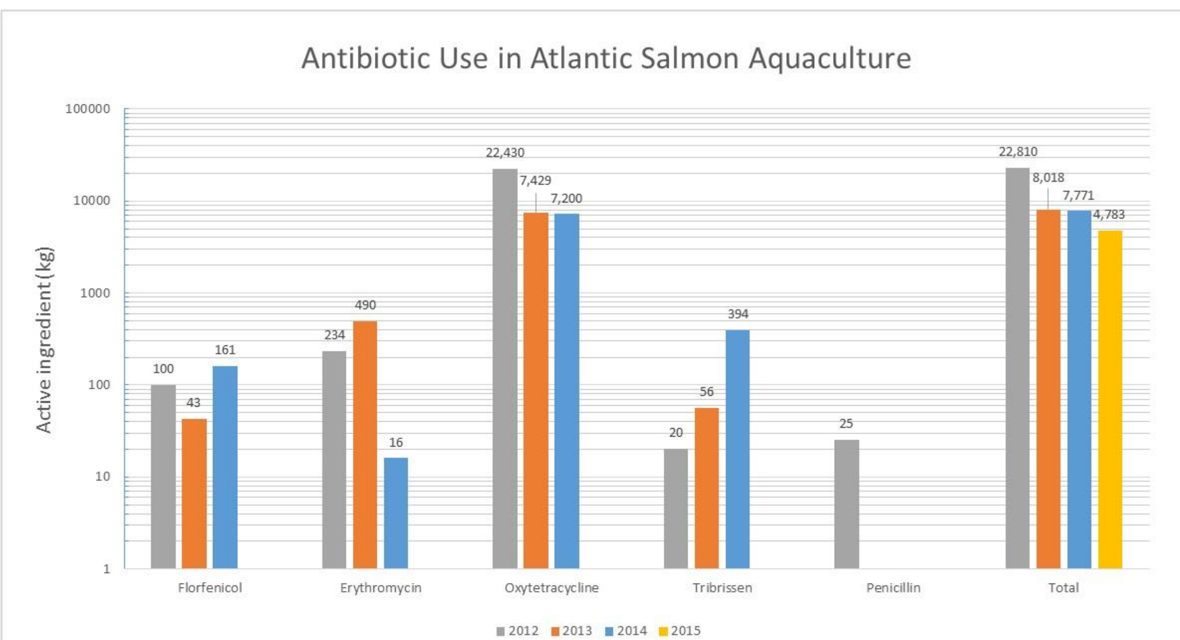


**Figure 11**: Antibiotic usage in Atlantic salmon net pen aquaculture, per drug and in total, in Atlantic North America for 2012, 2013, and 2014. Total use only was available for 2015. ***Note***: The scale is logarithmic. Data from an industry-suppled document.

It must be emphasized that the antibiotic treatment dose and duration varies considerably between different types of antibiotics, and therefore direct comparisons of antibiotic use between different regions that use different drugs must be made with caution. However, it is clear that antibiotic use on a per-ton of production basis in Atlantic North America is, with the exception of Chile, markedly high relative to per-ton antibiotic use in other salmon-farming regions (Table 3). Data in Table 3 for British Columbia, Norway, Scotland, and Chile represents antibiotic use in 2013, but data for Atlantic North America is presented three ways: the mean of use in 2012 to 2015, use in 2012 alone, and use in 2015 alone. For the four-year average (2012-2015) of per-ton use data, use in Atlantic North America represents a 5-times higher use than in British Columbia, a 168-times higher use than in Norway, and a 198-times higher use than in Scotland. It remains merely 31% of the antibiotic usage in Chile. Because use in 2012 (412 g ton$^{-1}$ of active chemical) was more than 2.5-times use in the following three years, the four-year average (218 g ton$^{-1}$) is markedly higher than the average for 2013-2015 alone (154 g ton$^{-1}$). Still, use in just 2013-2015 represents a 3.5-, 118-, and 140-times higher use than in British Columbia, Norway, and Scotland, respectively.

Accepting the same caution regarding different dosage rates of the different treatments used in different regions, when considering antibiotic use on a total volume use basis, use in Atlantic North America ranks substantially higher than most other salmon-farming regions despite achieving a fraction of their respective total fish productions. While the four-year average of use in Atlantic North America remains 3.2% of the per-ton use employed in Chile, it is nonetheless 3-, 7-, and 65-times higher than per-ton use in British Columbia, Norway, and Scotland, respectively. For 2012 alone, when antibiotic use in Atlantic North America totaled 22,810 kg of active chemical, this represents a 6.2-, 14-, and 136-times greater use than in those three regions, respectively.

**Table 3:** Total annual active ingredient antibiotic use (kg) and use on a per-ton of production basis (g ton$^{-1}$) in Atlantic North America, compared to four other salmon-farming regions. Production data for 2012–2014 Atlantic North America from FAO 2015. Production for 2015 calculated from industry-supplied data. **a ;** averaged from 2012–2015 (antibiotic use data from industry-suppled document) **b , c ;** antibiotic use data from industry-supplied document **d ;** all data from Bridson (2014a)

| | **ATL N.A.** 2012-2015[a] | **ATL N.A.** 2012[b] | **ATL N.A.** 2015[c] | **British Columbia**[d] | **Norway**[d] | **Scotland**[d] | **Chile**[d] |
|---|---|---|---|---|---|---|---|
| **Total Annual Use** | **10,846** kg | **22,810** kg | **4,783** kg | **3,650** kg | **1,591** kg | **168** kg | **343,600** kg |
| **Per-ton of Production** | **218** g ton$^{-1}$ | **412** g ton$^{-1}$ | **134** g ton$^{-1}$ | **43.7** g ton$^{-1}$ | **1.3** g ton$^{-1}$ | **1.1** g ton$^{-1}$ | **701** g ton$^{-1}$ |

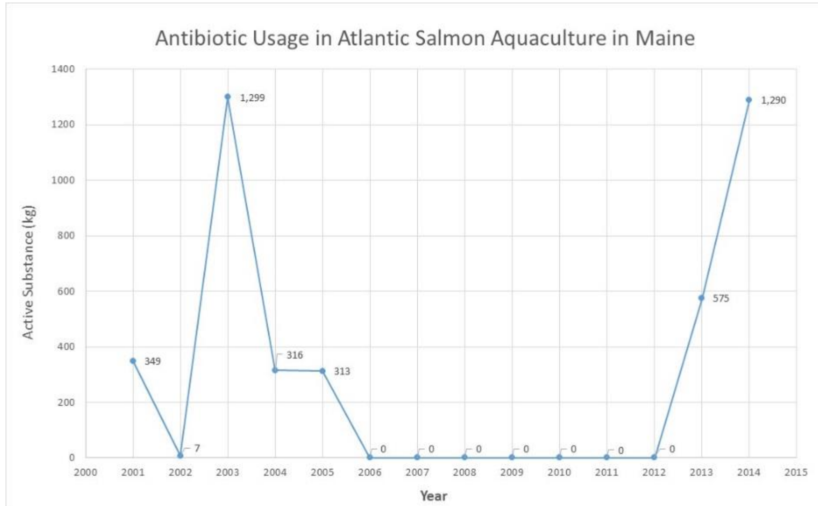


**Figure 12:** The time series in total antibiotic use in Atlantic salmon aquaculture in Maine from 2001 to 2014. Data from a Maine DMR public document (M DMR 2009) for 2001-2009, and from M DMR-supplied environmental monitoring data for 2009-2014.

Longer-term data (2001-2014) was obtained for salmon production specific to Maine, and shows a high degree of variation in antibiotic use (Figure 12). In three of the five years from 2001 to 2005, an average annual total of 326 kg of active ingredient were used, with the other two years being significantly lower (7 kg in 2002) and significantly higher (1,299 kg in 2003). In the years 2006-2012, however, no antibiotics were used; this is in stark contrast to the norm in other salmon-farming regions, where a stepwise reduction in use has generally been observed over time, but at least *some* use has been employed in every year (see Bridson 2014b, 2014c, 2014d, 2014e). Had antibiotic non-use in Maine continued until present, the cause for concern would be markedly lower. However, in 2012, antibiotic use in Maine salmon farms rose to 575 kg of active ingredient, and in 2013, more than doubled to 1,290 kg of active ingredient.

Of the five antibiotics most recently (2012-2014) used in Maine and Canada, four are listed as either *Highly* or *Critically Important Antimicrobials* by the World Health Organisation (WHO 2011). Two of those used in Atlantic North American salmon farming, florfenical and oxytetracycline, are *highly important*, and two, erythromycin and penicillin, are *critically important*. Their use renders a high cause for concern for antibiotic residues, and the effects and potential effects of those residues, becoming incorporated into the receiving ecosystem in which the net pens are sited.

Although every use of antibiotics potentially selects for resistance genes in bacteria, currently, there is no evidence that antibiotic use in Atlantic North American salmon farming has resulted in the development of clinical antibiotic-resistance (i.e., resulting in failed treatments). However, the ubiquity of importance of some antibiotics used, the volume of their use, the apparent consistency of their use, and the unpredictability in their necessity (as evidenced by two successive years of increasingly-high use in Maine after seven years of non-use) renders the concern for developed resistance significant.

<u>Pesticides</u>
Industry-supplied data confirmed the recent (2012-2014) use of five pesticides administered to treat parasitic sea lice (Table 4).

**Table 4:** The chemicals 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 | Noromectin® | In-feed |
| Teflubenzuron | Calicide® | In-feed |

Though industry-wide trend data (i.e., >3 years) could not be obtained, recent usage (i.e., 2012-2014) can be analyzed (Table 5, Figure 13) from an industry-supplied document. The two pesticides administered as a bath treatment were the most heavily used. Of these, hydrogen peroxide use, at 657 t (i.e., 637,000 kg) annual average, was significantly higher than azamethiphos, at 138 kg annual average. However, like antibiotics, the total quantity of different chemicals used must be considered alongside their relative toxicities in these comparisons. Because of the environmentally-benign nature of hydrogen peroxide (i.e., it quickly dissociates into water and molecular oxygen), the industry's increasing reliance on it for topical sea lice treatment is encouraging.

Of those pesticides administered as in-feed supplements, only ivermectin and emamectin benzoate were used in all three years; teflubenzuron, while being used in the highest quantity (by a large margin) in one year of any of the in-feed medications (79 kg in 2013), was not used in either 2012 or 2014. Total use over those three years and the annual average was higher for ivermectin than for emamectin benzoate, but use in 2014 was higher for emamectin benzoate than for ivermectin.

**Table 5:** The volume of pesticides used (in kg) by the Atlantic North American salmon farming industry from 2012-2014. The differing toxicities of those administered as bath treatments does not allow for accurate or meaningful mean calculation. Those administered in feed are totaled and averaged.

| Admin. Method | Chemical | 2012 | 2013 | 2014 | Total | Avg. |
|---|---|---|---|---|---|---|
| Bath | Salmosan® | 48 | 162 | 203 | **413** kg | **138** kg |
| | Interox® Paramove® 50 | 557,000 | 680,000 | 673,000 | **1.91 mil** kg | **637,000** kg |
| | | | | | | |
| In-Feed | SLICE® | 8.6 | 4.4 | 14 | **27** kg | **9** kg |
| | Calicide® | 0 | 79 | 0 | **79** kg | **26** kg |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Noromectin® | 19 | 13 | 5.4 | **37.4** kg | **12** kg |
| | **Total** | **27.6** kg | **96.4** kg | **19.4** kg | **143.4** kg | **15.7** kg |

As with antibiotics, there is a significant concern for sea lice to develop resistance to controlling treatments, and evidence of resistance supports this concern. In the late 1990s, Salmosan® was one of two products used to control sea lice, but as the initially-more efficacious one, was relied upon heavily. As a result of this reliance, resistance developed and Salmosan® became less effective (Burridge & Van Geest 2014). In response, SLICE® was granted an emergency registration by PMRA in 1999 (Armstrong et al. 2000). Its successful action and ease of use (as an in-feed ingredient) led to it becoming the treatment of choice throughout Canada (Stone et al. 2000a, 2000b); registration of other treatments were not completed and SLICE® was the only available anti-louse product for nearly ten years (Jones et al. 2012; Burridge & Van Geest 2014). In 2008, resistance to SLICE® was suspected in Nova Scotia (Jones et al. 2012; ACFFA 2010, 2014b), as post-treatment sea lice abundance was, in all 12 monitored weeks post-treatment, higher than pre-treatment abundance (Jones et al. 2013). Subsequent research has confirmed a decrease in efficacy. Jones et al. (2013) found a reduction in treatment effectiveness over time. While they admitted that treatment *resistance* may not be solely responsible for decreased *efficacy*, it was suggested that resistance was at least a contributing factor. However, bioassay analysis by Igboeli et al. (2012) revealed that sea lice collected in 2011 required a 4- to 26-fold higher SLICE® dose for the treatment to be effective when compared to similar research (Westcott et al. 2008) carried out from 2002 to 2005, confirming the development of SLICE®-resistance in sea lice.

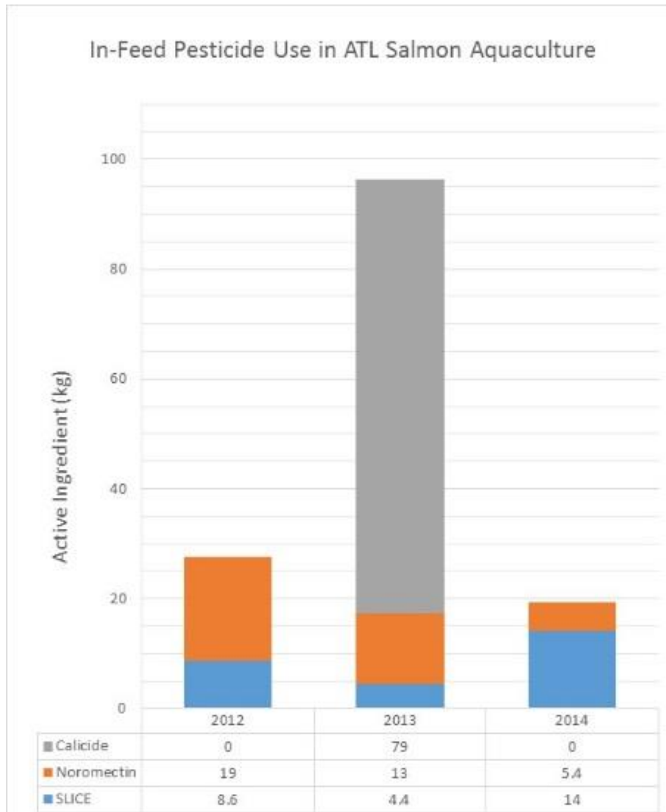


**Figure 13:** The use of in-feed pesticides to treat sea lice on farmed Atlantic salmon in Atlantic North America in 2012, 2013, and 2014. Numerical values in the table are in kg of active ingredient. Data from an industry-supplied document

Evidence of resistance in New Brunswick prompted the emergency registration of Salmosan®, Paramove®, and deltamethrin-based AlphaMax® in 2009 and 2010, though the AlphaMax® registration was retracted in fall 2010 (Burridge & Van Geest 2014).

In response to the decreased efficacy of SLICE® and a lack of additional resources (e.g., alternative treatments, well boats, etc.), a cypermethrin-based pesticide was administered as a bath treatment at Canadian-sited farms between October and December 2009. While cypermethrin is an approved ingredient for use in the US, permission for use in the marine environment had not been granted in Canada (use in terrestrial agriculture, however, is permitted). Despite an immediately-observed environmental impact (detailed in Criterion 9X) and the knowledge that Environment Canada would be conducting routine inspections to monitor compliance, the presence of cypermethrin was detected in fish sampled from the same farm sites as much as one year later; it was determined that a cypermethrin-based therapeutant was again unlawfully applied in April and November 2010. The use of cypermethrin at 15 farm sites throughout southwestern New Brunswick was prosecuted, as evidence by an *Agreed Statement of Facts* (Anonymous, undated). While the application of an illegal chemical is not believed to be wholly representative of the industry's operating procedures, and there is no evidence to suggest it has been used since, its use in successive years does warrant some concern. Continued law abidance will reduce this concern.

Antifoulants/Biocides

Antifouling biocides are used frequently in net pen aquaculture to inhibit the growth of marine microorganisms on an operation's infrastructure (i.e., nets, pen moorings, etc.), and copper-based products are the most universally-used (Burridge et al. 2010; Dürr & Watson 2010). 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). In some cases, the presence of copper in the water column and in the sediments in the vicinity of farm sites exceeds regulatory limits (Loucks et al. 2012). The concern for their high-volume and/or persistent use is rooted in their toxicity and their broad range of target organisms (and, it has been argued, their ease of application) (Braithwaite et al. 2007; Guardiola et al. 2012). 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). There is evidence that the bioavailability of copper to infaunal organisms is low in the presence of elevated sulfide concentrations (Brooks et al. 2003, 2004; Hambrey & Nickell 2011), which, as demonstrated in Criterions 2 and 3, is not generally the widespread case at farm sites in Atlantic North America.

Through communication with an industry representative, only 13 of the 461 containment nets in current use were treated with antifouling biocide (J Wiper, pers. com.), but no details regarding the chemical formulations used or their application volume or concentration could be determined. There is indeed some concern that copper-based and other antifouling products could accumulate in the environment surrounding salmon farms, but this concern is less serious than that for antibiotic and antiparasitic use.

**Conclusion**

In summary, the concern for chemical use in the Atlantic North American salmon farming industry is serious. The use of antibiotics (in both total volume and per-ton of fish production) is markedly high and antibiotics deemed *Highly*- and *Critically Important to Human Health*, as defined by the WHO, are used. Oxytetracycline, which accounted for 92–98% of all antibiotic usage, is listed as a *Highly Important* antimicrobial. In addition, there is a history of sea lice developing resistance to the few products permitted to treat them. Finally, in response to that resistance, a cypermethrin-based pesticide was used, illegally, at farm sites in New Brunswick in 2009 and again in 2010.

For all of Atlantic North America, these three concerns result in a final score for Criterion 4 – Chemical Use of 1 out of 10.

# 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.*
- *Sustainability unit: 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: aquaculture operations source only sustainable feed ingredients, convert them efficiently and responsibly, and minimize and utilize the non-edible portion of farmed fish.*

**Criterion 5 Summary**
**Maine, US and Atlantic Canada**

| Feed parameters | Value | Score | |
|---|---|---|---|
| F5.1a Fish In: Fish Out ratio (FIFO) | 1.97 | 5.06 | |
| F5.1b Source fishery sustainability score | | -2.00 | |
| F5.1: Wild Fish Use | | 4.67 | |
| F5.2a Protein IN | 13.49 | | |
| F5.2b Protein OUT | 17.43 | | |
| F5.2: Net Protein Gain or Loss (%) | +29.22 | 10 | |
| F5.3: Feed Footprint (hectares) | 7.60 | 7 | |
| **C5 Feed Final Score** | | **6.59** | **YELLOW** |
| Critical? | NO | | |

**Brief Summary**

The data used for assessment of Criterion 5 – Feed is complete for the growout cycle of the industry's 2012 year-class. The cycle-mean feed conversion ratio (FCR) is calculated to be 1.69. While fishmeal inclusion for the industry (6.43%) is markedly lower than that in other salmon-farming regions, fish oil inclusion (8.59%) is only marginally lower. The partial use of byproduct sources (24% of FM and 32% of FO) results in a moderate initial Fish In: Fish Out (FIFO) value of 1.97. Marine ingredients (herring, menhaden, anchovy) are sourced from fisheries in Atlantic Canada, Atlantic US and Gulf of Mexico, and Peru; these fisheries currently have no serious conservation concerns. The low fishmeal inclusion rate is most evident in calculating the protein budget, where it is supplemented by higher-than-average land animal byproduct use (42% of feed, supplying 70% of total protein), crop byproduct use (~10.5% of feed, ~3% of protein), and other crop ingredients (~24.5% of feed, ~16.5% of protein). The processing byproducts from the harvested salmon are used in cat food production. These aspects work in concert to achieve a net edible protein gain of 29.2%. Finally, the low marine ingredient dependence reduces the ocean area necessary to support the industry on a per-ton of production basis and the overall feed footprint. The final score for Criterion 5 – Feed for all of Atlantic North America is 6.59 out of 10.

**Justification of Ranking**

Four feed manufacturing companies (Charlotte Feeds, EWOS, Northeast Nutrition, Skretting) are known to have provided feed for the industry in Atlantic North America. A document authored by the industry provides information on the sustainability of marine raw materials (i.e., fishmeal and fish oil) used by each of the four feed manufacturers in the production of their respective feeds for the industry. One feed manufacturer provides feed for the hatchery phase only, and as such, is considered outside the scope of this assessment (which concentrates on the much larger volume of feeds used in growout). One of the three remaining feed manufacturers provides feed for only the first few months of the net pen growout phase of production. Feed use data obtained from the farming industry was specific to the 2012 year class only, though was inclusive of all but two farm sites. While acknowledging that feed formulations and ingredient sourcing changes over time, this data is considered a representative snapshot of feed use and efficiency for the purposes of this assessment. The composition of these feeds were verified by statements from feed manufacturers. For the 2012 year-class, feed from only two of the four feed companies were used during the net pen growout phase of production. While one of those feed companies accounted for 96.7% of the total feed used, both formulators' feed ingredients and sources are used for the calculations and assessment in Criterion 5.

**Factor 5.1. Wild Fish Use**

<u>Factor 5.1a – Fish In : Fish Out (FIFO)</u>

Recent trends in feeding regime and feed formulation for carnivorous finfish show an increasingly efficient conversion of feed fed to weight gained by the fish (i.e., feed conversion ratio, or FCR) (Sarker et al. 2013), a decrease in wasted (i.e., unconsumed) feed (Wang et al. 2012; Sarker et al. 2013), and a decrease in the inclusion of fish meal and oil (Sarker et al. 2013; Rust et al. 2014). Currently, industry-average FCRs for Atlantic salmon aquaculture in other regions (i.e., Norway, Chile, Scotland, British Columbia) range from 1.15 to 1.3 (Bridson 2014a). Fishmeal inclusion rates are typically 15–22%, with 15–25% of that coming from byproducts, and fish oil inclusion rates are typically 11–13%, with anywhere from 0% to 23% coming from byproducts (Bridson 2014b, 2014c, 2014d, 2014e).

Data regarding the use of wild fish in the production of feed for the Atlantic North American industry is shown in Table 6. Compared to the Atlantic salmon net pen aquaculture industry in other regions, the reported FCR in Atlantic Canada and Maine is higher, at 1.69, but both fish meal and oil inclusion rates are low, at 6.43% and 8.59%, respectively. The proportional incorporation of byproducts is similar for fishmeal, at 24.06%, and higher for fish oil, at 32.01%. In the absence of data specific to the industry being assessed, the percent-yield values used for fish meal and oil (22.5% and 5% respectively) are those used in key literature (Tacon & Metian 2008; Péron et al. 2010) and for other Seafood Watch assessments (e.g. Bridson 2014a, 2014b, 2014c, 2014d, 2014e; Tucker 2014). While the resulting FIFO value for fishmeal in Atlantic

North America (0.37) is markedly lower than that for others Atlantic salmon farming regions, the FIFO value for fish oil (1.97), being the higher of the two, is used, and is within the range of those calculated for other regions. Reflecting the data described above, the calculated FIFO score, Factor 5.1a, is 5.06 out of 10.

**Table 6:** The parameters used and their calculated values to determine the use of wild fish in feeding farmed Atlantic salmon in Atlantic North America.

| Parameter | Data |
|---|---|
| Fishmeal inclusion level | 6.43% |
| Percentage of fishmeal from byproducts | 24.06% |
| Fishmeal yield (from wild fish) | 22.50%[4] |
| Fish oil inclusion level | 8.59% |
| Percentage of fish oil from byproducts | 32.01% |
| Fish oil yield | 5.00%[5] |
| Economic Feed Conversion Ratio (eFCR) | 1.69 |
| **Calculated Values** | |
| Fish In : Fish Out ratio (fishmeal) | 0.37 |
| Fish In : Fish Out ratio (fish oil) | 1.97 |
| **Seafood Watch FIFO Score (0-10)** | **5.06** |

Factor 5.1b – Sustainability of Source Fishery

According to the industry-authored raw materials data sheet previously mentioned, the source fisheries for fishmeal used in 96.7% of growout feed for the 2012 year-class are 65% International Fishmeal and Fish Oil Organisation (IFFO)-certified, 30% "MSC (certified) and/or by-product," and 5% from a "managed fishery." Sources of fish oil used in the same feed were reported to be 60% IFFO-certified, 12% "MSC (certified) and/or by-product," and 28% from a "managed fishery."

Fishmeal and fish oil are obtained from fisheries in the western North Atlantic (Canada and the US) and Peru. For the production of moist feed used during the first few months of growout (3.3% of total feed used for the 2012 year-class), all fish protein is derived from herring sourced from New England, New Brunswick, and Nova Scotia. Fish oil used in moist feed production is derived from Nova Scotian-caught herring or, when herring is not available, from Peruvian anchovy. For the production of growout feed used after moist feed (96.7% of total feed used for 2012 year-class), fish meal and oil are sourced from the Peruvian anchovy and Nova Scotian herring fisheries, with additional menhaden-derived fishmeal being sourced from the Gulf Menhaden stock in the Gulf of Mexico. In addition to IFFO-certification, the Peruvian anchovy

[4] 22.5% is a fixed value from the Seafood Watch Criteria based on global values of the yield of fishmeal from typical forage fisheries. Yield estimated by Tacon and Metian (2008).

[5] 5% is a fixed value from the Seafood Watch Criteria based on global values of the yield of fish oil from typical forage fisheries. Yield estimated by Tacon and Metian (2008).

fishery attains five of six FishSource[6] scores of ≥6 and one score of 10.0. The Nova Scotian herring fishery is currently under Marine Stewardship Council (MSC) assessment, but attains all six FishSource scores of ≥6. Finally, the Gulf Menhaden fishery is IFFO-certified and attains FishSource scores of ≥6, ≥6, ≥8, 8.8, and 10.0. Since all FishSource scores are at least ≥6, with some but not all scores >8, the most appropriate score for adjustment factor (5.1b) is -2 out of -10 (where an adjustment factor of zero denotes a fully sustainable source fishery and -10 denotes a demonstrably unsustainable fishery).

Combining the Factor 5.1a FIFO score of 5.06 with the 5.1b adjustment factor of -2, gives the final calculated score for Factor 5.1 of 4.67 out of 10.

**Factor 5.2. Net Protein Gain or Loss**

<u>Protein Input</u>
As a piscivorous species, salmon have a high dietary protein requirement. For the 96.7% of the feed used for salmon growout in Canada and the US, the mean protein inclusion is 40.17%; this is similar to that used in other salmon-farming regions (Bridson 2014b, 2014c, 2014d, 2014e). Of the total protein content of the feed, 10.66% is fishmeal-derived. Of this, 8.10% is attained through the incorporation of whole fish and 2.56% is gained through the use of fishery byproducts (i.e., non-edible). Forty-two percent of the total feed composition is land animal products, all of which are considered to be byproducts, and this accounts for 70% of the total protein content of the feed. Approximately 35% of the total feed composition is crop-derived. On average, 9–12% of the total feed is comprised of wheat that was grown as "milling wheat" (i.e., with the intent of use in human food) but has subsequently not met the requirements to do so, as per the Canadian Grain Commission Grading Standards (A Donkin, pers. com.). For the current assessment 10.5% (i.e., the mean of 9 and 12%) was used for calculations in Criterion 5, and considered to be a non-edible crop ingredient. This wheat contributes 2.88% of the total protein content of the feed. Collectively, non-edible ingredients (fishmeal-, land animal-, and crop-derived) represent 75.44% of the feed's total protein content. The total edible protein input is 13.49 kg per 100 kg, or 134.9 kg per ton of farmed salmon (Table 7).

[6] Fishsource: http://www.fishsource.com/

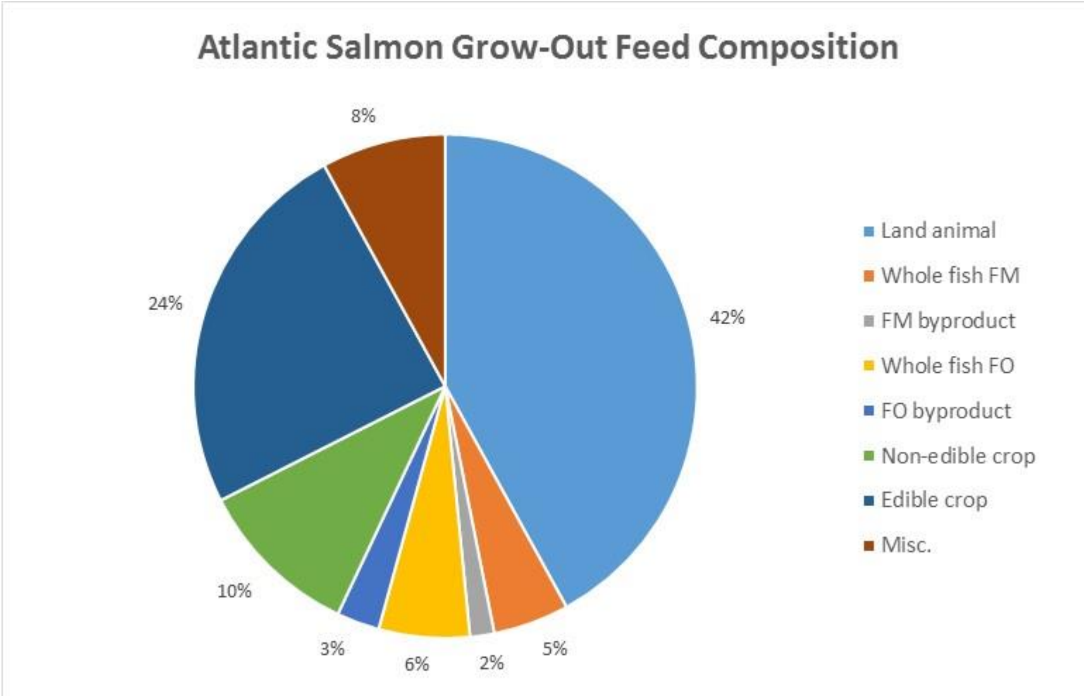


**Figure 14:** The approximate composition of the growout feed used for Atlantic salmon aquaculture in Canada and the US. *Note:* **FM** = fishmeal; **FO** = fish oil; **Misc.** = miscellaneous, unknown ingredients likely to include vitamin and mineral premixes, etc.

Protein Output

In the absence of industry-specific data, the estimated protein content of harvested whole salmon is 17.5%; this estimate is slightly higher than that used in other Seafood Watch salmon assessments (e.g., 16.9% by Bridson 2014b, 2014c, 2014d, 2014e), but based on a more recent version (Ytrestøyl et al. 2014) of the publication cited in those assessments, Nofima (2011). According to an industry-authored document, the dressed, fat-trimmed yield from a harvested 4.5-kg fish is 60.0% of its round (i.e., whole) weight. It was communicated, and verified by invoice documents, that nearly all of the non-edible byproducts from harvested salmon are used in the production of cat food; only the skin from one fish-smoking plant is not, and this is composted. The percentage of fish processing byproducts used for other food production was therefore estimated to be 99.0%, and overall, the total utilized protein output is calculated to be 17.43 kg per 100 kg, or 174.3 kg per ton of farmed salmon.

**Table 7:** The protein budget for Atlantic salmon aquaculture in Atlantic North America.

| Parameter | Data |
|---|---|
| Protein content of feed | 40.17% |
| Percentage of total protein from non-edible sources (byproducts, etc.) | 75.44% |
| Percentage of protein from edible crop sources | 16.40% |
| Feed Conversion Ratio | 1.69 |
| **Protein INPUT** per ton of farmed salmon | 134.9 kg |

| | |
|---|---|
| Protein content of whole harvested salmon | 17.50%[7] |
| Edible yield of harvested salmon | 60% |
| Percentage of farmed salmon byproducts utilized | 99.0% |
| Utilized **protein OUTPUT** per ton of farmed salmon | 174.3 kg |
| **Net protein gain** | + 29.22% |
| **Seafood Watch Score (0-10)** | **10** |

With an edible protein input of 134.9 kg/ton and a utilized protein output of 174.3 kg/ton, a net protein gain of 29.2% is achieved per ton of farmed Atlantic salmon.  While the Atlantic salmon farming industry in British Columbia, Canada also achieves a net protein gain, other regions (i.e. Norway, Scotland, Chile) operate with a net protein loss of 35–50% (Bridson 2014a).  The net protein gain for the Atlantic North American industry, due primarily to the substantial use of land animal byproduct proteins, attains a score 10 out of 10 for Factor 5.2.

**Factor 5.3. Feed Footprint**
Marine-derived ingredients contribute 15.02% of the total feed composition.  Using the FCR of 1.69 and fixed values in the Seafood Watch Criteria for ocean primary productivity, the equivalent of 6.60 h of ocean area is appropriated for every ton of salmon production.  With 35% and 42% of crop and land animal inclusion rates into salmon feed, respectively, by using the fixed values of 2.64 h of land area necessary to produce one ton of crop ingredients and a ratio of 2.88:1 for the conversion of crop ingredients to land animal product, it is calculated that 1.00 h of land area are appropriated per ton of salmon production.

**Table 8:** Marine, crop, and land animal inclusion in Atlantic salmon feed, and the ocean and land areas necessary to support one ton of farmed fish production.

| Parameter | Data |
|---|---|
| Marine ingredients inclusion | 15.02% |
| Crop ingredients inclusion | 35.0% |
| Land animal ingredients inclusion | 42.0% |
| Ocean area (hectares) used per ton of farmed salmon | 6.60 |
| Land area (hectares) used per ton of farmed salmon | 1.00 |
| Total area (hectares) | 7.60 |
| **Seafood Watch Score (0-10)** | **7** |

According to the Seafood Watch Criteria, the substantial use of crop and land animal ingredients and the resulting total area appropriation of 7.60 h per ton of farmed fish production is considered ‘low-moderate’; the score for Factor 5.3 is 7 out of 10.

**Conclusion**
The Atlantic North American industry attains 70% of its protein for feed from land animal products, which are considered to be non-edible byproducts.  This allows for the marked

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[7] As reported by Ytrestøyl et al. 2014. Resource utilization of Norwegian salmon farming in 2012 and 2013. Nofima 36/2014. October 2014.

reduction in fishmeal and, to a lesser extent, fish oil inclusion rates. Additionally, the high use of byproducts for marine ingredient inclusion and the largely-responsible marine ingredient sourcing helps to achieve a moderate Wild Fish Use score. The high use of land animal byproducts is also evident in calculating the protein budget, where it is supplemented by higher-than-average crop byproduct use and the almost complete utilization of farm-fish processing byproducts in cat food production. This achieves a net edible protein gain of 29%. Finally, the low marine ingredient dependence and high use of terrestrial byproducts reduce the ocean area and the total area necessary to support the industry's feed use on a per-ton of production basis.

The final score for Criterion 5 is calculated as the average of its three factors, with double-weighting on Factor 5.1, the adjusted FIFO score. For all of Atlantic North America, factors 5.1, 5.2 and 5.3 combine to give Criterion 5 – Feed a final numerical score of 6.59 out of 10.

# Criterion 6: Escapes

***Impact, unit of sustainability and principle***

- *Impact: competition, genetic loss, 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.*
- *Sustainability unit: affected ecosystems and/or associated wild populations.*
- *Principle: aquaculture operations pose no substantial risk of deleterious effects to wild populations associated with the escape of farmed fish or other unintentionally introduced species.*

**Criterion 6 Summary**

**Maine, US**

| Escape parameters | Value | Score | |
|---|---|---|---|
| F6.1 Escape Risk | | 3.00 | |
| F6.1a Recapture and mortality (%) | 30 | | |
| F6.1b Invasiveness | | 3.5 | |
| **C6 Escape Final Score** | | **4.00** | **YELLOW** |
| Critical? | NO | | |

**Atlantic Canada**

| Escape parameters | Value | Score | |
|---|---|---|---|
| F6.1 Escape Risk | | 0.00 | |
| F6.1a Recapture and mortality (%) | 30 | | |
| F6.1b Invasiveness | | 2.5 | |
| **C6 Escape Final Score** | | **2.00** | **RED** |
| Critical? | NO | | |

**Brief Summary**

Escapes have been historically-problematic for the salmon aquaculture industry. Improvements in net design and husbandry practices have resulted in a decreasing trend of escaped fish, but hundreds of thousands of salmon still escape from farms around the world every year. In all Atlantic North American salmon farming regions, Code of Containment protocols are in effect and elements generally include requirements for siting, system design, materials strength, maintenance and inspection, stock loss and recovery, and best practices for fish-handling procedures that typically increase the risk of escapement. While Codes are in place and similar in content for each region of the industry, their efficacy and enforcement differ markedly. In Maine, the Code is one part of a multi-faceted Containment Management System mandated by the Maine DEP Net Pen Aquaculture General Permit and has resulted in significantly-improved fish containment. Furthermore, the requirement to maintain a genetic database of hatchery families allows escaped fish to be traced back to the specific production site(s) from which they escaped. Maine-sited farms have not reported a breach of containment since 2003, and in only four years since 2003 were any farm-origin fish identified in rivers emptying into the Gulf of Maine; the 11-year average representation of farm fish amongst all adult returns is 0.24%. In all Canadian regions, Codes of Containment are self-regulated. Reportable escape events in Canada do still occur, and non-reported 'leakage' escapes are likely high, as farm fish representation in the Magaguadavic River over the same 11-year time period has averaged 70.3%.

Potential impacts that escapees may have on their wild counterparts fall primarily into ecological and genetic categories. The most significant competitive and/or disruptive ecological impacts that farm escapees have likely occur in coastal areas and in rivers. Potential genetic impacts are a result of introgression of farm fish gene complexes into those of wild fish. These interactions and their potential population-level effects are particularly significant in Atlantic North America where wild Atlantic salmon populations are a small fraction of their historic levels and are considered endangered in both the US and Canada; just a few hundred wild salmon return to all North American rivers annually. One study concluded: "*available data in eastern NA* (North America) *suggest that the potential risk of both genetic homogenization and a loss of local adaptation in NA wild Atlantic salmon populations due to introgression with farmed fish should be considered high*." In recognition of both this continued risk but also greatly-improved fish containment by farms in Maine (as evidenced by the very low numbers of escapees identified in Maine rivers), the final numerical score for Criterion 6 – Escapes Maine, US is 4 out of 10. Because of the ongoing risk of impact that fish escaping from Canadian-sited farms may have on their wild counterparts (as evidenced by the higher numbers of escapees in Canadian rivers), the final numerical score for Criterion 6 – Escapes for Atlantic Canada is 2 out of 10.

**Justification of Ranking**

**Factor 6.1a. Escape Risk**

Net pen farming systems have an inherently high risk of escapement of fish when compared to land-based systems. In general, due to the typically depressed populations of wild salmon, the numbers of escaped farm-origin salmon are large relative to their wild conspecifics (Thorstad et al. 2008). Improvements in net design and husbandry practices have resulted in a decreasing trend of escaped fish (Thorstad et al. 2008; Olesen et al. 2011; Rust et al. 2014), but hundreds of thousands of salmon still escape from farms around the world every year (Glover et al. 2012). Recent evidence of this still-relevant concern includes the escapement, in the same month (January 2014), of over 200,000 fish between an episode in Norway (55,000 fish) and one in Scotland (154,000 fish), and over 230,000 fish in a single episode in February 2014 in Ireland (Bridson 2014a). In June 2015, approximately 16,000 salmon, averaging 4.5 kg in weight, escaped from a farm in Scotland (Intrafish 2015).

There is a history of escape events in Atlantic North America. It was cited that as early as 1983 (three years after the commencement of commercial salmon farming in the region), 5.5% of salmon returns to the Magagaudavic River, in the middle of the New Brunswick salmon farming industry, were farm-origin escapees (Martin 1984). In 1997, authors citing Martin (1984) reported that farm-origin fish "now dominate(d) the run" (Carr et al. 1997). A literature review (Morris et al. 2008) on the historical (i.e., 1984-2006) prevalence and recurrence of escaped farm-origin salmon in Atlantic North American rivers collated the documented escape events in the region; Table 9, taken directly from Morris et al. (2008), illustrates these events.

**Table 9:** Documented escapes of farmed Atlantic salmon adults and juveniles from sea cages and hatcheries. Table taken from Morris et al. 2008.

| Year | Number | Life stage | Location | Cause |
|---|---|---|---|---|
| 1984 | 5 000 | 1.5–3 kg | East Dover, NS | Vandalism |
| 1994 | 20 000–40 000 | | SW NB | Storm |
| 1994 | | | Eastport, ME | |
| Feb. 1995 | 100 000 | Parr | NL | Storm |
| June 1995 | 20 000 | | Cape Breton, NS | Vandalism |
| 1996 | | | Cape Breton, NS | Vandalism |
| 1996 | | | Libby Island, ME | Storm |
| 1998 | 8 000 | | Annapolis Basin, NS | |
| 1998 | 63 300 | Parr | Jeddore Lake, NL | |
| 1999 | 50 000 | | Annapolis Basin, NS | |
| 1999 | 200 | | Vyse Cove, NL | Handling error |
| 1999 | 6 300 | Smolts | May Cove | Gear failure |
| 2000 | 30 000 maximum | | Tinkers Island, NB | Gear failure |
| 2000 | 100 000–170 000 | 5 lb | Stone Island, ME | Storm |
| 2000 | 13 000 | 2–2.5 lb | Eastport, ME | Boat crash |
| Dec. 2000 | 15 000 | 800 g | Nantucket Island, NB | Storm |
| 2000 total | 175 000 minimum in six escape events | Salmon and rainbow trout | Eastern NA | Storms (3), vandalism (1), boat crash (1), unknown (1) |
| 2001 | 3 000–5 000 | | Eastport, ME | |
| 2001 | 6 | Smolts | Deblois Hatchery, ME | |
| 2003 | 2 000 | | Birch Cove, ME | Storm |
| May 2003 | 6 500 | Adults | NL | |
| 2004 | | 800 g | ME | Storm |
| April–May 2005 | 26 300 | 1.5 and 2.4 kg | Deer Island, NB | Vandalism |
| Aug. 2005 | 20 000 | 400–500 g | St. Andrew's, NB | Vandalism |
| Summer 2005 | Tens of thousands | Adults | Cooke's Aquaculture, NB | Vandalisms (3) |
| Nov. 9, 2005 | 100 000 | 4–5 kg | Cooke's Aquaculture, NB | Vandalism |

These authors (Morris et al. 2008) concluded that 87% of rivers investigated within 300 km of the aquaculture industry have held Atlantic salmon escapees. Furthermore, 80% of these rivers were found to hold farm-origin fish in multiple years, and farm-origin fish were observed in 49% of all conducted searches. Across all searched rivers, it was determined that escaped fish represented a *mean* of 9.2% of all adult salmon in those rivers, essentially twice what has been suggested as a maximum threshold of relative presence by other authors [4% by Taranger et al. (2015) and 5% by Hindar & Diserud (2007)] before there is at least a moderate risk of population-level changes to the wild genotype. In some years in some rivers, however, farm-origin fish represented much more. For at least one year, Morris et al. (2008) report:

- >10% farm fish presence in 12 of 22 rivers;
- >20% farm fish presence in 9 of 22 rivers;

- >80% farm fish presence in 5 of 22 rivers, and;
- 100% farm fish presence in 3 of 22 rivers.

As a result of these losses (and the potential ecological and direct financial implications), in all Atlantic North American salmon farming regions, Code of Containment protocols are now in effect. With the exception of Nova Scotia, each constituency (Maine, New Brunswick, and Newfoundland and Labrador) has a Code specific to its region. Generally, elements of the Codes include requirements for siting, system design (i.e., net pen structure, mooring system, predator exclusion, etc.), materials strength, maintenance and inspection (including strength testing), stock loss and recovery, and best practices for fish-handling procedures that typically increase the risk of escapement (e.g., grading, weight sampling, sea lice counts, transport, well-boat treatments, harvesting, etc.) (MAA 2002; NBSGA 2008; NB DFA 2012; DEP 2014). Regular inspection of the containment structures can help identify potential threats to the integrity of the system and suspicion of a containment breach, and the Codes suggest that farm workers conduct daily surface inspections and contracted divers carry out weekly underwater inspections. Any suspicion of a breach of containment is immediately evaluated by an above- and/or below-water inspection. Upon a confirmed breach, immediate action is taken to secure and re-establish the integrity of the net pen. The state of Maine and each Canadian province have specific qualifiers which dictate the response to a containment breach. In Maine, any known or suspected escape of 25% or more of a cage population and/or more than 50 fish with an average weight of ≥2 kg each must be reported within 24 hours (DEP 2014) to the members of the Escape Reporting Contact List (including representatives from Army Corps of Engineers, Maine DEP, Maine DMR, National Marine Fisheries Service, and US Fish & Wildlife Service). The report includes 14 descriptive pieces of information that detail the scale of escape in terms of number of cages, number of fish, size of fish, medication profile, etc., and the planned response actions. In New Brunswick and Newfoundland, escape events of 100 or more fish from any one cage mandate notification, within 24 hours, of designated officials at DFO and their respective provincial authorities (NBDAA and NBSGA in New Brunswick, DFA in Newfoundland) (NBSGA 2008; NB DFA 2012). Though referenced in an industry-supplied summary of containment efforts, no finalized containment plan specific to Nova Scotia could be obtained. According to industry, terms of Nova Scotian leases require the lessee to comply with the New Brunswick Code of Containment.

While Codes of Containment are in place and similar in content for each region of the industry, their efficacy and enforcement differ markedly. In all Canadian regions, Codes of Containment are essentially self-regulated. From the New Brunswick Code of Containment: "*…farming companies will make all reasonable efforts to conform to the principles and provisions of the Code. As such, primary responsibility for enforcement of the Code resides with the companies themselves*" (NBSGA 2008). In Maine, however, the Code of Containment is one part of a multi-faceted Containment Management System (CMS) mandated by the Maine DEP Net Pen Aquaculture General Permit; "*The permittee must employ a fully functional marine Containment Management System (CMS) designed, constructed, operated, and audited so as to prevent the accidental or consequential escape of fish to open water*" (DEP 2014). CMS plans include a site schematic and description, and procedures and requirements for inventory control, predator control, escape response, storm and unusual event (e.g., vandalism, etc.) management, employee training, auditing, and record keeping. Each farm site is required to develop, get approved, and carry out a site-specific CMS. Plans are based on the design of Hazard Analysis Critical Control Point (HACCP) plans, with Critical Control Points (CCP) identified as locations and processes where escapes could potentially occur and address the specific location, control mechanisms, monitoring procedures, critical limits, appropriate corrective actions, and record keeping and verification procedures. Each active site's CMS plan is annually audited by a third party (approved by the United States Fish and Wildlife Service and National Marine Fisheries Service) and within 30 days of a reportable escape, and corrective actions to deficiencies must be re-audited.

The requirement to develop and hold a CMS plan, and the robustness of its content, has resulted in significantly-more successful fish containment at Maine sites than at Canadian sites. In the eight years preceding the 2003 commencement of the CMS requirement implementation, there were three reported escape events from Maine-sited farms, the largest of which totaled approximately 170,000 fish (M DMR 2008). Since 2003, however, there have been zero reportable escapes from farm sites in Maine. In Canada, while escape events are seemingly less frequent than they may have been in decades past, and in other salmon-farming regions (e.g., Norway, Scotland) currently, they do still occur. The most serious recent event occurred in 2013, when a storm caused pen array anchors to drag and three pens became partially submerged; an estimated 20,000 fish escaped. Two less serious events in 2012 resulted in the cumulative escapement of approximately 12,600 fish.

It must be acknowledged that while reportable, large-scale escape events are now less common in all regions of Atlantic North America, frequent, low-level "trickle" losses are harder to enumerate (Baarøy et al. 2004; Thorstad et al. 2008) and, in other salmon-farming regions, considered to be significant (Skilbrei & Wennevik 2006; Skilbrei & Jørgensen 2010; Taranger et al. 2015). This notion is supported by the fact that a wide size range has been found in escapees in Norway, suggesting the fish came not from single, distinct events, but were repeatedly escaping (Fiske et al. 2005, 2006). Based on the aforementioned reporting requirement thresholds (and the practicalities of actually noticing a given pen's loss of less than a few dozen fish out of approximately 30,000), trickle losses go unreported in Atlantic North America. However, in addition to the requirement for each Maine-sited farm to develop and maintain a CMS plan, an 'identity-marking' requirement exists. Farm-origin fish in all global regions can be identified as such by scale analysis; the concentric circuli of farm-reared fish are nearly or entirely equidistant from one another, whereas those of wild fish display variation caused by seasonal growth rates. In Maine, however, a condition of the DEP General Permit requires all fish stocked in marine net pens to be able to be genetically identified to their specific parental origin. This genetic parentage identification subsequently allows for the identification of the hatchery facility, the hatchery sub-lot, and finally, the marine site in which that sub-lot was stocked; effectively, this identification allows government and industry to know exactly where a farm-origin fish escaped from. When farm-origin fish from net pens in Maine and in Canada are captured in river systems during government and non-government monitoring, the ability for farm-site attribution can help estimate the significance of unreported "leakage" escapees and therefore determine their risk of having deleterious impacts on their wild conspecifics. Figures 15 and 16, based on data obtained from the US Atlantic Salmon Assessment Committee (USSAC 2015, 2014, 2013, 2012…2001) and the Atlantic Salmon Federation (Morris et al. 2008; J Carr, pers. com., unpublished data) illustrate the vast differences in farm-fish representation between select rivers in Maine and in Canada.


**Figure 15:** The relative proportions (bars) and actual numbers of farm-escaped (blue) and wild (orange) Atlantic salmon captured in rivers in the US and Canada from 2000-2014. **(a)** Fish captured in rivers utilized by the Gulf of Maine Distinct Population Segment (GOM DPS), Maine, US. **(b)** Fish captured in the Magaguadavic River, NB, Canada.

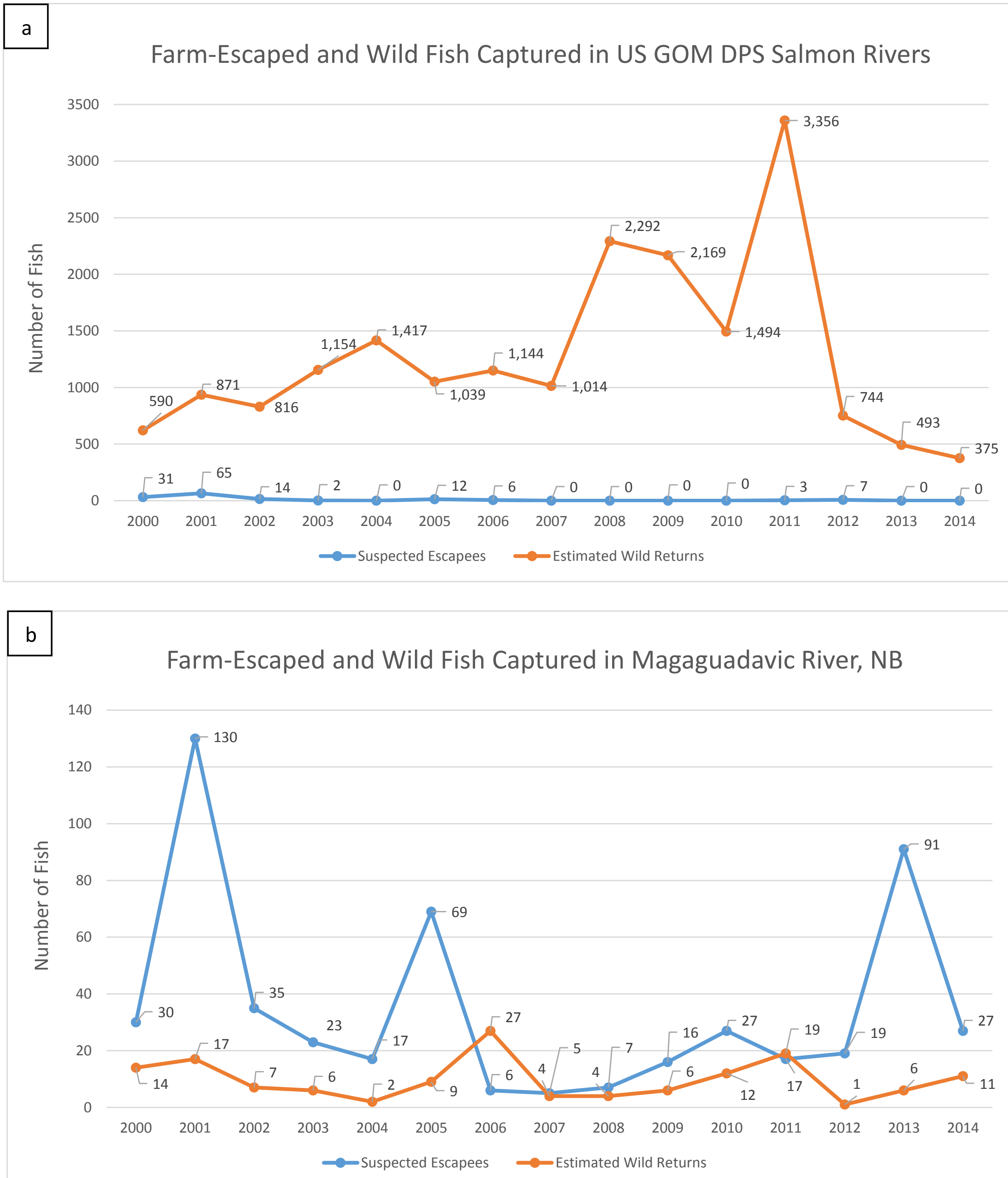



**Figure 16:** The numbers of farm-escaped (blue) and wild (orange) Atlantic salmon captured in rivers in the US and Canada from 2000-2014. **(a)** Fish captured in rivers utilized by the Gulf of Maine Distinct Population Segment (GOM DPS), Maine, US. **(b)** Fish captured in the Magaguadavic River, NB, Canada.

Figures 15a and 16a illustrate the efficacy of the regulatory and management measures employed in Maine-sited farms. While it is acknowledged that the numbers of wild fish returning to rivers of the Gulf of Maine Distinct Population Segment (GOM DPS) are far greater than those returning to the Magaguadavic River in New Brunswick, both the total number of farm escapees and their relative proportion to all fish in these rivers strongly suggests that the CMS requirements for farm sites in Maine do result in more successful fish containment. In seven of the 12 years since the 2003 commencement of the CMS implementation, and six of the last eight years, no farm-origin fish were captured in any GOM DPS rivers (spanning south to north from the Androscoggin River to the St. Croix River). In contrast, farm escapees numbered anywhere from 4 to 91 over the same period in the Magaguadavic River, and actually *outnumbered* wild returnees in all but two of those years (Figures 15b and 16b). Since 2000, farm-origin fish accounted for greater than 60% of all adult fish in the Magaguadavic in 12 of 15 years (Figure 15b). While salmon are highly-roving fish and therefore could theoretically escape from farm sites on one site of the border and enter rivers on the other side, there has been no evidence that farm-origin fish found in Canadian rivers are genetically-attributed to farm sites in Maine.

<u>Conclusion</u>
Escapes have been historically-problematic for the salmon aquaculture industry. In Maine, a requirement to develop and maintain a HACCP-based CMS plan has resulted in significantly-improved containment performance. Maine-sited farms have not reported a breach of containment since 2003, in only four years since 2003 were any farm-origin fish identified in rivers emptying to the Gulf of Maine, and in those years the percentage of farm fish amongst all adult returns never exceeded 1.2%. While the nature of net pens does present a significant level of risk, the initial, unadjusted score for Maine, US for Factor 6.1a, Escape Risk is 3 out of 10 in recognition of greatly-improved containment practices. In contrast, Codes of Containment in Canada are self-regulated. While improvements in infrastructure and husbandry practices have rendered large-scale escape events less common than in decades past, their occasional occurrence and the continued observation (and domination) of farm-origin fish in rivers, likely the result of non-reported chronic losses, still present considerable concern. As a result, the initial, unadjusted score for Factor 6.1a, Escape Risk is 0 out of 10.

**Recapture and Mortality Score (RMS)**
The RMS allows for improvement upon the baseline escape score if it can be demonstrated that escapees are recaptured or do not survive long enough to have deleterious impacts on the ecology of the receiving environment.

In a recent study (Benfey 2015), the following summation made clear the challenges associated with estimating the impact that farm-origin escapees have on the receiving ecosystem:

> "As currently practiced, Atlantic salmon farming can realistically be expected to lead to *some* degree of escapes. Given that: (i) Atlantic salmon are highly mobile and adaptable, (ii) most Atlantic salmon farming takes place in habitats well suited for the survival of escaped fish, and (iii) farmed Atlantic salmon are not sufficiently domesticated to prevent them from surviving, and potentially even thriving, in the

> wild (e.g., Jensen *et al.* 2013; Skilbrei 2013), attempts to recover or eradicate escaped farmed Atlantic salmon (by angling, netting, attraction to traps, poisoning, etc.) are difficult to undertake, will never be fully effective, and cannot be made without some impact on wild Atlantic salmon populations or other species. This difficulty does not preclude the importance of immediate attempts to recover escaped fish in the event of a major release (e.g. Chittenden *et al.* 2011), but it cannot be expected that every fish can be recaptured or killed within a short time of its escape."

<u>Recapture</u>

Because of the intricacies of regulations (e.g., escape reporting, and thus recapture attempts, is mandated only should more than a given number of fish escape), small-scale escapes, as well as those occurring from the aforementioned trickle-losses, will very likely never be incidentally recaptured, as all commercial and recreational fisheries for Atlantic salmon in Maine (USASAC 2015), New Brunswick (DFO 2015b), and Nova Scotia (DFO 2015b) are closed, and a daily retention limit of just two fish is in effect in Newfoundland and Labrador (DFO 2015c). The only practical opportunities for recapture of escaped fish, therefore, are after escape events of reportable volume.

All regions of the industry have pre-approved recapture protocols. In Newfoundland, for example, individual farmers are required to complete and submit a "Recapture Plan and License Application" which indicates how they propose to recapture escapees. The plan must provide detail regarding the individuals responsible for conducting the recapture procedure, the inventory and location of all recapture gear, and the disposal procedure for recaptured fish. It is a requirement that the individuals responsible for recapture complete DFO-approved training for proper deployment and retrieval of gear – gill nets and/or traps in the case of Newfoundland. The recapture response must commence within 24 hours of a containment breach, and gear is to be deployed for seven days and checked for recaptured and bycatch fish at least twice per day. Any bycatch of non-farm origin fish must be released immediately. Though not specified in the provincial-scale Code of Containment for New Brunswick (i.e., NBSGA 2008), a 2011 application for site approval under the Navigable Waters Protection Act (NWPA) for eight sites in BMA 2b states that in the event of an escape, gill nets are deployed with the approval of DFO and are to be "set until they no longer captured farmed salmon" (SIMCorp 2011). While the New Brunswick Code of Containment does specify that the decision to activate the recovery plan is made through discussions between the farm, DFO, and NBDAA, a specific loss threshold for enactment cannot be verified. The Code for farm sites in Maine does not provide information on recapture strategies or protocols.

Though there is a framework in place in some locations of the industry to attempt recapture of farm escapees, the degree of success is less clear. Little research has been done in Atlantic North America, but some research, mostly conducted in Norway, has shown that (under the right conditions) a large proportion of escaped fish can be recaptured. During a study conducted in a Norwegian fjord basin, 40–67% of >1,000 intentionally-released (i.e., "escaped") Atlantic salmon were recaptured (Skilbrei and Jørgensen 2010). Most recaptures occurred within 40 km of the release site and within the first 40 days of release, and the efficacy of gill nets over other gear types supports previous research (Soto et al. 2001; Morton & Volpe 2002). Another, smaller-scale, escape simulation conducted by some of the same authors recaptured 62.5% of released fish (Skilbrei et al. 2010). And while the results of another study (Chittenden et al. 2011) are not comprehensively applicable to the industry in the US and Canada (based on their use of bag net fishing rather than gill net fishing), they do support the importance of capture within the first month of escape, where they recaptured 80% of “escaped” fish. However, two actual escape events occurred in Norway in 2005, with an estimated 500,000 and 95,000 fish escaping, respectively, and had much lower recapture success. In both instances, less than 3% of escaped fish were recaptured (Thorstad et al. 2008 citing Anfinsen 2005, Skilbrei 2006). In at least one of these episodes, however, the organized recapture effort was not formally commenced until two weeks after the escape (Skilbrei 2006; Thorstad et al. 2008). A previous study, where recreational and commercial anglers reported capture of previously-released farm-origin fish, found that less than 5% of those fish were recaptured at all (Hansen 2006).

Studies have shown that significant percentages of “escaped” fish can disperse rapidly – within hours to days – from the aquaculture (i.e. release) site (e.g., Skilbrei & Jørgensen 2010; Skilbrei et al. 2010; Chittenden et al. 2011; Solem et al. 2013; Skilbrei 2013; Skilbrei et al. 2014). While most research has been conducted in Norway, one study conducted in Cobscook Bay, Maine (Whoriskey et al. 2006), a site of Atlantic salmon farming for the industry assessed here, found that surviving escapees dispersed >1 km from the cage site within a few hours and, as a result, were unlikely to be recaptured. They state: “The rapid dispersal of the fish from the release site suggests that efforts to recapture farmed salmon in the event of an escape may not be possible in this high-energy coastal environment and that effective containment strategies are required to safeguard critically endangered salmon populations in the area.” Following the actual escape of >100,000 fish from Canadian-sited net pens in the Bay of Fundy, no fish were recaptured in either of two attempts (Thorstad et al. 2008, referencing Whoriskey, unpublished data). In 2013, after the escapement of approximately 20,000 fish from a farm site in Newfoundland, 1,615 fish – an estimated 8% – were recaptured over the following 18 days.

Ultimately, the significance of trickle-losses, the logistical and physical difficulties of employing a recapture effort, and the evidence presented by research and actual events in Atlantic North America and elsewhere make clear that recapture success of farm escapees is likely very low.

<u>Mortality</u>

There is evidence that mortality of escaped fish is likely much higher than that seen for recapture (Hansen 2002, 2006; Green et al. 2012; Skilbrei 2013). Early research suggested that escapees are initially unfamiliar with their wild environment and that farmed fish may be poorly adapted to foraging and predator avoidance behaviors (McKinnell et al. 1997; Brown & Laland 2001; Fleming & Petersson 2001). Subsequent studies did demonstrate that escaped farm-origin fish may not be effective hunters; Soto et al. (2001), Niklitschek et al. (2011), and Noakes (2011) found that between 40% and 80% of escapees in Chile and British Columbia had empty stomachs (though Arismendi et al. (2012, 2014) concluded that escaped Atlantic salmon may be less successful in their non-native Pacific Ocean than in the Atlantic). While few studies actually propose numerical estimates of mortality, Skilbrei (2013) did, concluding 37% of "escaped" (i.e. released) fish in Norway resulted in mortality within the 3- to 4-month battery life of the acoustic transmitters used in the study.

In Atlantic North America specifically, there is evidence that post-escape mortality may be higher. In the aforementioned study conducted in Cobscook Bay, Maine (Whoriskey et al. 2006) captive-reared fish were intentionally released at two times from a cage site and acoustically tracked for at least 360 days throughout the region. It was concluded that mortality was high—56% in winter (January) and 84% in spring (March)—in the bay and the surrounding coastal region, and that seal predation was the likely cause. Harbor seals and grey seals are common in the region and known to prey on salmon (Hammill & Stenson 2000); their greater abundance in spring and summer than in winter (Jacobs and Terhune 2000) correlates well with increased salmon mortality in January observed by Whoriskey et al. (2006).

Recapture and Mortality Conclusion

Recapture of escapees in Atlantic North America is considered unlikely, and as such, does not mitigate the risk of escapees entering the environment. Mortality is probably markedly higher, though could be highly variable and depend on several factors such as fish size, location, and time of year. While the research cited above suggest that mortality of escapees could be between 35% and 85%, both the size of fish (smolts in Skilbrei et al. 2013) and the number of fish (273 in Whoriskey et al. 2006) may have resulted in higher percentages of mortality by predation than if large numbers of near-to-harvest fish were to escape from commercial aquaculture operations. In recognition of these data *and* their potential limitations, a conservative RMS adjustment of 30% is applied.

The final, adjusted score for Factor 6.1a, Escape Risk, is 5.1 out of 10 for Maine, US, and 3.0 out of 10 for Atlantic Canada.

**Factor 6.1b. Invasiveness**

There is a history of debate regarding the population-level impacts of escaped farmed salmon on their wild counterparts. Generally, potential impacts fall in two, though ultimately related, categories: ecological and genetic.

Ecological impacts are those caused by farm escapees competing with wild fish for resources, namely food, habitat, and spawning mates (Thorstad et al. 2008; Sundt-Hansen 2015). Though little is known about the actual competitive interactions in the greater marine environment (Naylor et al. 2005), it has been shown that salmon survival in the marine environment is not density-dependent and thus, likely under the carrying capacity (Jonsson & Jonsson 2004). This is very probable for salmon native to Atlantic North America, whose populations are severely depleted and not likely to experience conspecific competition for resources at sea, even with the addition of farm escapees. Rather, the most significant competitive and/or disruptive impacts that farm escapees have likely occur in coastal areas and in rivers (Jonsson et al. 1998;

Jonsson & Jonsson 2006). Indeed, research has shown that farm-fish offspring and hybrid offspring from farm-fish/wild-fish crosses display a faster growth rate which likely resulted in the observed displacement from habitat of wild/wild offspring parr (McGinnity et al. 2003). Furthermore, farm-origin fish and farm/wild hybrids are more aggressive at early stages than wild fish (Sundt-Hansen et al. 2015), thereby increasing the potential for wild parr displacement, but have a decreased response to potential predation (Fleming & Einum 1997; Johnsson et al. 2001) and lower overall survival in both freshwater and marine conditions (McGinnity et al. 2003; Fraser et al. 2008). In addition, displaced parr have been shown to grow slower (Bujold et al. 2004), and thus, would be more likely to be preyed upon than if they had not been displaced.

These competitive interactions and their potential population-level effects are particularly unique in Atlantic North America, where wild Atlantic salmon populations are a small fraction of their historic levels. Figure 17 shows Atlantic salmon returns to US rivers and net pen Atlantic salmon production in Maine between 1980 and 2014. In 2014, just 450 Atlantic salmon were estimated to have returned to *all* east coast US rivers – the lowest in the 1991-2014 time series (USASAC 2015). This represents a 26% decrease from 2013 returns (611 fish) and an 89% decrease from the time series-high 2011 returns (4,167 fish). This is in stark contrast to the numbers which allowed for the commercial harvest of 45-90 metric tonnes in the late 1800s and early 1900s (USASAC 2014). The Gulf of GOM DPS, which currently represents the majority of all returns (typically some 68–85%) (USASAC 2015), is listed as "Endangered" and managed under the US Fish & Wildlife Endangered Species Act (ESA); it represents the last naturally-spawning stocks of Atlantic salmon in the US, yet has a 19–75% extinction risk within 80-100 years even when considering the continuation of heavily-relied-upon supplementation of hatchery-raised smolts and fry (NOAA 2015a). Furthermore, the farm sites are located in and/or adjacent to water bodies deemed, as a condition of the ESA listing, "critical habitat" for wild populations (US DOC 2009). In Canada, abundance has experienced a significant historical decline. While more recent assessments (i.e., those for the last three generations) have shown an overall, country-level stabilization, population increases in Labrador have masked a continued decline in other regions. The Committee on the Status of Endangered Wildlife in Canada has listed several designatable population units (DU) – equivalent to the US's DPS grouping – as "Endangered," and some of those – the Outer Bay of Fundy DU, Inner Bay of Fundy DU, and the Nova Scotian Upland DU – are characterized by their use of habitat in which farms have subsequently been sited (Figure 18). The Inner Bay of Fundy DU was first listed as Endangered in 2001, with re-examination and confirmation in 2006 and 2010, and the Outer Bay of Fundy and Nova Scotian Upland DUs were first listed in 2010. Fewer than 200 Inner Bay of Fundy DU individuals were estimated to have returned to their

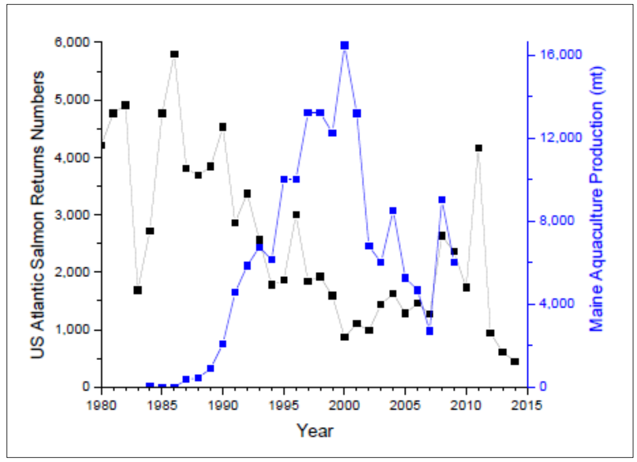



**Figure 17:** Atlantic salmon returns to US rivers (number of adults) and net pen aquaculture production in Maine (metric tonnes) from 1980 to 2014. [Image taken from USASAC (2015)]

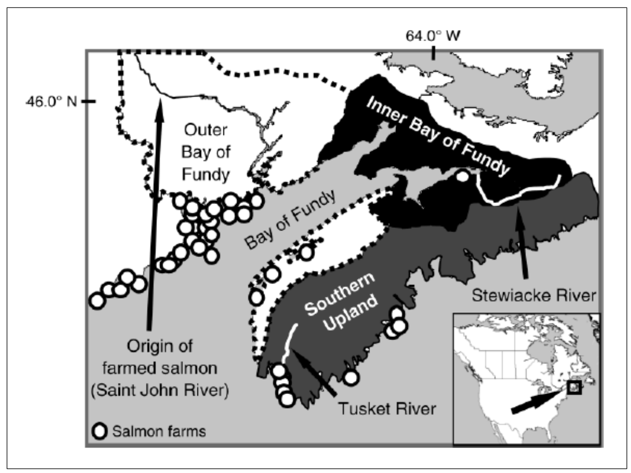



**Figure 18:** Map of the Atlantic salmon Designatable Unit (DU) population segments and the general location of salmon net pen farming sites. [Image taken from Fraser et al. (2010)]

natal waters in 2008 (COSEWIC 2010). As anadromous fish, salmon are contributors to both freshwater and marine ecology, moving nutrients between ecosystems and linking energy flow as prey and as predators within ecosystems. The vulnerability of the Atlantic North American Atlantic salmon population therefore, cannot be overstated.

Potential genetic impacts are a result of introgression of farm fish gene complexes into those of wild fish. Early research demonstrated that while breeding performance of escaped, farm-origin fish is less than that of wild fish (Fleming et al. 1996, 2000), it could nevertheless be adequate *enough* for successful hybridization (Crozier 1993, 2000; Clifford et al. 1998a, 1998b). Research specific to Atlantic North America has confirmed that farm-origin salmon can spawn successfully in area rivers; 20% of redds sampled in a study of the Magaguadavic River, chosen for its location in the center of the New Brunswick salmon-farming industry, contained *only* eggs from farm-origin fish, and an additional 35% contained a mix of eggs from farm-origin fish and wild fish (Carr et al. 1997). Farm fish are well-known to be less genetically diverse than wild fish (Norris et al. 1999; McGinnity et al. 2003, 2004; Morris et al. 2008; Karlsson et al. 2011), and farm/wild hybrids reflect this homogeneity (Fleming et al. 2000; Tufto & Hindar 2003). This genetic introgression of selected-for characteristics [i.e. faster growth rate (Gjøen & Bentsen 1997; Debes & Hutchings, 2014)] into the genotype of wild fish has resulted in lower genetic variability in those wild fish (McGinnity et al. 2004) and the resulting phenotypic traits are likely associated with reduced reproductive success in the wild (Bourret et al. 2011). Ultimately, genetic introgression of farm-origin fish into wild genotypes results in lower overall fitness of those offspring (McGinnity et al. 2003; Fraser et al. 2008; Thorstad et al. 2008; Debes & Hutchings 2014; Yeates et al. 2014). In other salmon-farming regions, there is evidence that genetic introgression can be found at the population level (Skaala et al. 2006, Glover et al. 2012) and some authors have warned that introgression in North America could contribute to future extinction of wild Atlantic salmon (McGinnity et al. 2003; Fraser et al. 2008). Some researchers (Hindar et al. 2006) have concluded, based on models, that a fixed farm-origin fish presence of 20% at spawning would result in "substantial changes (taking) place in wild salmon populations within ten salmon generations." The most recent research (conducted in Norway) suggests that the representation of farm-origin fish among the wild population should not exceed 4% to have low or no risk of population-level genetic impact (Taranger et al. 2015). As stated, some authors have found that farm escapees represent nearly 10% of fish found across *all* Atlantic North American rivers (Morris et al. 2008) and concluded that:

> "Thus, although limited, available data in eastern NA suggest that the potential risk of both genetic homogenization and a loss of local adaptation in NA wild Atlantic salmon populations due to introgression with farmed fish should be considered high."

Sub-regional data, however, demonstrate the significant differences between Maine and Canada. Despite the severely depleted (i.e., endangered) populations of wild Atlantic salmon in Atlantic North America, in GOM DPS rivers, farm-origin fish have averaged 0.24%, and not in any year exceeded 1.2%, of all returning fish since 2003. Farm fish representation in the Magaguadavic over the same time period has averaged 70.3%. Bourret et al. (2011) concluded "homogenization between wild and aquaculture fish…suggests that the wild population of

Magaguadavic River likely suffer from a loss of local adaptation exacerbated by introgression from farmed salmon."

Conclusion

While ecological impacts of escapees in the marine environment is likely low, evidence from other salmon-farming regions verify that competition for space, particularly in coastal and river ecosystems, can have negative impacts on wild fish. Though robust data for farm-origin fish presence in Canada is limited to the Magaguadavic River, monitoring in rivers throughout the Gulf of Maine suggest that competitive interactions there are significantly fewer. The observed genetic introgression of farm-origin genotypes into the wild salmon population is evidence that escapees have indeed competed with wild fish during spawning throughout Atlantic North America. All fish stocked in net pens in Maine and Canada are diploid, mixed-sex fish, and therefore continue to have a considerable possibility of breeding with, and at least attempting to breed (i.e., competing) with, their wild counterparts. Because of the historical genetic introgression but currently very low proportion of farm escapees in GOM rivers, the score for Factor 6.1b, Invasiveness for Maine, US is 3.5 out of 10. Farm-origin fish, at least in the Magaguadavic River, still dominate returning runs and as such, the score for Factor 6.1b, Invasiveness for Canada is 2.5 out of 10.

**Conclusion**

The mandatory Containment Management System (CMS) for Maine-sited farms has resulted in significantly-improved fish containment than in decades past. No reportable escape events have occurred since 2003, and research and Gulf-wide river monitoring suggest that if 'leakage' escapes do occur, mortality is likely high and very few fish return to rivers where interactions with wild salmon are more likely to occur. Though wild Atlantic salmon are listed under the US Endangered Species Act, and there is some potential for further genetic introgression of farm fish into the wild genotype, the near absence of farm escapees in the Gulf of Maine presents a markedly reduced risk ecological impact. In contrast, Codes of Containment in Canada are self-regulated, and while large-scale escape events are less common than in decades past, farm-origin fish are still present in rivers in proportionally-high numbers, likely the result of non-reported chronic losses. The continued vulnerability of net pen systems and the impact that escaped fish may have on their Species At Risk Act-listed wild counterparts represents a high cause for concern.

For Maine, US, Factors 6.1a (5.1 out of 10) and 6.1b (3.5 out of 10) combine in the final scoring table for Criterion 6 – Escapes to give a final numerical score of 4 out of 10.

For Atlantic Canada, Factors 6.1a (3.0 out of 10) and 6.1b (2.5 out of 10) combine in the final scoring table for Criterion 6 – Escapes to give a final numerical score of 2 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 retransmission to local wild species that share the same waterbody.*
- *Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites.*
- *Principle: aquaculture operations pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.*

**Criterion 7 Summary**

**Maine, US**

| Pathogen and parasite parameters | Score | |
|---|---|---|
| C7 Biosecurity | 4.00 | |
| **C7 Disease; pathogen and parasite Final Score** | **4.00** | **YELLOW** |
| Critical? | **NO** | |

**Atlantic Canada**

| Pathogen and parasite parameters | Score | |
|---|---|---|
| C7 Biosecurity | 3.00 | |
| **C7 Disease; pathogen and parasite Final Score** | **3.00** | **RED** |
| Critical? | **NO** | |

**Brief Summary**

Fish grown in net pens are vulnerable to infection by pathogens and parasites in the environment, and as a result of the density with which farm fish are typically reared, the potential for pathogen and parasite amplification within the farm population is high. Both this increased pathogen load and the fact that farms may serve as unnatural temporal reservoirs for disease allow for the possibility for retransmission to wild fish. In the three years 2012-2014, prescriptions were written to treat bacterial kidney disease (BKD), sea lice, and “skin lesions” on farm fish. Sea lice was the most prescribed-for condition, with an annual mean of 86 for an estimated 40 farm sites. From 2009 to 2014, mean numbers of adult female sea lice per fish at New Brunswick-sited farms ranged seasonally from 0.1 to 17. Certain years and certain Bay Management Areas (BMAs), however, have experienced much higher means, sometimes approaching and/or exceeding 50-60 lice per fish. The annual mean number of lice per fish in Maine-sited farms between 2009-2015 ranged from 1.52-12.75, with a six-year mean of 5.5. No regulatory thresholds exist for sea lice loads in Atlantic North America, but these data show that sea lice loads exceed threshold goals set forth in the industry-authored Sea Lice Management and Treatment Plan. Infectious Salmon Anemia (ISA) is a highly virulent viral disease for which no treatment is applied, and in Canada, the presence of pathogenic ISA has been confirmed in 2012, 2013, and 2015. Monthly monitoring reports by the USDA, however, indicate that farms in Maine have been ISA-free since 2006. While there may be a high degree of concern that on-farm diseases could impact vulnerable wild salmon in Atlantic North America, the available evidence to date has shown that such transmission has not occurred. Both returning and outmigrating wild salmon have been found to have no or low levels of sea lice, wild non-salmonids appear to not typically host the louse species most commonly associated with on-farm infections, and there have been no confirmed mortalities due to ISA in wild fish. With the recognition of a lower risk of ISA transmission, and an overall moderate degree of concern for impact to wild fish populations, the final numerical score for Criterion 7 – Disease for Maine, US is 4 out of 10. Because of ongoing incidence of pathogenic ISA in New Brunswick, and a marginally-higher degree of concern for impact to wild fish populations, the final numerical score for Criterion 7 – Disease for Atlantic Canada is 3 out of 10.

**Justification of Ranking**

Fish grown in net pens are inherently vulnerable to infection by pathogens and parasites occurring in the wild. However, as a result of the density with which farm fish are typically reared, the potential for pathogen and parasite amplification within the farm population is high, and both this increased load and the fact that farms may serve as unnatural temporal reservoirs for disease allow for the possibility of retransmission to wild fish (Hammell et al. 2009; Johansen et al. 2011). In regions where aquaculture operations are located in and/or in proximity to habitat important to wild salmon, the expansion of the industry has raised many salmon conservation concerns.

An industry-provided document details the number of therapeutant prescriptions written and the cause for their administration (i.e., what disease or condition they are aiming to treat) for all regions of Atlantic North America in 2012, 2013, and 2014. In the three years 2012-2014, prescriptions were written to treat bacterial kidney disease (BKD), sea lice, and "skin lesions"; Figure 19 illustrates the frequency that prescriptions were written for each of the three conditions. The number of active sites for each of those years was 21 (2012), 27 (2013), and 22 (2014).

Skin Lesions

One of the three conditions reported to have occurred in 2012, 2013, and 2014 was the presence of "skin lesions." Without further data, it cannot be confirmed that any specific pathogen(s) was responsible for causing the lesions. However, given that all of the prescriptions written to treat skin lesions were for antibiotics (Aquaflor®, oxytetracycline, erythromycin, and tribrissen), it can be affirmed that all conditions were bacterial in nature. While a given set of bacterial pathogens are known to affect salmon, the number of different antibiotic products (four) and the scope of potential bacteria that each of them may target (several), there is insufficient data to presume that the lesions were caused by a given bacterium or bacteria. As noted previously, skin lesions were the condition which resulted in the lowest number of prescriptions in each of the three years.

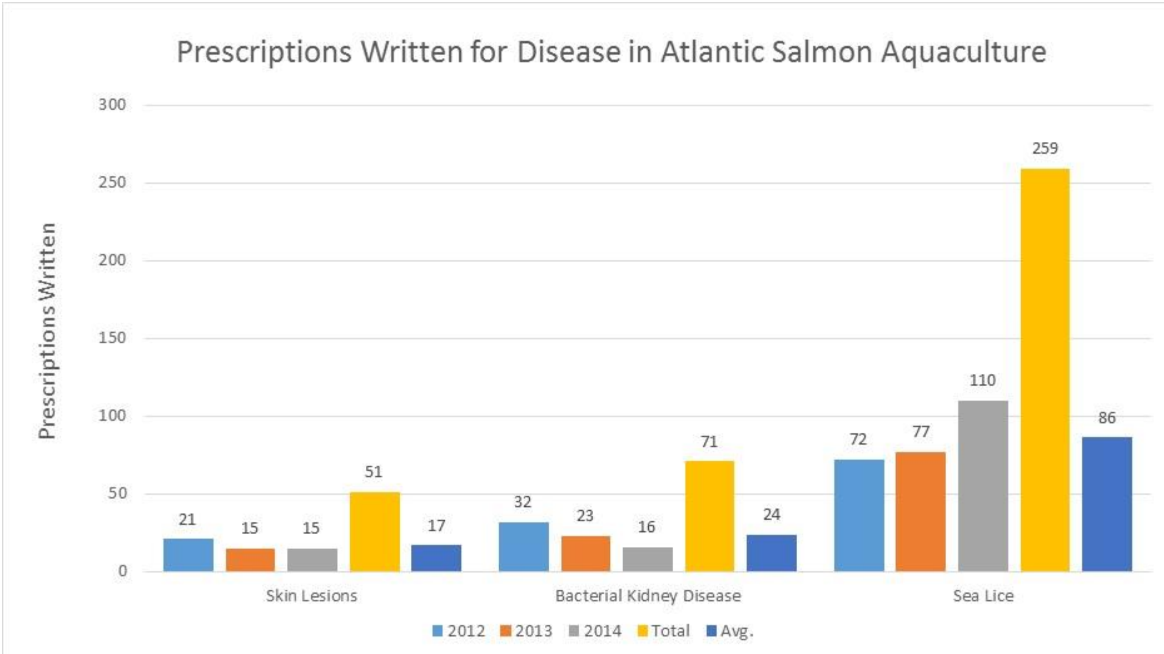



**Figure 19:** The frequency per annum of prescriptions written for each of three disease conditions in Atlantic salmon aquaculture in Atlantic North America for the years 2012, 2013, and 2014. Data from an industry-supplied document.

Bacterial Kidney Disease

Bacterial Kidney Disease (BKD) is caused by the gram-positive bacterium *Renibacterium salmoninarum*. Transmitted both vertically (Fryer & Sanders 1981; Evelyn et al. 1986) and horizontally (Mitchum & Sherman 1981), clinical signs include external lesions, abdomen distention, exophthalmia, the darkening and mottling of the skin, and pallor and swelling of the liver (Wiens 2011; ICES 2015). The kidney itself is plagued with petechial hemorrhages which increase in number as the condition progresses, and in advanced cases, the entire kidney becomes enlarged, pale, and necrotic (Fryer & Sanders 1981; Byrne et al. 1998). In Atlantic North America, a total of 71 antibiotic prescriptions (49 for oxytetracycline, 20 for erythromycin, one for penicillin, and one for florfenicol) were written to treat BKD between 2012 and 2014 (Figure 19). However, the parameters (i.e., dosage, treatment duration, etc.) of each prescription are unknown; estimating the infection and mortality rates, therefore, is not possible. Treatment and control of BKD has been deemed to be difficult (BCCAHS 2010). An excerpt from BCCAHS (2010), a study prepared for DFO to investigate the impacts of BKD on the Canadian salmon farming industry (and included surveys completed by industry representative), states:

> "At saltwater facilities, prevalence ranged from less than 1% (at low prevalence sites) to greater than 5% (at high prevalence sites) with one respondent estimating a prevalence of 30% at his/her highest prevalence saltwater location. Generally, these respondents felt that there was no to some increase in BKD prevalence at freshwater and

> saltwater facilities during the past 5 and 10 years. A decrease in BKD prevalence was noted by several respondents at those sites with the highest BKD prevalence. One respondent with over 15 years of aquaculture experience felt that during his/her early career BKD was a manageable problem, but that as interprovincial fish movements have increased that control and management of this disease has been lost."

The likelihood of BKD transmission (or retransmission) from farm fish to wild fish is ultimately unknown and has been debated. While some researchers (e.g., Halstein and Lindstad 1991, see review by Murray et al. 2011) and the BCCAHS (2010) report concluded that "It is important to make every effort to reduce BKD infection levels in cultured fish from not just a fish welfare perspective, but also from the perspective of reducing point sources of infection that could threaten wild fish," Cubitt et al. (2006) determined that disease transfer from farmed to wild fish had a "very remote chance." Ultimately, BKD transmission from farm fish to wild fish is a small, yet contributing factor to the overall risk of impact.

Infectious Salmon Anemia

Infectious Salmon Anemia (ISA) is an orthomyxovirus viral disease caused by pathogenic strains of Infectious Salmon Anemia Virus (ISAV), and has been known to occur in most salmon-farming regions around the world (Jones et al. 2015), including Norway (Thorud & Djubvik 1988), Scotland (Rodger et al. 1998), the Faroe Islands (Anonymous 2000), and most recently, Chile (Godoy et al. 2008). There has been a history of ISA outbreaks in the Atlantic North American industry. It was first observed (in Atlantic North America) in New Brunswick in 1996 (Mullins et al. 1998), and in Maine a few years later at a farm site less than 5 km from New Brunswick sites experiencing outbreaks (Bouchard et al. 1999, 2001). ISA has subsequently been reported in Nova Scotia, Prince Edward Island, and Newfoundland (CFIA 2014). There is a volume of research and peer-reviewed evidence that demonstrates the virulence of the ISAV can be very high (e.g. Jones et al. 1999; Lovely et al. 1999; Bouchard et al. 2001; McClure et al. 2005; McBeath et al. 2015), with mortality reaching 100% in some cases (McBeath et al. 2015). In Atlantic North America specifically, one early study found more than 75% mortality of ISA-infected fish (Jones et al. 1999), and on-farm realities resulted in the destruction of 7.5 million fish between 1997 and 2003 (Moore 2003; McClure et al. 2005). More recently, data from the Canadian Food Inspection Agency confirms the presence of virulent ISA in 2012, 2013, and 2015 at farm sites in New Brunswick, Nova Scotia, and Newfoundland (CFIA 2014). One Canadian Broadcasting Company (CBC) article from 2012 reported that 800,000 fish were destroyed as a result of two ISA outbreaks (CBC 2012). Though accounting for less than 3% of the industry-reported 30 million fish in the water during 2012, this cull supports the notion that ISA is an ongoing problem for much of the salmon farming industry.

Notably, monthly monitoring reports available from the United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service indicate that the last positive sample of pathogenic ISA from fish stocked in Maine-sited farms occurred in February 2006. This ten-year absence supports the recognition that the risk of Maine-stocked fish transmitting ISA to wild salmon is far less than that for fish stocked at farm sites in Canada.

To reduce the risk of the on-farm development of ISA, vaccines are available and utilized, though strain-specificity is often important and vaccines are known to not be 100% effective, including for ISA (Gomez-Casado et al. 2011; Wolf et al. 2014). Indeed, outbreaks occur every year in Norway (Nylund et al. 2007; Rimstad et al. 2011; Aamelfot et al. 2014), and as mentioned above, still occur regularly in parts of Atlantic North America. In addition, a complex relationship exists between the pathogen, the host, and environmental conditions (Gustafson et al. 2007a, 2007b; McBeath et al. 2015), which makes forecasting outbreaks difficult. The mechanisms and pathways of transmission are many (Nylund et al. 1994; McClure et al. 2005), including the demonstration that sea lice can be horizontal ISA transmitters (Nylund et al. 1993, 1994; Rolland & Nylund 1998). These factors, coupled with the aforementioned regular presence and high virulence of ISA in Atlantic North America, justify the presence of a considerable degree of concern, particularly in Canada. But while there is risk that ISA transmission from farm fish to wild fish could occur and (especially given the endangered status of wild Atlantic salmon) some population-level impact could result, it must be acknowledged that there has been no confirmed mortality of wild fish due to ISA in any salmon-farming region to date. In addition, it has been noted that modern biosecurity and integrated disease management strategies, such as those employed in Atlantic North America (e.g., frequent and regular monitoring, area-based coordinated fallowing, etc.), significantly mitigate the risk of large-scale ISA outbreak (Jones et al. 1999, Murray et al. 2010, Lyngstad et al. 2011, Werkman et al. 2011, Murray 2013), and that if these measures are employed, transmission to wild fish and subsequent disease in the wild population is "unlikely" (Jones et al. 2015).

<u>Sea Lice</u>

Sea lice are ectoparasitic copepods that feed on the mucus, skin, and blood of host fish (Jones et al. 2012). First acknowledged in print as early as 1750 (Berland & Margolis 1983; Torrissen et al. 2013), sea lice are thought to have co-evolved with salmonids (DFO 2014b) and have long been known to occasionally result in morbidity and mortality in wild Atlantic salmon in Atlantic North America (e.g., White 1940). Much attention has been focused on their role in net pen salmon aquaculture, and as early as the 1970s, sea lice have impacted Atlantic salmon aquaculture production (Brandal et al. 1976; Brandal & Egidius 1977; Johannessen 1978). The first sea lice epidemic in Atlantic Canada occurred in 1994 (Hogans 1995; Chang et al. 2011b). In Atlantic North America, two species of sea lice infect host salmon – *Lepeophtheirus salmonis* and *Caligus elongates* – with *L. salmonis* being the more pathogenic of the two (Boxaspen 2006; Jones et al. 2012; DFO 2014b). There are several thorough reviews of the (complex) life cycle and environmental tolerances of sea lice (e.g., Rae 1979; Pike & Wadsworth 1999; Boxaspen & Naess 2000; Boxaspen 2006; Chang et al. 2011b; Torissen et al. 2013), but clinical signs of infection on host fish include the physical attachment of chalimus-stage larvae and the subsequent epidermal erosion, exposure of the dermis and, if the condition is severe, exposure of skeletal muscle (Torissen et al. 2013; Burridge & Van Geest 2014). Infections can result in mortality, often the result of secondary pathogens or inability to adequately osmoregulate (Wooten et al. 1982; Pike 1989; Torissen et al. 2013; DFO 2014b).

When salmon are stocked in marine net pens, they are free of sea lice, but may become infected from wild fish or other farmed fish (DFO 2014b). Research has demonstrated that once fish inside the net pen acquire sea lice, there is significant potential for the infestation to be amplified and/or harbored (Birkeland 1996; Pike & Wadsworth 1999; Tully et al. 1993, 1999; Bjørn et al. 2001; Bjørn & Finstad 2002; Pearsall 2008), and subsequently re-transmitted to their wild counterparts (Tully & Whelan 1993; Costelloe et al. 1996, 1998a,b; McVicar 1997, 2004; Todd et al. 1997; Mackenzie et al. 1998; Tully et al. 1999; Bjørn et al. 2001; Bjørn & Finstad 2002; Marshall 2003; Morton & Williams 2004; Morton et al. 2004; McKibben & Hay 2004; Penston et al. 2004; Carr & Whoriskey 2004; Krkošek et al. 2005; Johansen et al. 2011; Torrissen et al. 2013; DFO 2014b), particularly when those fish pass by lice-infected farm sites during migrations. While the threat to adult salmon returning to their natal stream to spawn is likely low (due to the osmotic shock to, and resultant detachment of, sea lice), the threat to outmigrating smolts is more significant. In Atlantic North America specifically, the situation is unique, considering the endangered status of the wild Atlantic salmon population. Chang et al. (2011b) completed a thorough review of the presence, and real and potential implications, of sea lice on farmed salmon in southwestern New Brunswick. Ultimately, they conclude that:

> "For salmon of the Magaguadavic and St. Croix Rivers, whose migration routes pass near salmon farms, both as postsmolts and adults, their numbers are currently very low, so the risk of large-scale transfer of sea lice from wild to farmed salmon would be expected to be low. However, the potential for sea louse transfer from farmed salmon to wild salmon of these rivers would be high, especially if there are high sea louse numbers on fish in salmon farms located near the wild salmon migration routes."

In contrast to British Columbia, where regulations require that farms maintain lice abundance below a threshold of three motile stage (adult and pre-adult stages) *L. salmonis* between March and June (Saksida et al. 2007), and Norway, where adult female lice must be maintained below either 0.5 or 1 individuals per fish depending on time of year (Torrissen et al. 2013), neither Atlantic Canada nor Maine have specific regulations limiting the number of sea lice on farmed salmon. Rather, industry-determined thresholds prompt farm-site management action (i.e., the administration of chemotherapuetants) (ACFFA 2010; Brewer-Dalton 2013). Since sea lice numbers are dependent on several factors (i.e., fish size, life stage of sea lice, season, water temperature, salinity, farm site location, etc.), treatments are applied when sea lice target thresholds are approached, but on a case-by-case basis that considers those factors (DFO 2014b). According to an industry-authored Sea Lice Management and Treatment Plan for 2015, the target thresholds are as follows:

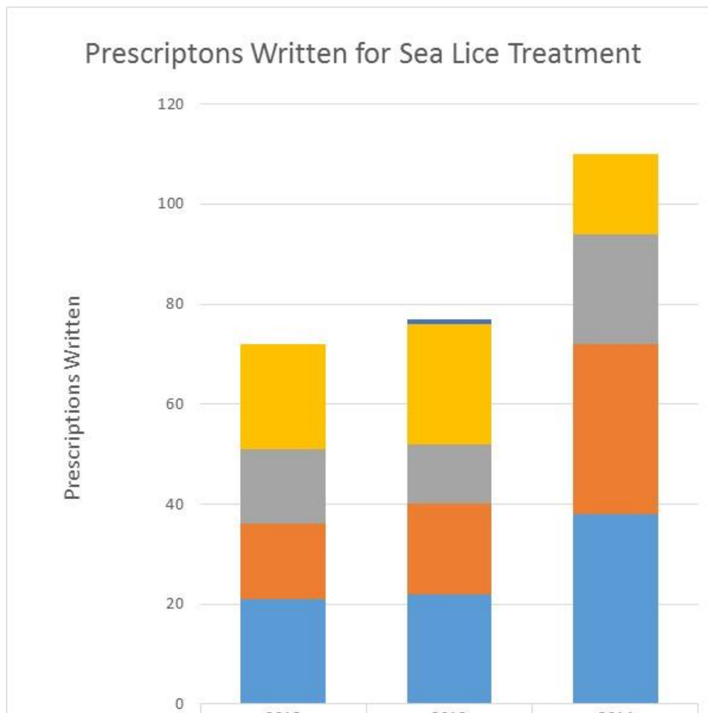
- Smolts
  - <u>Entry to September</u> → average of < 1 *L. salmonis* of any stage per fish, and avoidance of gravid females
  - <u>September to December</u> → average of < 2 *L. salmonis* of any stage per fish, and avoidance of gravid females
- 2nd Year Fish
  - <u>January to September</u> → average of < 5 *L. salmonis* of any stage per fish

- <u>September to harvest</u> → average of < 10 *L. salmonis* of any stage per fish

According to the Management and Treatment Plan, sea lice monitoring is typically conducted monthly when sea surface temperature (SST) is below 5° C and weekly when SST is above 5° C. Monitoring is carried out by the removal of (typically) five fish from each of four to six net pens within a farm site. The pens chosen to be sampled may be randomly selected or selected based on their position relative to other pens at the site (e.g., those on the tidal flood side are preferentially selected). Feed is administered to the cage to attract fish to the surface and fish are dip-netted out to be inspected, a method determined to be adequate in describing sea lice abundance at the cage/farm level (DFO 2014b)

According to an industry-authored document, sea lice was, by far, the most prescribed-for condition in the Atlantic North American salmon farming industry, with a total of 259 prescriptions written between 2012 and 2014 and an annual mean of 86 (Figures 19, 20) for an average of 24 active sites. The number of prescriptions written in 2012 and 2013, and thus the presumed sea lice load, were similar (72, 77, respectively). The number of prescriptions written in 2014 (110) suggest a higher prevalence and/or intensity of sea lice on farm fish.

Data regarding mean sea lice loads on salmon grown in all New Brunswick-sited farms is available for the years 2009-2014, and is illustrated in Figure 21. While precise numbers cannot be determined (as the Figure was taken directly from an industry-authored document and without accompanying raw data), it can be approximated that the *mean* number of adult female sea lice on farm fish was between 0.1 and 17; the raw data would show that the actual range observed is outside that mean. As a time series, the data do not exhibit significant inter-annual variation or a clear increasing or decreasing trend, though counts in 2009 and 2010 were each mostly higher than those in other




| | 2012 | 2013 | 2014 |
|---|---|---|---|
| Calicide | 0 | 1 | 0 |
| Noromectin | 21 | 24 | 16 |
| SLICE | 15 | 12 | 22 |
| Salmosan | 15 | 18 | 34 |
| Interox Paramove | 21 | 22 | 38 |

**Figure 20:** The products prescribed and their relative contribution to the total prescriptions to treat sea lice in the Atlantic North American salmon farming industry in 2012, 2013, and 2014. Data from an industry-authored document.

years; 2010 was noted as a particularly "bad" year for sea lice infestation throughout New Brunswick, most likely a result of a decreased efficacy of SLICE® (and likely increased sea surface temperature). Within any year, sea lice numbers were typically at their lowest in the first and second weeks of June, but generally increased thereafter through the summer and fall.

In

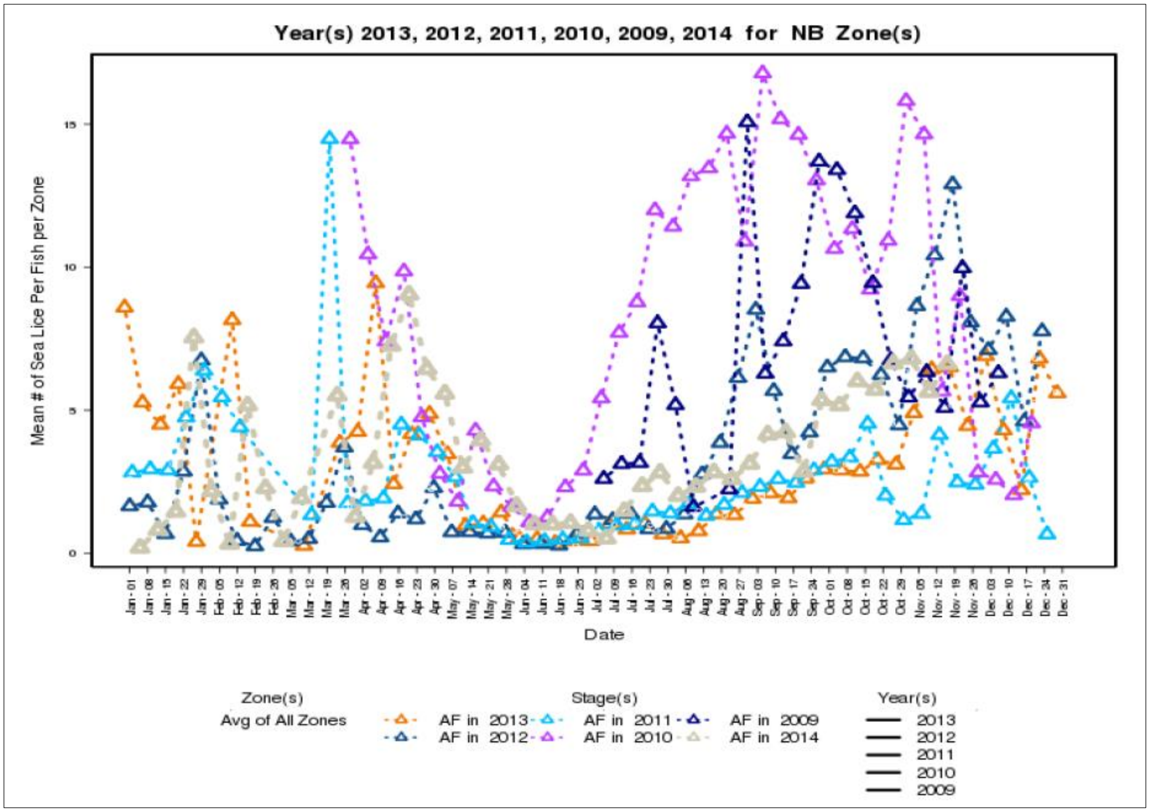



**Figure 21:** The mean number of adult female sea lice on net pen-reared Atlantic salmon in New Brunswick, by year, from 2009-2014. Image taken from ACFFA 2014b.

November, the mean number of adult female sea lice on farm fish appears to be approximately 5 per fish. Certain years and certain Bay Management Areas (BMAs), however, have indeed experienced much higher means (Figure 22). In 2010 for example, the number of adult female sea lice on farm fish grown in sites within BMA-3A and 3B approached and/or exceeded 50-60 per fish. The load was similar again in 2012 for fish in BMA-2A and 2B. Demonstrating the continued struggle to completely control sea lice, fish grown in 2014 at sites within BMA-1 were markedly more affected by sea lice than fish grown in other BMAs that year, and with a mean number of sea lice around 10 per fish through most of the year, experienced a mean of more than 40 per fish in early November. These data also show that actual mean sea lice loads exceed threshold goals set forth in the industry-authored Management and Treatment Plan. As mentioned, those targets included individuals of *all* life stages, while the monitoring counts presented here were for adult female sea lice only.

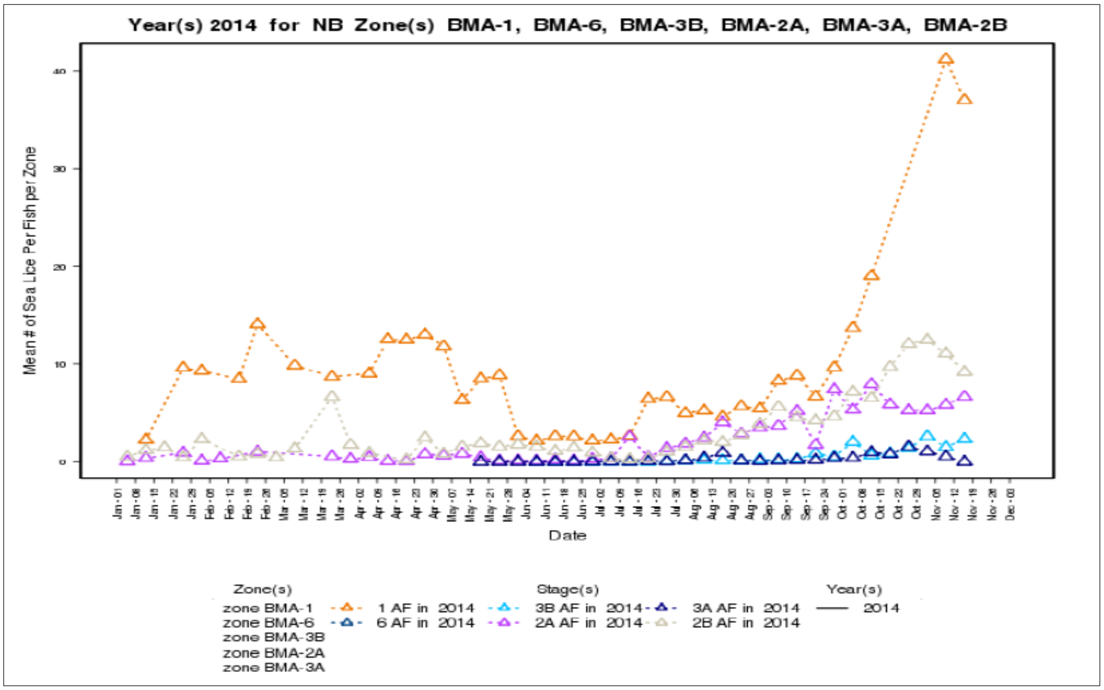



**Figure 22:** The mean number of adult female sea lice on net pen-reared Atlantic salmon in New Brunswick, according to Bay Management Area (BMA), in 2014. Image taken from ACCFA 2015.

Aggregated, averaged data for sea lice intensity at Maine-sited farms from 2009 to 2015 was obtained from an industry representative (Table 10). While lacking the granularity (e.g., seasonal variation) of data obtained for New Brunswick-sited farms, these reported annual means do not appear significantly different than those which could be inferred (but not calculated with precision) from New Brunswick data. For example, the reported average number of *L. salmonis* per fish in Maine-sited farms in 2014 is 3.08. The intra-annual variation of lice per fish in New Brunswick for the same year (grey triangles and trendline in Figure 21) suggests that the province's average number is likely similar. For 2013, it would appear that farm fish in Maine experienced heavier lice loads than fish in New Brunswick; while the annual average for sites in Maine is reported to have been 12.76 lice per fish, all 53 sampling averages for New Brunswick were less than 10 lice per fish.

**Table 10:** The annual average number of *L. salmonis* sea lice (of all stages) per farm-reared Atlantic salmon at farm sites in Maine from 2009 to 2015. Data obtained from industry.

| Year | Avg. *L. salmonis* per fish |
|---|---|
| 2009 | 1.52 |
| 2010 | 4.58 |
| 2011 | 2.62 |
| 2012 | 12.39 |
| 2013 | 12.76 |
| 2014 | 3.08 |
| 2015 | 1.58 |
| **MEAN** | **5.50** |

To demonstrate the severity of sea lice infestation in the Atlantic North American salmon farming industry, Figure 23 illustrates the mean number of adult female sea lice per farmed salmon in Norway for each year from 2002 to present (data collection for 2015 is still ongoing). As mentioned, regulations in Norway require that sea lice be maintained below 0.5 adult females per fish. It is clear that not only has the Norwegian salmon-farming industry been generally successful at meeting those requirements, but the prevalence of sea lice in Norway is markedly less than that in New Brunswick and Maine.

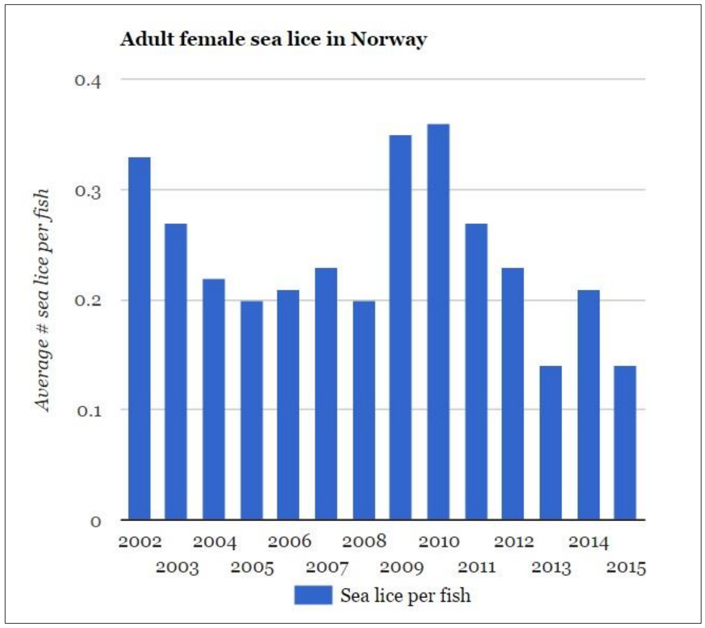



**Figure 23:** Mean number of adult female sea lice per farmed salmon in Norway, from 2002 to present. Graph taken directly from www.mysalmon.no, using data from lusedata.no.

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 (Aas et al. 2011). The research that has been conducted, however, 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 seaward-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 *Caligus* sp. lice in 2001, 2002, and 2003, respectively, at a maximum intensity of 1 louse per fish. In addition, they 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 Grimnes 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."

Research is underway to better understand sea lice dynamics in the Gulf of Maine. Some investigation has shown that, despite residency in the vicinity of salmon farms, wild non-salmonids hosted only *C. elongatus* (Jensen 2013, Jensen et al. 2015), the louse species not typically associated with on-farm infections. And, supporting the findings by Lacroix and Knox (2005), Bricknell et al. (2015) determined “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.”

While evidence for linkages between lice on farms and lice on wild fish may be stronger in other salmon-farming regions, research suggests that the sea lice burdens observed on farmed salmon in Atlantic North America may not actually present as great a risk to their wild counterparts as has been hypothesized, and there is growing and recent recognition of this notion. 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 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.”

**Conclusion**

The high levels of sea lice on farm fish in New Brunswick and Maine, the inherently open nature of net pens, the siting of farms in and/or adjacent to migration routes of wild Atlantic salmon, and the highly vulnerable status of wild Atlantic salmon in the region collectively justify a high degree of concern that on-farm diseases could impact wild salmon in Atlantic North America. In Canada, this risk is increased due to the continued presence of ISA. However, the available evidence to date has shown that such transmission has not occurred. Both returning and outmigrating wild salmon have been found to have no or low levels of sea lice, and there have been no confirmed mortalities due to ISA in wild fish. It would be expected that if diseases on farms resulted in morbidity and mortality of their wild counterparts, evidence of such impact would have been found in the 30+ years of salmon farming in the region. With the recognition of a lower risk of ISA transmission, and an overall moderate degree of concern for impact to wild fish populations, the final numerical score for Criterion 7 – Disease for Maine, US is 4 out of 10. Because of ongoing incidence of pathogenic ISA in New Brunswick, and a marginally-higher degree of concern for impact to wild fish populations, the final numerical score for Criterion 7 – Disease for Atlantic Canada is 3 out of 10.

# Criterion 8: Source of Stock; Independence from Wild Fisheries

***Impact, unit of sustainability and principle***

- *Impact: the removal of fish from wild populations for ongrowing to harvest size in farms*
- *Sustainability unit: wild fish populations*
- *Principle: aquaculture operations use eggs, larvae, or juvenile fish produced from farm-raised broodstocks, use minimal numbers, or source them from demonstrably sustainable fisheries*

**Criterion 8 Summary**
**Maine, US and Atlantic Canada**

| Source of stock parameters | Score | |
|---|---|---|
| C8 % of production from hatchery-raised broodstock or natural (passive) settlement | 100 | |
| **C8 Source of stock Final Score** | **10.00** | **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 final numerical score for Criterion 8 – Source of Stock for all of Atlantic North America is 10 out of 10.

**Justification of Ranking**
Importation of salmon and salmon eggs of European strain into Canada and the US is prohibited. As such, 100% of production in both Canada and Maine (J Wiper, pers. com.; J Lewis, pers. com.) is supported by domestic, hatchery-raised broodstock. It was communicated by an industry representative that 13 hatcheries are owned by the growout operator, and supplied with eggs from at least two broodstock facilities (at least one each in the US and Canada). An additional 4-6 hatcheries are contracted to supplement egg and fry production.

Broodstock in Maine are reported to be at least ten generations removed from wild populations (S Belle, pers. com.; J Lewis, pers. com.), and the lineage originated from the Gulf of Maine stock (J Lewis, pers. com.). According to an industry-authored document, hatchery production in Canada is in its fourth generation of selection. Overall, the industry is considered to be independent of wild fisheries for both broodstock and juveniles.

Of additional note, the endangered status of wild Atlantic salmon in both the US and Canada prohibit the removal of such fish from the ecosystem with few exceptions. Furthermore, captive breeding programs for Atlantic salmon have been successful in selecting for characteristics advantageous to aquaculture that are less pronounced in wild genotypes; it is therefore in the industry's best interest to maintain production reliant on successive generations of captive fish.

The final numerical score for Criterion 8 – Source of Stock for all of Atlantic North America is 10 out of 10.

# Criterion 9X: Wildlife and Predator Mortalities

*A measure of the effects of deliberate or accidental mortality on the populations of affected species of predators or other wildlife.*

*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 9X Summary**
**Maine, US and Atlantic Canada**

| Wildlife and predator mortality parameters | Score | |
|---|---|---|
| **C9X Wildlife and predator mortality Final Score** | **-5.00** | **YELLOW** |
| Critical? | NO | |

**Brief Summary**
At all 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 tensioned predator control nets and pen-top bird netting. Active, non-lethal measures permitted include the use of acoustic deterrent devices, but their use is infrequent. Lethal action against predators or wildlife is prohibited. Interactions between wildlife and net pen operations do, however, occasionally result in mortality. In 2013, birds (18), sharks (10), seals (7), and tunas (4) each had direct interactions that resulted in mortality. Though mortalities are occasional, a lack of species-specificity for reported mortalities and the presence of endangered and/or threatened tuna and shark species presents a moderate concern. The final numerical deduction score for Criterion 9X – Wildlife Mortalities for all of Atlantic North America is -5 out of -10.

**Justification of Ranking**
As net pen operations are sited in the natural environment and are open to wildlife, there is a significant potential for direct and indirect interaction between such wildlife and the fish being grown in the pens.

At all 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.). 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 Canada, the DFO Marine Mammal Regulations govern the provision of a license for lethal action and reporting (MOJ 2015; J Wiper, pers. com.). Daily monitoring of the condition of net pens and their control measures is required and are employed by farm staff.

Despite the control measures, lethal interactions with wildlife are known to occur. Adopted from an industry-authored statement, Table 11 details the predator and wildlife interactions that resulted in mortality in 2013 across all sites in the industry. While the specific species within each family of wildlife are unknown (though could be assumed), birds were the most commonly affected, followed by sharks, seals, and tunas. Though mortalities are occasional, a lack of species-specificity for reported mortalities and the presence of endangered and/or threatened tuna and shark species (e.g., Atlantic bluefin tuna, white sharks, porbeagle sharks, and shortfin mako sharks are all COSEWIC-listed) presents a moderate concern. It is unknown if this 2013 data is typical or atypical of the frequency and distribution of lethal interactions between wildlife and net pen aquaculture systems in Atlantic North America.

**Table 11:** The interactions between predators and wildlife that resulted in mortality across all salmon-farming operations in Atlantic North American in 2013. Data from an industry-authored statement.

| **Lethal Interactions Between Wildlife and Net Pen Aquaculture Systems in 2013** | | | |
|---|---|---|---|
| **Birds** | **Seals** | **Sharks** | **Tunas** |
| 18 | 7 | 10 | 4 |

Indirect interaction may occur when products of the farming operation are discharged into the ambient environment. Though the production/use and potential impacts of that production/use are assessed in previous criteria (i.e., fish waste in Criterions 2 and 3, chemical use in Criterion 4, disease transmission in Criterion 7), there is evidence of some impacts to wildlife which are outside the purview of those criteria or are similarly applicable here. For example, in November and December of 2009, it was determined that the use of a non-registered cypermethrin-based therapeutant was used in an attempt to control sea lice at farm sites in southwestern New Brunswick. Administered as a bath treatment, the pesticide was released into ambient waters post-use. Crustaceans are particularly sensitive to cypermethrin (hence its use for sea lice control), and as a result of this release, lobster mortalities occurred. The causation was evidenced by the presence of cypermethrin in dead lobsters found in lobster traps positioned in proximity to the active farm sites, and in salmon sampled from those sites. An *Agreed Statement of Facts* (Anonymous, undated) document for a case brought against the farm sites' controlling company confirms that, for a given site, it was "the only possible source of the Cypermethrin detected in the dead lobsters." While the cumulative number of lobster mortalities is unknown, one site of mortality was estimated at "several hundred pounds."

Nearly 12,000 mt of lobsters were harvested in New Brunswick in 2010 (and more than 67,000 mt in all of Atlantic Canada) (DFO 2013), so the mortalities resulting from cypermethrin toxicity were nearly negligible, and as such, do not contribute to the scoring of Criterion 9X. Rather, they represent the reality and significance of the relationship between a farm and the ecosystem in which it is sited, and the importance of abiding by the principles and regulations that govern that relationship.

**Conclusion**

Wildlife mortalities are considered to occur beyond exceptional cases. Though they do occur in relatively low numbers, a lack of species-specificity for reported mortalities and the presence of endangered and/or threatened tuna and shark species presents a moderate concern. The final numerical deduction score for Criterion 9X – Wildlife Mortalities for all of Atlantic North America is -5 out of -10.

# Criterion 10X: Escape of Unintentionally Introduced Species

*A measure of the escape risk (introduction to the wild) of alien species other than the principle farmed species unintentionally transported during live animal shipments.*

*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 and Atlantic Canada**

| Escape of unintentionally introduced species parameters | Score | |
|---|---|---|
| F10Xa International or trans-waterbody live animal shipments (%) | 9.00 | |
| F10Xb Biosecurity of source/destination | 8.00 | |
| **C10X Escape of unintentionally introduced species Final Score** | **-0.20** | **GREEN** |

**Brief Summary**
While the industry arguably operates within the same general waterbody, some international movement of eggs and/or live fish occurs between the US and Canada. Biosecurity at the source (hatcheries) is high with serial inspections to affirm the absence of diseases and pathogens of concern necessary for a facility to obtain a Fish Health Certificate. However, some facilities operate as flow-through systems and only mechanical filtration is used for effluent water treatment, ultimately having the potential to transfer unwanted organisms (e.g., pathogens) to the destination environment. The final score for Criterion 10X – Escape of Unintentionally Introduced Species for all of Atlantic North America is a deduction of -0.2 out of -10.

**Justification of Ranking**
The transfer of fish without inspection, quarantine, or other appropriate management procedures can lead to the simultaneous introduction of unintentional accompanying animals, pathogens, and parasites (other than principal farmed species) during live animal shipments. As an exceptional criterion, 10X generates a negative (i.e., deductive) score which is subtracted from the final score for those aquaculture operations where it is a concern.

**Factor 10Xa International or Trans-waterbody Live Animal Shipments**
The industry is supported by at least 19 land-based facilities for the production of fish (eggs, fry, parr, or smolts) to be stocked in net pens. The majority (15) are located in Canada, and the majority of those are in New Brunswick. While it was communicated by an industry representative that all fish stocked in net pens in Newfoundland are spawned, hatched, and grown in Newfoundland-based facilities, there is some otherwise interprovincial and international movement of eggs and hatched fish. According to industry-supplied data, of fish of the 2012, 2013, 2014, and 2015 year classes stocked in net pens, 5.4%, 2.5%, 0.3%, and 0%, respectively, were moved internationally; all movements were from Maine-sited facilities to

Canadian-sited facilities. Despite the decreasing trend of international fish movements, it is unknown how permanently its current absence is. As such, the score for Factor 10Xa is 9 out of 10.

**Factor 10Xb Biosecurity of Source/Destination**

A score for Factor 10Xb is attained by assessing the level of biosecurity of the source – in this case, hatcheries – and the destination – in this case, growout net pen facilities. The higher of the two scores (i.e., the most biosecure) is used when calculating the overall risk of shipping live fish across international boundaries or between water bodies.

<u>Source</u>

All hatcheries supplying eggs are freshwater, land-based facilities. Industry-authored documents suggest that approximately half of the hatcheries are designed as recirculating systems and some as single-pass flow-through systems. Influent water is likely subject to mechanical filtration and ultraviolet radiation for the control of pathogens entering the hatchery (Piper 1982), but specific details of the treatment scheme of influent water could not be obtained for the industry. A summary of effluent water treatment reports the employment of settlement ponds and/or drum filters as the dominant treatment regimes. An industry-authored biosecurity plan for freshwater facilities was submitted to Seafood Watch, and it details requirements for the movements of personnel and equipment, disinfection procedures, and record keeping.

The international and interprovincial movement of eggs and fish is highly regulated. Less information regarding the regulations for transport into Maine could be obtained, but the *Fish Health Protection Regulations* document, authored by DFO Canada, details the requirements and protocols for egg and fish movement into and within Canada (DFO 1984). First authored in 1984, the most recent revision was completed in 2011.

The importation into Canada from an international location of eggs and live fish is governed by the Canadian Food Inspection Agency (CFIA). Before importation, an application obtained from the CFIA must be submitted and approved, affirming the absence of notifiable diseases for each susceptible species. For live Atlantic salmon, those are: infectious pancreatic necrosis (IPN); Ceratomyxosis (*Ceratomyxa shasta*); infectious haematopoietic necrosis (IHN); infectious salmon anemia (ISA); Whirling disease (*Myxobolus cerebralis*); viral haemorrhagic septicaemia (VHS); Gyrodactylosis (*Gyrodactylus salaris*); and Salmonid alphavirus. For Atlantic salmon germplasm they are: IPN; IHN; ISA; VHS; and Salmonid alphavirus. A permit is generated by the affirmation of disease absence, and importation may occur. There are some pathogens not listed by the CFIA but are of concern to DFO according to the *Fish Health Protection Regulations* and are therefore required to be not present in imported eggs or fish.

Within Canada, interprovincial movement of eggs and live fish requires a permit for the origin facility and is governed by DFO. To obtain a permit, the facility must acquire a Fish Health Certificate which affirms they have met the requirements set forth in the *Fish Health Protection Regulations* document, including having had four consecutive satisfactory inspections by a Fish

Health Officer not less than 90 but not more than 270 days apart. The following pathogens are of concern and assayed for: the redmouth bacterium (*Yersinia ruckeri*); the furunculosis bacterium (*Aeromonas salmonicida*); the protozoans causing whirling disease (*Myxobous cerebralis*) and ceratomyxosis (*Ceratomyxa shasta*); the viruses causing VHS, IHN, IPN, and ISA; and other pathogens considered to be notifiable, such as the bacterial kidney disease bacterium (*Renibacterium salmoninarum*). In addition to the four consecutive satisfactory inspections required to obtain a Fish Health Certificate, there is a requirement for once-annual (for facilities using groundwater or a fish-free water source) or twice-annual (for facilities using surface water) inspections to occur after the Certificate is granted (DFO 1984). Valid Fish Health Certificates were obtained for 11 hatchery facilities, confirming both compliance with regulations and the absence of pathogens required to be assayed for.

<u>Destination</u>
Growout net pens are considered a 'High Risk' system. Though escapes of farmed fish – including those internationally- or trans-waterbody transported – is considered relatively low and discussed in Criterion 6, this Criterion (10X) assesses *unintentional* introductions, namely pathogens and parasites. Because receiving facilities are not required to verify the pathogen status of shipped eggs and/or fish, and because net pens are open to the environment, there would be considerable concern for the unintentional introduction of pathogens from one waterbody to another.

The biosecurity of the freshwater facilities (i.e., the source of animal movements) is high, with demonstrated compliance with regulations, though some facilities operate as flow-through systems and only mechanical filtration is used for effluent water treatment. The biosecurity at net pen sites is markedly lower. Therefore, a score of 8 out of 10 for the source is used in the overall calculation of risk for Factor 10Xb.

**Conclusion**
Factor 10Xa: International or Trans-waterbody Live Animal Shipments received a score of 9 out of 10. Factor 10Xb: Biosecurity of the Source/Destination received a score of 8 out of 10 (for Source). The final numerical deduction for Criterion 10X – Escape of Unintentionally Introduced Species for all of Atlantic North America is -0.2 out of -10.

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# Appendix 1–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. Yellow cells represent data entry points.

## State of Maine, US

### Criterion 1: Data Quality and Availability

| **Data Category** | **Relevance (Y/N)** | **Data Quality** | **Score (0-10)** |
|---|---|---|---|
| Industry or production statistics | *Yes* | 10 | 10 |
| Effluent | Yes | 7.5 | 7.5 |
| Locations/habitats | Yes | 10 | 10 |
| Chemical use | Yes | 7.5 | 7.5 |
| Feed | Yes | 7.5 | 7.5 |
| Escapes, animal movements | Yes | 7.5 | 7.5 |
| Disease | Yes | 5 | 5 |
| Source of stock | Yes | 10 | 10 |
| Predators and wildlife | Yes | 2.5 | 2.5 |
| Other – (e.g., GHG emissions) | No | Not relevant | n/a |
| **Total** | | | **67.5** |

| | | |
|---|---|---|
| **C1 Data Final Score** | 7.50 | GREEN |

### Criterion 2: Effluents

| | | |
|---|---|---|
| **C2 Effluent (Evidence-Based) Final Score** | 5.00 | YELLOW |

## Criterion 3: Habitat

### Factor 3.1. Habitat Conversion and Function

| | |
|---|---|
| F3.1 Score | **7** |

### Factor 3.2a. Regulatory or management effectiveness

| Question | Scoring | Score |
|---|---|---|
| 1–Is the farm location, siting and/or licensing process based on ecological principles, including an EIAs requirement for new sites? | Mostly | 0.75 |
| 2–Is the industry's total size and concentration based on its cumulative impacts and the maintenance of ecosystem function? | Moderately | 0.5 |
| 3–Is the industry's ongoing and future expansion appropriate locations, and thereby preventing the future loss of ecosystem services? | Moderately | 0.5 |
| 4–Are high-value habitats being avoided for aquaculture siting? (i.e., avoidance of areas critical to vulnerable wild populations; effective zoning, or compliance with international agreements such as the Ramsar treaty) | No | 0 |
| 5–Do control measures include requirements for the restoration of important or critical habitats or ecosystem services? | Moderately | 0.5 |
| | | 2.25 |

### Factor 3.2b Siting regulatory or management effectiveness

| Question | Scoring | Score |
|---|---|---|
| 1–Are enforcement organizations or individuals identifiable and contactable, and are they appropriate to the scale of the industry? | Yes | 1 |
| 2–Does the farm siting or permitting process function according to the zoning or other ecosystem-based management plans articulated in the control measures? | Moderately | 0.5 |
| 3–Does the farm siting or permitting process take account of other farms and their cumulative impacts? | Moderately | 0.5 |
| 4–Is the enforcement process transparent - e.g., public availability of farm locations and sizes, EIA reports, zoning plans, etc.? | Mostly | 0.75 |
| 5–Is there evidence that the restrictions or limits defined in the control measures are being achieved? | Mostly | 0.75 |
| | | 3.5 |

| | |
|---|---|
| **F3.2 Score (2.2a*2.2b/2.5)** | **3.15** |

| | | |
|---|---|---|
| **C3 Habitat Final Score** | **5.72** | **YELLOW** |
| | Critical? | NO |

## Criterion 4: Evidence or Risk of Chemical Use

| Chemical Use parameters | Score | |
|---|---|---|
| C4 Chemical Use Score | 1.00 | |
| **C4 Chemical Use Final Score** | **1.00** | **RED** |
| Critical? | NO | |

## Criterion 5: Feed

### Factor 5.1. Wild Fish Use

Factor 5.1a – Fish In : Fish Out (FIFO)

| | |
|---|---|
| Fishmeal inclusion level (%) | 6.43 |
| Fishmeal from byproducts (%) | 24.06 |
| % FM | 4.882942 |
| Fish oil inclusion level (%) | 8.59 |
| Fish oil from byproducts (%) | 32.01 |
| % FO | 5.840341 |
| Fishmeal yield (%) | 22.5 |
| Fish oil yield (%) | 5 |
| eFCR | 1.69 |
| FIFO fishmeal | 0.37 |
| FIFO fish oil | 1.97 |
| Greater of the 2 FIFO scores | 1.97 |
| **FIFO Score** | **5.06** |

Factor 5.1b – Sustainability of Source Fishery

| | |
|---|---|
| SSWF | -2 |
| SSWF Factor | -0.35042046 |

| | |
|---|---|
| **F5.1 Wild Fish Use Score** | **4.67** |

### Factor 5.2. Net Protein Gain or Loss

| **Protein INPUTS** | |
|---|---|
| Protein content of feed | 40.17 |
| eFCR | 1.69 |
| Feed protein from NON-EDIBLE sources (%) | 75.44 |
| Feed protein from EDIBLE CROP sources (%) | 16.4 |

| Protein OUTPUTS | | |
|---|---|---|
| Protein content of whole harvested fish (%) | | 17.5 |
| Edible yield of harvested fish (%) | | 60 |
| Non-edible byproducts from harvested fish used for other food production | | 99 |
| | | |
| Protein IN | | 13.49 |
| Protein OUT | | 17.43 |
| **Net protein gain or loss (%)** | | 29.22 |
| | Critical? | NO |
| **F5.2 Net protein Score** | **10.00** | |

**Factor 5.3. Feed Footprint**

Factor 5.3a – Ocean area of primary productivity appropriated by feed ingredients per ton of farmed seafood

| | |
|---|---|
| Inclusion level of aquatic feed ingredients (%) | 15.02 |
| eFCR | 1.69 |
| Average Primary Productivity (C) required for aquatic feed ingredients (ton C/ton fish) | *69.7* |
| Average ocean productivity for continental shelf areas (ton C/ha) | *2.68* |
| **Ocean area appropriated (ha/ton fish)** | 6.60 |

Factor 5.3b – Land area appropriated by feed ingredients per ton of farmed seafood

| | |
|---|---|
| Inclusion level of crop feed ingredients (%) | 35 |
| Inclusion level of land animal products (%) | 42 |
| Conversion ratio of crop ingredients to land animal products | *2.88* |
| eFCR | 1.69 |
| Average yield of major feed ingredient crops (t/ha) | *2.64* |
| **Land area appropriated (ha per ton of fish)** | 1.00 |

| | |
|---|---|
| **Value (Ocean + Land Area)** | **7.60** |

| | |
|---|---|
| **F5.3 Feed Footprint Score** | **7.00** |

| | | |
|---|---|---|
| **C5 Feed Final Score** | **6.59** | **GREEN** |
| | Critical? | **NO** |

## Criterion 6: Escapes

### Factor 6.1a. Escape Risk

| | |
|---|---|
| Escape Risk | **3** |

| **Recapture & Mortality Score (RMS)** | |
|---|---|
| Estimated % recapture rate or direct mortality at the escape site | 30 |
| Recapture & Mortality Score | 0.30 |
| **Factor 6.1a Escape Risk Score** | **5.1** |

### Factor 6.1b. Invasiveness

Part A – Native Species

| | |
|---|---|
| **Score** | 0 |

Part C – Native and Non-native Species

| **Question** | **Scoring** | **Score** |
|---|---|---|
| Do escapees compete with wild native populations for food or habitat? | To some extent | 0.5 |
| Do escapees act as additional predation pressure on wild native populations? | No | 1 |
| Do escapees compete with wild native populations for breeding partners or disturb breeding behavior of the same or other species? | Yes | 0 |
| Do escapees modify habitats to the detriment of other species (e.g., by feeding, foraging, settlement or other)? | No | 1 |
| Do escapees have some other impact on other native species or habitats? | No | 1 |
| | | 3.5 |

| | |
|---|---|
| **F 6.1b Score** | **3.5** |

| | | |
|---|---|---|
| **Final C6 Score** | **4.00** | **YELLOW** |
| | Critical? | **NO** |

## Criterion 7: Disease; pathogen and parasite interactions

| **Pathogen and parasite parameters** | | **Score** | |
|---|---|---|---|
| C7 Biosecurity | | 4.00 | |
| **C7 Disease; pathogen and parasite Final Score** | | **4.00** | **YELLOW** |
| Critical? | | NO | |

### Criterion 8: Source of Stock; independence from wild fisheries

| Source of stock parameters | Score | |
|---|---|---|
| C8 % of production from hatchery-raised broodstock or natural (passive) settlement | 100 | |
| **C8 Source of stock Final Score** | **10** | **GREEN** |

### Criterion 9X: Wildlife and predator mortalities

| Wildlife and predator mortality parameters | Score | |
|---|---|---|
| **C9X Wildlife and Predator Final Score** | **-5.00** | **YELLOW** |
| Critical? | NO | |

### Criterion 10X: Escape of unintentionally introduced species

| Escape of unintentionally introduced species parameters | Score | |
|---|---|---|
| F10Xa International or trans-waterbody live animal shipments (%) | 9.00 | |
| F10Xb Biosecurity of source/destination | 8.00 | |
| **C10X Escape of unintentionally introduced species Final Score** | **-0.20** | **GREEN** |

## Atlantic Canada

### Criterion 1: Data Quality and Availability

| Data Category | Relevance (Y/N) | Data Quality | Score (0-10) |
|---|---|---|---|
| Industry or production statistics | *Yes* | 10 | 10 |
| Effluent | Yes | 7.5 | 7.5 |
| Locations/habitats | Yes | 10 | 10 |
| Chemical use | Yes | 7.5 | 7.5 |
| Feed | Yes | 7.5 | 7.5 |
| Escapes, animal movements | Yes | 5 | 5 |
| Disease | Yes | 5 | 5 |

| | | | |
|---|---|---|---|
| Source of stock | Yes | 10 | 10 |
| Predators and wildlife | Yes | 5 | 5 |
| Other – (e.g., GHG emissions) | No | Not relevant | n/a |
| **Total** | | | **65** |

| | | |
|---|---|---|
| **C1 Data Final Score** | 7.22 | GREEN |

## Criterion 2: Effluents

| | | |
|---|---|---|
| **C2 Effluent (Evidence-Based) Final Score** | 5.00 | YELLOW |

## Criterion 3: Habitat

### Factor 3.1. Habitat Conversion and Function

| | |
|---|---|
| F3.1 Score | **7** |

### Factor 3.2a. Regulatory or management effectiveness

| Question | Scoring | Score |
|---|---|---|
| 1–Is the farm location, siting and/or licensing process based on ecological principles, including an EIAs requirement for new sites? | Mostly | 0.75 |
| 2–Is the industry's total size and concentration based on its cumulative impacts and the maintenance of ecosystem function? | Moderately | 0.5 |
| 3–Is the industry's ongoing and future expansion appropriate locations, and thereby preventing the future loss of ecosystem services? | Moderately | 0.5 |
| 4–Are high-value habitats being avoided for aquaculture siting? (i.e., avoidance of areas critical to vulnerable wild populations; effective zoning, or compliance with international agreements such as the Ramsar treaty) | No | 0 |
| 5–Do control measures include requirements for the restoration of important or critical habitats or ecosystem services? | Moderately | 0.5 |
| | | 2.25 |

### Factor 3.2b Siting regulatory or management effectiveness

| Question | Scoring | Score |
|---|---|---|
| 1–Are enforcement organizations or individuals identifiable and contactable, and are they appropriate to the scale of the industry? | Yes | 1 |
| 2–Does the farm siting or permitting process function according to the zoning or other ecosystem-based management plans articulated in the control measures? | Moderately | 0.5 |
| 3–Does the farm siting or permitting process take account of other farms and their cumulative impacts? | Moderately | 0.5 |
| 4–Is the enforcement process transparent–e.g., public availability of farm locations and sizes, EIA reports, zoning plans, etc.? | Mostly | 0.75 |
| 5–Is there evidence that the restrictions or limits defined in the control measures are being achieved? | Mostly | 0.75 |
| | | 3.5 |

| | |
|---|---|
| **F3.2 Score (2.2a*2.2b/2.5)** | **3.15** |

| | | |
|---|---|---|
| **C3 Habitat Final Score** | **5.72** | **YELLOW** |
| | Critical? | NO |

## Criterion 4: Evidence or Risk of Chemical Use

| Chemical Use parameters | Score | |
|---|---|---|
| C4 Chemical Use Score | 1.00 | |
| **C4 Chemical Use Final Score** | **1.00** | **RED** |
| Critical? | NO | |

## Criterion 5: Feed

### Factor 5.1. Wild Fish Use

Factor 5.1a – Fish In : Fish Out (FIFO)

| | |
|---|---|
| Fishmeal inclusion level (%) | 6.43 |
| Fishmeal from byproducts (%) | 24.06 |
| % FM | 4.882942 |
| Fish oil inclusion level (%) | 8.59 |
| Fish oil from byproducts (%) | 32.01 |
| % FO | 5.840341 |
| Fishmeal yield (%) | 22.5 |
| Fish oil yield (%) | 5 |
| eFCR | 1.69 |
| FIFO fishmeal | 0.37 |
| FIFO fish oil | 1.97 |
| Greater of the 2 FIFO scores | 1.97 |
| **FIFO Score** | **5.06** |

Factor 5.1b – Sustainability of Source Fishery

| | |
|---|---|
| SSWF | -2 |
| SSWF Factor | -0.35042046 |

| | |
|---|---|
| **F5.1 Wild Fish Use Score** | **4.67** |

### Factor 5.2. Net Protein Gain or Loss

| **Protein INPUTS** | |
|---|---|
| Protein content of feed | 40.17 |
| eFCR | 1.69 |
| Feed protein from NON-EDIBLE sources (%) | 75.44 |
| Feed protein from EDIBLE CROP sources (%) | 16.4 |
| **Protein OUTPUTS** | |

| | |
|---|---|
| Protein content of whole harvested fish (%) | 17.5 |
| Edible yield of harvested fish (%) | 60 |
| Non-edible byproducts from harvested fish used for other food production | 99 |
| | |
| Protein IN | 13.49 |
| Protein OUT | 17.43 |
| **Net protein gain or loss (%)** | 29.22 |

| | | |
|---|---|---|
| | Critical? | NO |
| **F5.2 Net protein Score** | **10.00** | |

**Factor 5.3. Feed Footprint**

Factor 5.3a – Ocean area of primary productivity appropriated by feed ingredients per ton of farmed seafood

| | |
|---|---|
| Inclusion level of aquatic feed ingredients (%) | 15.02 |
| eFCR | 1.69 |
| Average Primary Productivity (C) required for aquatic feed ingredients ton C/ton fish) | *69.7* |
| Average ocean productivity for continental shelf areas (ton C/ha) | *2.68* |
| **Ocean area appropriated (ha/ton fish)** | 6.60 |

Factor 5.3b – Land area appropriated by feed ingredients per ton of farmed seafood

| | |
|---|---|
| Inclusion level of crop feed ingredients (%) | 35 |
| Inclusion level of land animal products (%) | 42 |
| Conversion ratio of crop ingredients to land animal products | *2.88* |
| eFCR | 1.69 |
| Average yield of major feed ingredient crops (t/ha) | *2.64* |
| **Land area appropriated (ha per ton of fish)** | 1.00 |

| | |
|---|---|
| **Value (Ocean + Land Area)** | **7.60** |

| | |
|---|---|
| **F5.3 Feed Footprint Score** | **7.00** |

| | | |
|---|---|---|
| **C5 Feed Final Score** | **6.59** | **GREEN** |
| | Critical? | **NO** |

## Criterion 6: Escapes

### Factor 6.1a. Escape risk

| | |
|---|---|
| Escape Risk | **0** |

| Recapture & Mortality Score (RMS) | |
|---|---|
| Estimated % recapture rate or direct mortality at the escape site | 30 |
| Recapture & Mortality Score | 0.30 |
| **Factor 6.1a Escape Risk Score** | **3.0** |

### Factor 6.1b. Invasiveness

Part A – Native Species

| | |
|---|---|
| **Score** | 0 |

Part C – Native and non-native species

| Question | Scoring | Score |
|---|---|---|
| Do escapees compete with wild native populations for food or habitat? | Yes | 0 |
| Do escapees act as additional predation pressure on wild native populations? | To some extent | 0.5 |
| Do escapees compete with wild native populations for breeding partners or disturb breeding behavior of the same or other species? | Yes | 0 |
| Do escapees modify habitats to the detriment of other species (e.g., by feeding, foraging, settlement or other)? | No | 1 |
| Do escapees have some other impact on other native species or habitats? | No | 1 |
| | | 2.5 |

| | |
|---|---|
| **F 6.1b Score** | **2.5** |

| | | |
|---|---|---|
| **Final C6 Score** | **2.00** | **RED** |
| | Critical? | **NO** |

## Criterion 7: Disease; pathogen and parasite interactions

| Pathogen and parasite parameters | | Score | |
|---|---|---|---|
| C7 Biosecurity | | 3.00 | |
| **C7 Disease; pathogen and parasite Final Score** | | **3.00** | **RED** |
| Critical? | | NO | |

## Criterion 8: Source of Stock; independence from wild fisheries

| Source of stock parameters | Score | |
|---|---|---|
| C8 % of production from hatchery-raised broodstock or natural (passive) settlement | 100 | |
| **C8 Source of stock Final Score** | **10** | **GREEN** |

## Criterion 9X: Wildlife and predator mortalities

| Wildlife and predator mortality parameters | Score | |
|---|---|---|
| **C9X Wildlife and Predator Final Score** | **-5.00** | **YELLOW** |
| Critical? | NO | |

## Criterion 10X: Escape of unintentionally introduced species

| Escape of unintentionally introduced species parameters | Score | |
|---|---|---|
| F10Xa International or trans-waterbody live animal shipments (%) | 9.00 | |
| F10Xb Biosecurity of source/destination | 8.00 | |
| **C10X Escape of unintentionally introduced species Final Score** | **-0.20** | **GREEN** |