Atlantic salmon

Salmo salar

Image © Monterey Bay Aquarium

British Columbia, Canada

Net Pens

December 6, 2021

Seafood Watch Consulting Researcher

Disclaimer

About Seafood Watch®

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

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

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

Guiding Principles

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

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

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

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

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

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

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

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

Final Seafood Recommendation

Atlantic salmon

Salmo salar

British Columbia, Canada

Marine net pens

Criterion	Score	Rating	Critical?
C1 Data	7.50	Green	n/a
C2 Effluent	5.00	Yellow	No
C3 Habitat	6.93	Green	No
C4 Chemicals	2.00	Red	No
C5 Feed	4.09	Yellow	No
C6 Escapes	5.00	Yellow	No
C7 Disease	0.00	Red	Yes
C8X Source of stock	0.00	Green	No
C9X Wildlife mortalities	-2.00	Green	No
C10X Introduction of secondary species	-3.20	Green	n/a
Total	25.32		
Final score (0-10)	3.62		

OVERALL RATING

Final Score	3.62
Initial rating	Yellow
Red criteria	2
Interim rating	Red
Critical Criteria?	No

Final Rating
Red

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

Summary

The final numerical score for Atlantic salmon (*Salmo salar*) farmed in marine net pens in British Columbia, Canada is 3.62 out of 10. With two red criteria (Chemical Use and Disease), the final rating is red and a recommendation of Avoid.

Executive Summary

British Columbia (BC) on Canada's Pacific coast currently produces approximately 85,000 to 90,000 metric tons (mt) of farmed Atlantic salmon each year (88,874 mt in 2019). Although this is small in comparison to (for example) Norway's 1.3 million mt, farmed salmon is BC's largest food and beverage export, and BC is a major source of farmed salmon in the United States. The industry is concentrated in the area between Vancouver Island and the mainland from the northern Georgia Strait through Queen Charlotte Sound, and on the west coast of Vancouver Island. Approximately 60 to 80 salmon farm sites are active at any one time.

Uncertainty in the degree of impact resulting from interactions between farmed and wild salmon continues to be a key characteristic of the industry's development in BC. Wild Pacific salmon are found throughout BC's coastal waters and are considered essential to life by First Nations, but many wild salmon populations are in decline throughout their range (not just in areas with salmon farms), with significant numbers categorized as threatened or endangered. In other major salmon farming countries such as Norway and Scotland, farmed salmon greatly outnumber the wild population, and while the opposite is true for BC as a whole, farmed salmon also likely outnumber their diminished wild counterparts in some areas. In many cases, farming areas coincide with important wild salmon migratory corridors, and while it is clear that salmon farms have not caused the widespread declines in wild salmon populations (i.e., in areas with and without salmon farming), any substantial contributions to their local declines or inhibitions of their recovery must be considered.

This Seafood Watch assessment includes criteria covering impacts associated with effluent, habitats, wildlife and predator interactions, chemical use, feed production, escapes, introduction of non-native organisms (other than the farmed species), disease, the source stock, and general data availability[1].

Salmon farming globally, including BC, has good data availability compared to most other aquaculture sectors, and in BC specifically there is a large amount of information available from the industry, the government and from peer reviewed research on many aspects of production and its impacts. Public reporting by companies associated with the Aquaculture Stewardship Council certification scheme has also increased data availability (e.g., sea lice numbers on wild fish). Nevertheless, some data categories are limited in functional timeliness (i.e., the data may be extensive, but delays in publication limit their immediate value to the industry, managers, or researchers), or are aggregated and lacking specificity. Some important types of data (e.g., sea lice bioassays to determine the development of resistance to pesticide treatments) are not made publicly available. The continued controversial nature of some key impacts in BC highlights the ongoing challenge of drawing robust conclusions with the available data and research. Overall, there is a large amount of information and research available with which to

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[1] The full Seafood Watch aquaculture criteria are available at: https://www.seafoodwatch.org/about-us/our-standards/standard-for-aquaculture

assess the industry, and the current state of knowledge is generally well understood. The score for Criterion 1 – Data is 7.5 out of 10.

Salmon farms discharge large quantities of waste nutrients and – as net pen systems open to the environment – depend on coastal waterbodies to assimilate them. Using evidence from dated studies conducted in BC and more recent research and reviews from other major salmon farming regions, the potential for soluble nutrients from salmon farms in BC to exceed the local or waterbody carrying capacity is low. For seabed impacts, on average 85% of farms in BC comply with the regulatory thresholds (80% in 2019), but farms clearly have a substantial cyclical impact in the immediate farm area during the production/fallow cycle. There is no evidence of cumulative impact at the waterbody or regional scale, and the seabed impacts are temporary in the context that they could recover with an extended fallow or cessation of production (noting that they typically do not recover fully during normal fallow periods). In most years, more than 10% of the sampled farms in BC exceed the government-mandated benthic limits at peak biomass, and the sites in these cases are not allowed to be restocked until they return to compliance. With sufficient data available, the Evidence-Based Assessment method has been used, and while there is no evidence of cumulative impacts at the waterbody or regional, the number of sites exceeding the regulatory thresholds is considered to be more than occasional. The final score for Criterion 2 – Effluent is 5 out of 10.

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

The regulatory systems and their enforcement for siting, licensing, and for managing impacts to the habitats in which salmon farms are located, continues to be that set out by DFO in the Fishery (General) Regulations, the Pacific Aquaculture Regulations, and the Aquaculture Activities Regulations. Nevertheless, with regard to the consent of First Nations to site salmon farms in their territory, and following their consultation, 17 farms in the Broughton Archipelago and 19 farms in the Discovery Islands must move or close by 2023 and mid-2022 respectively. With regard to the specific habitat impacts of the floating net pens considered here, the DFO system includes some aspects of the physical structure, but their application to all the potential impacts of the site infrastructure and operation, and particularly potential cumulative impacts across multiple sites, are not clear. The literature indicates that the realization of any or all of these potential impacts does not significantly impact the functionality of the ecosystems in which farms are sited, and more basically, the siting of net pen arrays does not result in habitat conversion in the same way that, for example, pond construction does. The removal of farm infrastructure would rapidly restore baseline biophysical processes. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management and enforcement system is broadly effective. The final score for Criterion 3 – Habitat is of 6.93 out of 10.

Antimicrobial use varies each year according to the treatment needs but has declined substantially since the peaks of the late 1990s (noting that much of this decline was due to the industry's transition from farming Chinook salmon to Atlantic salmon in the mid-2000s, with the former species requiring higher uses of antimicrobials). The publication of data by DFO is somewhat delayed (2019 data is the latest available as of September 2021) but GSI data show antimicrobial use in 2020 was relatively low at 53 g/mt of production, compared to approximately 140 g/mt in 2018. Approximately half of active sites are treated with antimicrobials each year in BC, with 52% and 54% of active sites receiving an antimicrobial treatment in 2018 and 2019 respectively (i.e., 48% and 46% of sites respectively received no antimicrobial treatments). Two antimicrobial types are used – oxytetracycline and florfenicol – both of which are listed as highly important for human medicine by the WHO. Approximately 1 in 10 active sites are treated each year with oxytetracycline, and half the sites are treated with florfenicol. A simple averaging across all active BC sites indicates a three-year average of 1.3 antimicrobial treatments per site per year from 2018 to 2020, but with a focus on treatments of small fish soon after entry to seawater (for mouth rot – *T. maritimum)* (and therefore relatively small amounts of antimicrobial used per treatment), the median treatment number per treated site was three treatments (using 2018 and 2019 DFO data). This indicates that while many sites are not treated, those that are treated have multiple treatments per year.

The industry follows prudent use guidelines for antimicrobials and complies with the recommendations of the WHO Guidelines on Use of Medically Important Antimicrobials in Food-producing Animals. However, the limited availability of data on antimicrobial resistance or efficacy monitoring, or other relevant research in BC, limits the ability to understand how the industry's antimicrobial use patterns (i.e., approximately half the sites receiving no treatments, and the other half receiving multiple treatments) drive or contribute to the presence or development (if any) of antimicrobial resistance. The industry considers the antimicrobial treatments to still be extremely efficacious after decades of antibiotic usage to treat fish when required.

The use of pesticides of environmental concern (i.e., emamectin benzoate, EB, and hydrogen peroxide) in BC is currently less than once per year per site. While the impacts of their use in BC are not yet fully understood, the available evidence indicates that significant impacts are likely to be constrained to an area commonly accepted as an “allowable zone of effect”, similar to that impacted by organic enrichment. While increased tolerance (i.e., resistance) to EB has been slow to develop in BC compared to other regions and the industry uses a variety of alternatives, reduced efficacy of EB treatments is increasingly being reported. It is an area of concern to follow. Overall, the open nature of the net pen production system provides no barrier to infection from environmental pathogens, and while many sites are not treated with antimicrobials, the three-year average number of treatments per site has been 1.3 and the median number of treatments at treated sites has been three in the most recent DFO data years (2018-2019). As such, the use of antimicrobials that are highly important for human medicine at >1 treatment per site per year is a high concern and the final score for Criterion 4 – Chemical Use is 2 out of 10.

An approximate feed composition of key ingredients was supplied by two BC feed companies via the BCSFA. Additional data from salmon farming company reports and reference feeds in the academic literature were also used to represent BC salmon feeds. Performance results were verified against public reporting where possible (e.g., GSI). With total fishmeal and fish oil inclusions of 5.2% and 10.5% respectively, modest use of fish oil from by-product sources, and an eFCR of 1.3, from first principles 1.56 mt of wild fish must be caught to produce the fish oil needed to grow 1.0 mt of farmed salmon. Information on the sustainability of source fisheries obtained directly from one BC company and from two additional major feed companies from the Ocean Disclosure Project showed a moderate overall sustainability and resulted in a Wild Fish Use score of 4.67 out of 10. There is a net loss of 63.8% of feed protein (score 3 out of 10) and an estimated feed ingredient footprint (global warming potential) of 23.54 kg CO_2-eq. per kg of harvested protein (score of 4 out of 10). Overall, the three factors combine to result in a final Criterion 5 – Feed score of 4.09 out of 10.

After eight years of very low reported escape numbers of Atlantic salmon in BC, the escape of nearly 21,000 fish at the end of 2019 (and those continually occurring in every other salmon farming region globally) highlighted the inherent risk of escapes from net pen production systems. Large escape events affect a very small proportion of sites in BC, but the ten-year average loss of Atlantic salmon is 2,229 fish per year. Significant undetected or unreported trickle escapes may also occur. With the exception of the recapture of many Atlantic salmon in BC in 2017 after an escape from Washington state in the US (just south of the BC industry), the numbers of Atlantic salmon detected in the wild in BC are low. Atlantic salmon are non-native in BC but there have been hundreds of deliberate efforts over more than a century to establish the species for sportfishing in BC. Evidence increasingly shows the species to be a poor colonizer outside of its native range, and despite the large numbers of escapes over recent decades, there is currently no evidence of establishment and Atlantic salmon are considered highly unlikely to become established in BC. The moderate-high risk of escapes combined with the low risk of competitive or genetic impacts results in a final score for Criterion 6 – Escapes of 5 out of 10.

Many species of Pacific salmon are in decline over large geographical areas, including areas with and without salmon farms or salmon farming industries. As such, it is clear that pathogens or parasites from salmon farms have not caused the widespread decline, but given the importance of wild salmon (considered essential to life by indigenous communities in BC), any substantial contributions to their local declines or inhibitions of their recovery must be considered. The consequences of pathogen infection are highly variable depending on the individual, the strain of the pathogen, and the circumstances, thus driving the challenge of studying their impacts effectively in wild populations. The DFO risk assessments (for the risk of nine pathogens from farms in the Discovery Islands impacting the abundance or diversity of Fraser River sockeye salmon) are important studies with which to frame the components to be considered, yet despite their findings that all nine viral and bacterial pathogens had a "minimal" risk of impact when considered individually, the limitations in their scope are apparent with regard to other pathogens and parasites (both individually and in combination), and to other species of salmon in other areas of BC. Recent research continues to develop rapidly on many fronts and is making many associations between farm viruses and wild salmon, yet with few robust conclusions on transmission, infection, morbidity, or mortality in wild salmon. This challenge of drawing conclusions is perhaps best illustrated by a 2021 publication from the Strategic Salmon Health Initiative that notes (emphasis added here) "the <u>risk</u> of disease transmission from farmed to wild fish has increased, with <u>potential to contribute</u> to declines in wild fish populations, but <u>the probability and magnitude of this transmission has not been determined</u>" (note the use of this statement here is not intended to imply any particular level of impact or concern, but is simply utilized to highlight the challenge in drawing conclusions and in determining the appropriate level of concern). It therefore currently remains largely impossible to clearly differentiate between the speculation that viruses are driving or significantly contributing to the declines of wild salmon and the contrasting position reflected in the DFO risk assessments and other recent studies that bacterial and viral pathogens from Atlantic salmon farms are of minimal concern to wild salmon in BC.

With regard to parasitic sea lice, the large amount of data available indicates high geographic and temporal variability in lice levels on farms in most regions. In contrast to a period of stability in sea lice numbers up to 2015, there have been substantial outbreaks (e.g., average lice levels above the three-lice treatment threshold) in one or more reporting regions in most of the last five years, and frequent high lice levels in some regions, particularly the west and northwest coasts of Vancouver Island. The regulations allow lice to increase to high levels on farms (above the treatment threshold) without breaching the conditions of license. The numbers of lice observed on out-migrating juvenile wild salmon are also highly variable both geographically and temporally. The tolerance of juvenile Pacific salmon to sea lice infection varies considerably by species and particularly by size. For some, even low abundances of lice on very small juvenile salmon may cause mortality or sublethal effects on physiology and behavior, but susceptibility in young fish changes rapidly with age, and therefore their risk of being impacted by on-farm lice changes substantially during the four-month outmigration period. Therefore, the prevalence and intensity of lice seen on wild fish does not necessarily imply mortality or significant impact to individual fish, yet given the high regional and temporal variability, it is likely that there will be substantial mortality in some areas in some years. Sub-lethal impacts and increased risk of predation may also be important. Like bacterial and viral pathogens, the ongoing controversy regarding the impacts of sea lice highlights the lack of conclusive outcomes to date, but with repeated lice outbreaks in some areas during the outmigration period, the level of concern has increased.

The analysis here has been limited to a simplistic overview and highlights the ongoing uncertainty in the cumulative impacts of pathogens and parasites from farms to wild salmon populations across BC, but given the status of wild salmon populations, the uncertainties largely define the need for a precautionary approach. While the volumes of data and research on this topic are large and continually increasing, the complexities (highlighted by the research) mean the impacts of salmon farming alone cannot be quantified robustly; as such, the Risk-Based Assessment method is used. Overall, the potential pathogen and parasite interactions between farmed and wild salmon in BC, and particularly the repeated sea lice outbreaks in some areas during the outmigration period, must be considered a high concern until further evidence indicates otherwise. With open production systems discharging viral, bacterial, and parasitic pathogens into waterbodies shared with vulnerable and endangered wild salmon populations, there is a high concern and the final score for Criterion 7 – Disease is 0 out of 10.

Atlantic salmon aquaculture has seen a multi-decadal establishment of breeding programs, aimed at selection for traits advantageous to farming (e.g., fast growth, disease resistance), which has been integral in the rapid growth of the industry (Asche et al., 2013; Heino et al., 2015; Gutierrez et al., 2016). Of the finfish species farmed for food, Atlantic salmon is among those that have been subject to the longest and most intense domestication regimes (Skaala et al., 2019); for example, Norwegian farmed salmon (from which Atlantic salmon populations in BC originated) have now undergone approximately 15 generations of targeted breeding and are now considered to be partially domesticated and adapted to a life in captivity (Grefsrud et al., 2020).

Detailed data from DFO allow for a robust understanding of the impact that wildlife interactions with salmon farms has on wildlife populations and allow the use of the Evidence-Based Assessment method. Accidental mortalities of harbor seals and California sea lions have continued to decline to an average of three (total) per year since 2016, and 2016 was the last time lethal control of seals was used. Two humpback whales died as a result of entanglement and one was released alive in 2016, with an additional entanglement and live release in 2018, but none since. A small number of birds are also entangled or drowned in farm infrastructure each year. Substantial numbers of fish are caught as "incidental catch" in salmon farms, most of which are Pacific herring, but the total caught is very small compared to the commercial fishery quota. These data, together with an understanding of the population sizes of affected species, demonstrate that wildlife mortalities are limited to exceptional cases, and do not significantly affect any of these species' population size. The final score for Criterion 9X – Wildlife and Predator Mortalities is -2 out of -10.

Although there are no longer considered to be any salmon egg imports into BC, the industry is dependent on the movements of live salmon from hatcheries to marine grow-out sites, and to a lesser extent between marine grow-out sites. These movements mostly take place within one large Salmonid Transfer Zone under transfer licenses, but approximately three-quarters of them in recent years cross Fish Health Zones. As systems open to the environment, the net pen sites that are the destination of most movements have inherently low biosecurity, so the tank-based freshwater hatcheries as the source of most salmon movements drives the overall risk. These systems typically have higher biosecurity (than net pens) and only a small proportion of movements from hatcheries to marine sites have designated fish health concerns. However, recent screening research shows the presence of many potential infective agents in hatcheries (including viruses that are newly discovered or otherwise not known to occur in salmon in BC), albeit mostly at low prevalence. All the agents recently detected in samples of farmed salmon in freshwater were also detected in marine samples and there is currently no evidence that these potential disease agents are associated with any disease in wild fish as a result of their movements with farmed salmon. Overall, there is considered to be a low-moderate risk of introducing a novel secondary species into new areas in BC, and the final score for Criterion 10X (a combination of Factors 10Xa and 10Xb) is a deduction of -3.2 out of -10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Overall, the final numerical score is 3.62 out of 10 and there are two red criteria for Criterion 4 – Chemical Use and Criterion 7 – Disease. The final recommendation is therefore a red “Avoid”. All data points are available in Appendix 1, and all scoring tables and calculations are available in the Seafood Watch Aquaculture Standard.

Table of Contents

Introduction

Scope of the analysis and ensuing recommendation

Species: Atlantic salmon (*Salmo salar)*
Geographic coverage: British Columbia (BC), Canada
Production method: Marine net pens

Species Overview

Atlantic salmon are native to the North Atlantic Ocean with high numbers of discreet genetic sub-populations through Western Europe in the NE Atlantic and the North America landmass in the NW Atlantic. It is not native to British Columbia. Atlantic salmon is an anadromous species; birth and early life stages occur in freshwater rivers and streams, followed by a migration downstream and over long oceanic distances where the bulk of feeding and growth take place. After one or more years in the ocean, they return upriver to their original spawning ground to complete the cycle.

Production System

The large majority of farmed salmon in BC are produced in floating net pens in coastal inshore environments, typical to the industry worldwide. The hatchery phase is conducted primarily in tank-based systems on land. According to Canadian Government's Department of Fisheries and Oceans (DFO), there are 99 sites licensed for Atlantic salmon in BC, and the BC Salmon Farmers Association (BCSFA) report approximately 60 to 70 are active[2] at any one time. Detailed DFO site listings[3] vary somewhat with these values with approximately 76 active salmon sites listed in 2019. Figure 1 shows a map of the farm sites and main farming regions.

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

[3] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/mar-rep-rap-2019/index-eng.html#reports

Figure 1: Annotated map of the production regions including active and inactive finfish aquaculture sites (i.e., including some non-Atlantic salmon sites) in British Columbia showing Vancouver Island and the mainland. Base map copied from DFO (downloadable version available at https://www.dfo-mpo.gc.ca/aquaculture/bc-cb/maps-cartes-eng.html).

Production Statistics

Salmon farming began in BC (with Pacific salmon species) in the late 1980s, and exceeded 1000 mt for the first time in 1987 (Noakes et al., 2000). According to data from DFO[4] (accessed August 2021), the 2019 production of farmed salmon (all species) in BC was 88,874 metric tons (mt). Chinook salmon (*Oncorhynchus tshawytscha*) are also farmed in BC but harvests are estimated at only 2,500 mt annually (Seafood Watch 2019); therefore, greater than 97% of

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[4] https://www.dfo-mpo.gc.ca/stats/aqua/aqua18-eng.htm

production reported by DFO is of Atlantic salmon. A time series of BC production data (1995-2019) is shown in Figure 2.

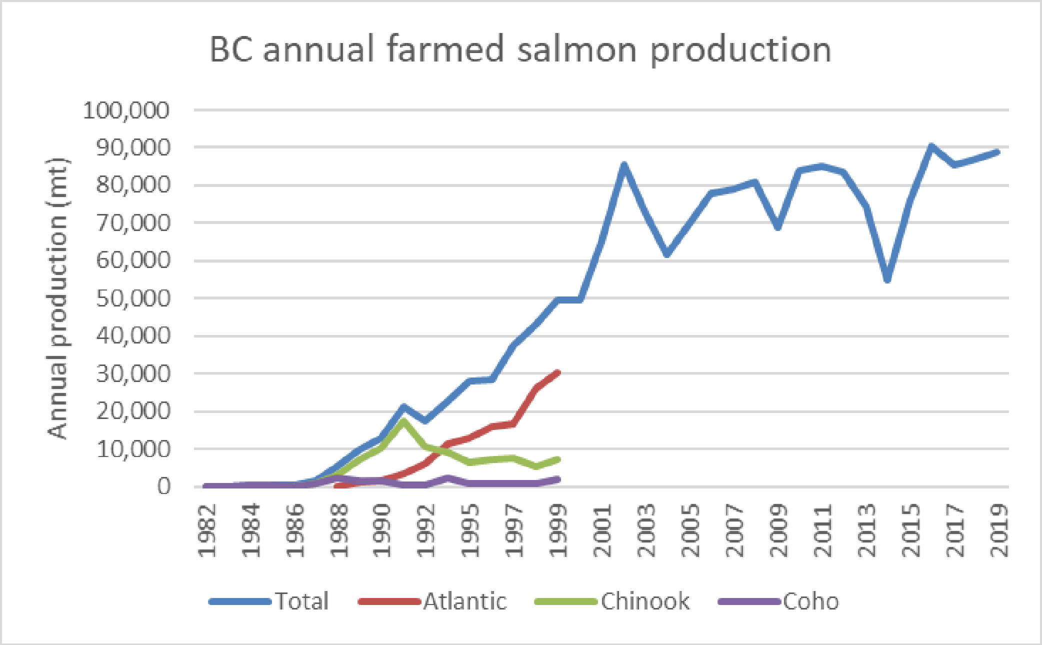

Figure 2: Total annual farmed almon production in BC. Individual species are shown from 1982 to 1999 using data from Noakes et al. (2000). As noted in the text, approximately 97% of current production is of Atlantic salmon. Total production data (blue line) to 1994 are from Noakes et al. (2000), and from 1995 to Data from DFO.

Import and Export sources and statistics

Farmed salmon continues to be BC's most valuable food and beverage export[5], with a 12% share of total agri-food and seafood provincial export sales in 2018[6]. According to NOAA's National Marine Fisheries Service import data, 80,075 mt of Atlantic salmon was imported into the US from Canada (i.e., including the east coast production) in 2019. DFO reports 60,700 mt of salmon was exported to the US from BC in 2018, but it is not known how much of this is wild salmon. Overall, the US is an important export market for farmed salmon from BC.

Common and Market Names

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

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[5] https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/statistics/industry-and-sector-profiles/sector-snapshots/sector_snapshot_2019_-_food_and_beverage.pdf

[6] Seawest News, Dec 16, 2019. Salmon farmers propel B.C. to a banner year for agriculture

Japanese	Taiseiyō sake

Product Forms

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

Criterion 1: Data Quality and Availability

Impact, unit of sustainability and principle

- Impact: poor data quality and availability limits the ability to assess and understand the impacts of aquaculture production. It also does not enable informed choices for seafood purchasers, 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

C1 Data Category	Data Quality
Production	7.5
Management	7.5
Effluent	7.5
Habitat	5.0
Chemical Use	7.5
Feed	7.5
Escapes	7.5
Disease	7.5
Source of stock	10.0
Wildlife mortalities	7.5
Introduction of secondary species	7.5
C1 Data Final Score (0-10)	**7.5**
	Green

Brief Summary

Salmon farming globally, including BC, has good data availability compared to most other aquaculture sectors, and in BC specifically there is a large amount of information available from the industry, the government and from peer reviewed research on many aspects of production and its impacts. Public reporting by companies associated with the Aquaculture Stewardship Council certification scheme has also increased data availability (e.g., sea lice numbers on wild fish). Nevertheless, some data categories are limited in functional timeliness (i.e., the data may be extensive, but delays in publication limit their immediate value to the industry, managers, or researchers), or are aggregated and lacking specificity. Some important types of data (e.g., sea lice bioassays to determine the development of resistance to pesticide treatments) are not made publicly available. The continued controversial nature of some key impacts in BC highlights the ongoing challenge of drawing robust conclusions with the available data and research. Overall, there is a large amount of information and research available with which to assess the industry, and the current state of knowledge is generally well understood. The score for Criterion 1 – Data is 7.5 out of 10.

Justification of Rating

The government of Canada, and specifically Fisheries and Oceans Canada (typically referred to as DFO) have recently improved the accessibility of data in Canada and particularly in BC. While often a little dated (2019 or 2020 being the most recent year for many data sets as of August 2021), DFO now publishes a report titled "Regulating and Monitoring British Columbia's Marine Finfish Aquaculture Facilities"[7] (latest version from 2019) that lays out all the monitoring and data collection in BC. At the end of the DFO report is a list of links to all available data (which include more recent data that the 2019 basis of the report), and this represents the primary starting point for many types of aquaculture data in BC. Other important resources are summarized below.

Industry and Production Statistics

DFO's Regulation and Monitoring report[8] provides maps of sites plus a list of all sites by company, location, and activity status (active/inactive). Information on annual total farmed salmon production is available from DFO, though these data are aggregated to include Atlantic and Chinook salmon production. Similar general industry information is available in the BC Salmon Farmers Association's annual Sustainability Progress Report (BCSFA, 2019a) and their 2019 Technical Report (BCSFA, 2019b). More specific information from the three major producer companies in BC are available in annual reports and/or sustainability reports. The data score for the Industry and Production statistics is 7.5 out of 10.

Management and Regulations

DFO's Regulation and Monitoring report provides a lot of general information on the practical regulation and monitoring/enforcement of the industry, plus the associated data. The DFO and connected Open Canada[9] websites contain all relevant regulations, but are somewhat challenging to navigate effectively, and data can be difficult to find. As such, personal communications identifying specific management changes were more effective than simple searches of DFO's sites (e.g., the June 2020 updates to BC's Conditions of License for salmon farms). The BCSFA website and their sustainability and technical reports have further information about farm-level management practices. Overall, general production and management are well understood, and the complete information on the regulatory system is available. The data score for management and regulations is 7.5 out of 10.

Effluent

There is no regulatory requirement for monitoring of soluble effluent in BC (historical evidence behind that decision is available, e.g., Brooks and Mahnken, 2003). Many sites do monitor water quality as a requirement of certification to the ASC Salmon Standard, but the data are not readily available in a practical format. DFO's website has industry-reported benthic monitoring results typically conducted by third-party companies[10], and the results of DFO's audits. DFO has

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[7] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/mar-rep-rap-2019/index-eng.html#reports

[8] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/mar-rep-rap-2019/index-eng.html#reports

[9] https://open.canada.ca/en

[10] http://www.pac.dfo-mpo.gc.ca/aquaculture/index-eng.html

information on the regulatory management of effluent including site separation, and there is a substantial body of academic literature on salmon net pen nutrient wastes (e.g., Price et al., 2015; Keeley et al., 2015). Key studies from other regions (e.g., Grefsrud et al., 2021a,b from Norway, and Tett et al., 2018 from Scotland) can be carefully used to make comparisons. In BC, references such as Backman et al. (2009) provide context, and Foreman et al. (2015) provide useful information about the models used in siting farms. Overall, there is both useful background information on effluents and specific site data for benthic impacts in BC, and the data score for Effluent is 7.5 out of 10.

Habitat

As noted above, the location and layout of each site's mooring system is available from DFO, and with readily available satellite images (e.g., Google Earth), these allow a simple overview of salmon farm locations and habitats. The review of McKindsey (2011) provides a useful compilation of potential impacts associated with the infrastructure, and other academic studies provide additional information on the attraction or repulsion of wildlife, hydrodynamics and other operational activities such as the use of submerged lights. In general, there are few specific data available on the impacts of the infrastructure or their operation (other than the discharge of nutrient wastes addressed in Criterion 2 – Effluent) and these potential impacts have been poorly studied and are difficult to quantify. Information on the regulatory system for siting and environmental impact assessments (and their enforcement) are available from DFO, but with some uncertainties in poorly understood impacts of industrial activities in the coastal zone, the data score for Habitat is 5 out of 10.

Chemical Use

Chemical use data in BC has recently improved with DFO now reporting antimicrobial and pesticide use per site annually, including the treatment type, frequency (not reported in 2019) and annual quantity used[11]. The DFO publication is delayed, with 2019 data being the latest available as of August 2021. Data on antimicrobial and pesticide use by two of the three main companies in BC are available from the Global Salmon Initiative website for the years 2013-2020[12] and values for the remaining major company are available in company reports. Specific monitoring data for antimicrobial resistance are limited (most recently in 2015), but resistance is the topic of many international academic studies (e.g., Santos & Ramos, 2018; Lilijwa et al., 2019; Quinones et al., 2019). For pesticide resistance and impacts, studies in BC (e.g., Saksida, 2016; Bateman et al.,2016; Messmer et al., 2018) provide some details but data from sea lice bioassays are typically not made publicly available. Wristen & Morton (2018) and Wristen (2020) review the sea lice treatment data from a critical perspective. Information on the potential environmental impacts of sea lice pesticides mostly comes from other regions, e.g., Bloodworth et al. (2019) in Scotland. While the impacts remain uncertain, the data score for Chemical Use is 7.5 out of 10.

Feed

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[11] https://open.canada.ca/data/en/dataset/288b6dc4-16dc-43cc-80a4-2a45b1f93383

[12] http://globalsalmoninitiative.org/sustainability-report/sustainability-indicators/

An approximate feed composition of key ingredients was supplied by two BC feed companies via the BCSFA. Additional categorical information was obtained from company annual reports and the Mowi Industry Handbook[13], and these data were supplemented by specific ingredients in each category from full feed compositions of (Norwegian) reference diets in Mørkøre et al. (2020) and Aas et al. (2019). As such, a best-fit feed composition was created that is considered to adequately represent the BC feeds for the purposes of this assessment. Robust data points on feed conversion ratios and protein contents were available from similar sources, and performance results (e.g., FFER) could be checked against data from two BC companies reporting through the GSI. The Global Feed Lifecycle Initiative database was used for the feed footprint calculations. The data score for Feed is 7.5 out of 10.

Escapes

DFO provides industry-reported data on escapes since 1987 for Atlantic and Pacific salmon[14]. The potential for undetected or unreported trickle losses can be inferred from peer reviewed literature, particularly Skilbrei and Wennevik (2006) and Skilbrei et al. (2015). DFO provides minimal information on recapture requirements[15], noting that DFO may approve fishing to recapture escapees, where it's warranted and effective, but there are no readily available data on previous approvals or their results. There is a substantial amount of information available on the potential establishment of Atlantic salmon in BC, and the BCSFA provided a 2020 review (referenced where appropriate to external sources). Results of earlier sampling periods reported in Volpe et al. (2000, 2001) and Fischer et al. (2014), are now dated, yet remain valid examples. Blasco (2019) provides a review of the Atlantic Salmon Watch Program and a summary of data. River monitoring surveys are available in Andres (2015) and various studies on feeding success of Atlantic salmon can be used to assess the likelihood of post-escape impacts through predation and/or competition for resources. While the available information does not give full confidence that the impact of escapes is understood, the data score for Escapes is 7.5 out of 10.

Disease

The Government of Canada provides information on fish health[16] and mortality[17] events in aquaculture in BC, and DFO reports carcass classifications by site[18] and by health zone[19], and average monthly mortality rates by Fish Health Zone[20]. A list of all available data is also provided[21]. DFO published nine risk assessments for viral and bacterial pathogens from farms in the Discovery Islands of BC[22]. Grant et al. (2019) produced a technical report on the status of

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

[14] https://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/escapes-evasions/index-eng.html#wb-auto-4

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

[16] https://open.canada.ca/data/en/dataset/deefd1d7-7184-44c7-83aa-ec0db91aad27

[17] https://open.canada.ca/data/en/dataset/7fbb2662-391a-4df7-99b4-3343fa68fc93

[18] https://open.canada.ca/data/en/dataset/0a8c5505-ecb3-4d8b-8120-462bd7def6bb

[19] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/carcass-health-zone-sante/index-eng.html

[20] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/carcass-health-zone-sante/index-eng.html

[21] https://open.canada.ca/data/en/dataset/3cafbe89-c98b-4b44-88f1-594e8d28838d

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

Canadian Pacific salmon and stock status is available from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC[23]). In 2018, the Canadian Government published an independent audit focused on whether DFO and the Canadian Food Inspection Agency (CFIA) managed the risks associated with salmon aquaculture in a manner that protected wild fish (Gelfand, 2018).

The Government of Canada provides data on sea lice counts at the site level[24] (including the numbers of net pens sampled, the sampling data, and the numbers of *L. salmonis* and *Caligus* lice) including audit counts, with monthly average levels provided for every site and by different categories of lice. The three main farming companies in BC also provide similar sea lice monitoring data at varying levels of detail. There is also a continuously evolving body of research on the pathogen and parasite dynamics of salmon farms in BC and their potential impacts to wild salmon individuals and populations. This includes annual monitoring of sea lice levels on wild juvenile salmon in multiple regions of BC[25],[26]. Although the available data does not result in clear conclusions regarding any potential impacts, the availability and quality of data is generally good. There are some gaps and substantial reporting delays for many datasets, and the data score for Disease is 7.5 out of 10.

Source of Stock

From a global perspective, it is now understood that farmed Atlantic salmon eggs and smolts are produced by domesticated broodstocks and are therefore independent of wild salmon populations. There is also literature available detailing selective breeding strategies and programs. The data score for Source of Stock is 10 out of 10.

Wildlife and Predator Mortalities

DFO[27] provides data on deliberate and accidental mortalities of marine mammals. The data are updated quarterly with approximately one-year time lag. Additional data (e.g., on birds) are available from GSI, or directly from company websites (for example, Cermaq[28]). Data on the incidental catch of fish is also available from DFO[29]. Information on population numbers and potential population impacts of affected species are available from a variety of sources, such as the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and Canada's Species at Risk Act (SARA), although the most recent population estimates for key species may be dated (e.g., humpback whales in 2011). While it is possible that some mortalities are unreported, the data score for Wildlife and Predator Mortalities is 7.5 out of 10.

Introduction of Secondary Species

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[23] http://www.cosewic.ca/

[24] https://open.canada.ca/data/en/dataset/3cafbe89-c98b-4b44-88f1-594e8d28838d

[25] https://mowi.com/caw/sustainability/wild-salmonid-lice-monitoring/

[26] https://griegseafood.com/bc-wild-pacific-salmon?fbclid=IwAR3Bzwc5U3DwbXzEvxDwdH4A2MzAqxg95TkAUabVwgb4b5Bc75bRbAGqb4Q

[27] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/mar-mam/index-eng.html

[28] https://www.cermaq.com/wps/wcm/connect/cermaq-ca/cermaq-canada/our-promise/public-reporting

[29] https://open.canada.ca/data/en/dataset/0bf04c4e-d2b0-4188-9053-08dc4a7a2b03

DFO published data on egg imports into BC until 2012, and the BCSFA confirmed there have been no imports since 2009. DFO provides background and regulatory information on transfer licenses and veterinary oversight, and specific data[30] on fish movements between freshwater hatcheries and marine grow-out sites (and between marine grow-out sites). The data include details on the fish health status of the movements, and the source and destination in terms of their fish health zones. Recent research highlights the potential for pathogens and parasites to be present in the freshwater hatcheries that are the source for most movements in BC (e.g., Bateman et al., 2021a), While there is no evidence of specific disease outbreaks in wild fish resulting from movements of farmed fish, the implications of moving infected fish across fish health zones remains uncertain and the data score is 7.5 out of 10.

Conclusions and Final Score

Salmon farming globally, including BC, has good data availability compared to most other aquaculture sectors, and in BC specifically there is a large amount of information available from the industry, the government and from peer reviewed research on many aspects of production and its impacts. Public reporting by companies associated with the Aquaculture Stewardship Council certification scheme has also increased data availability (e.g., sea lice numbers on wild fish). Nevertheless, some data categories are limited in functional timeliness (i.e., the data may be extensive, but delays in publication limit their immediate value to the industry, managers, or researchers), or are aggregated and lacking specificity. Some important types of data (e.g., sea lice bioassays to determine the development of resistance to pesticide treatments) are not made publicly available. The continued controversial nature of some key impacts in BC highlights the ongoing challenge of drawing robust conclusions with the available data and research. Overall, there is a large amount of information and research available with which to assess the industry, and the current state of knowledge is generally well understood. The score for Criterion 1 – Data is 7.5 out of 10.

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[30] https://open.canada.ca/data/en/dataset/700fe290-7653-49e1-b961-741dc1ead924

Criterion 2: Effluent

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

Risk-Based Assessment

C2 Effluent Final Score (0-10)	**5**	Yellow

Brief Summary

Salmon farms discharge large quantities of waste nutrients and – as net pen systems open to the environment – depend on coastal waterbodies to assimilate them. Using evidence from dated studies conducted in BC and more recent research and reviews from other major salmon farming regions, the potential for soluble nutrients from salmon farms in BC to exceed the local or waterbody carrying capacity is low. For seabed impacts, on average 85% of farms in BC comply with the regulatory thresholds (80% in 2019), but farms clearly have a substantial cyclical impact in the immediate farm area during the production/fallow cycle. There is no evidence of cumulative impact at the waterbody or regional scale, and the seabed impacts are temporary in the context that they could recover with an extended fallow or cessation of production (noting that they typically do not recover fully during normal fallow periods). In most years, more than 10% of the sampled farms in BC exceed the government-mandated benthic limits at peak biomass, and the sites in these cases are not allowed to be restocked until they return to compliance. With sufficient data available, the Evidence-Based Assessment method has been used, and while there is no evidence of cumulative impacts at the waterbody or regional, the number of sites exceeding the regulatory thresholds is considered to be more than occasional. The final score for Criterion 2 – Effluent is 5 out of 10.

Justification of Rating

The Effluent Criterion considers impacts of nutrient-related farm wastes within and beyond the immediate farm area for both soluble effluents in the water column and particulate wastes on the seabed. With good benthic impact data, supported by a substantial body of scientific literature, the score for the Effluent category in Criterion 1 – Data is 7.5 out of 10. As such, the Evidence-Based Assessment method in the Seafood Watch Aquaculture Standard has been used.

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

The analysis of the salmon industry's nutrient-related impacts is separated into the impacts of soluble effluents in the water column and, secondly, particulate wastes on the seabed. However, it is important to note that these impacts are connected; that is, increased production of phytoplankton and zooplankton in the water column (resulting from increased nutrient availability) also leads to increased settlement of organic material to the seabed (with consequences for benthic and suprabenthic oxygen concentrations and animal communities) (Grefsrud et al., 2021a,b). Also, the breakdown and resuspension of concentrated wastes on the seabed below net pens returns nutrients to the water column and/or results in resettlement in distant locations (Grefsrud et al., 2021a,b).

Soluble effluent

The potential impacts of soluble nutrient releases from fish excretion (e.g., increased phytoplankton production) vary primarily by location (e.g., enclosed or semi-enclosed waterbodies verses open coast) and the intensity of production (Grefsrud et al., 2021a,b; Hoddevik, 2019). There is no legal requirement for routine monitoring of soluble effluent from fish farms in BC, although many sites in BC do monitor following the requirements of the Aquaculture Stewardship Council (ASC) Salmon Standard. There is now a rich body of literature (partly from BC but also from other countries that have more extensive monitoring and research) with which to robustly reflect on the likely impacts in BC.

The research effort in recent years in BC has not been focused on soluble effluent impacts, but more than ten years ago, Backman et al. (2009) noted soluble wastes from salmon farms do not normally cause environmental impact concerns where naturally high levels of dissolved inorganic nitrogen occur (as a result of upwelling), or where primary production is generally light-limited, and/or where the receiving water volume is capable of assimilating these nutrients. Brooks and Mahnken (2003), who showed "in no case was dissolved inorganic nitrogen significantly increased at >30 m downcurrent when compared to upcurrent reference", concluded that outside of shallow, poorly flushed environments (which are poor locations for growing fish, and therefore typically no longer used by BC farmers), the potential for aquaculture discharges to enhance phytoplankton populations is remote or nonexistent. Brooks (2007) calculated 15.8 t/day of dissolved inorganic nutrients are released from salmon farms in BC, which was considered to be negligible in comparison to ~2,000 t/day delivered via upwelling. The same study concluded: "primary production in the Northeast Pacific is generally light and not nutrient limited and salmon aquaculture has minimal potential to affect phytoplankton production in much of this region".

In the Norwegian industry (which produces approximately 1.3 million mt of farmed salmon, compared to approximately 87,000 mt in BC), the concentration of nutrients is measured at stations along the coast through various monitoring programs, and while noting that aquaculture is the major source of anthropogenic soluble nutrients to coastal waters along the large majority of the coast of Norway, the increase in phytoplankton production due to nutrient emissions from fish farming varies from 1.0% to 17.7% across Norway's 13 production regions (Grefsrud et al., 2021a). This is well below the 50% increase classified as eutrophication by Svåsand et al. (2017) referencing OSPAR (2010). In addition, the Norwegian Institute of Marine Research's annual risk assessment of the salmon farming industry (published as Grefsrud et al., 2021a) shows that in the densest farming region, the in-situ measurements of phytoplankton show "very good" to "good" environmental condition at all monitoring stations, and they state with high confidence (due to the combination of their modelling results and physical monitoring data) that there is a low risk of environmental effects as a result of increased nutrient supply from aquaculture. Previous studies, such as Husa et al. (2014), also show little direct impact even in very densely-farmed fjords (for example, the Hardangerfjord in Norway, where a single fjord produces approximately the same quantity of farmed salmon as BC).

DFO regulations in BC require aquaculture facilities to be distanced by at least three kilometers from an existing marine finfish facility, and while there are legal exceptions for farms operating under coordinated Health Management Plans or owned by the same company, a simple visual assessment and measurement of farm site separation in the main farming areas of BC using Google Earth (as evidenced by visible net pen structures) indicated few, if any, examples where operational farms (i.e., those with at least basic net pen infrastructure in the water, but not necessarily actively stocked with fish) were located closer than 3 km apart.

More generally, the review by Price et al. (2015) concluded modern operating conditions have minimized impacts of individual fish farms on marine water quality; effects on dissolved oxygen and turbidity have been largely eliminated through better management, and near-field nutrient enrichment of the water column is usually not detectable beyond 100 m of the farm (when formulated feeds are used, feed waste is minimized, and farms are properly sited in deep waters with flushing currents). However, when sited nearshore, extra care should be taken to manage farm location, size, biomass, feeding protocols, orientation with respect to prevailing currents, and water depth to minimize near- and far-field impacts, and Price et al. (2015) caution that regardless of location, other environmental risks may still face this industry; for example, significant questions remain about the additive (i.e., cumulative) impacts of discharge from multiple, proximal farms, potentially leading to increased primary production and eutrophication. Hoddevik (2019) and Svasand et al. (2017) also note there is a large variation in phytoplankton biomass and species composition during any one year and between years, and significant differences in small geographical areas are also recorded; they also note a high level of uncertainty surrounding the amount of dissolved nutrients discharged from farms and therefore a potential for impacts (of which the scale of impact is not specified) in some local areas remains.

Referring again to studies conducted in other salmon farming regions, the Scottish review by Tett et al. (2018) and studies in Chile (Niklitschek et al., 2013; Mayr et al., 2014; Elizondo-Patrone et al., 2015) note changes to total nutrient levels and the ratios of different nutrients can lead to changes in phytoplankton communities or microbial communities and food webs. Again, the severity of the impacts (e.g., from "detectable" upwards) is uncertain, and while Tett et al. (2018) note the 'balance of organisms' in the phytoplankton is changing in at least one Scottish loch used for salmon farming, they consider this is likely due to causes other than nutrients from aquaculture. Tett et al. (2018) also note farm nutrients might locally enhance growth of opportunistic green algae, but it is unlikely to be impactful to the greater ecosystem.

Benthic impacts

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

According to DFO (2012a), BC's total lease area (for 174 marine finfish site tenures at that time, of which only 60-80 were actively producing salmon – approximately the same number as DFO reports currently active) covered 4,575 hectares of coastal area in 2010/2011, and without performing a specific calculation, this area (and that of today's industry) can be considered to be very small compared to the total area of BC's inshore waters.

Under DFO's Aquaculture Activities Regulations, marine finfish farm operators in BC must monitor and submit regular reports to DFO on the benthic impacts of their sites (an infographic and further information on monitoring at soft- and hard-bottom sites is available from DFO[31]). Every site must be sampled at peak biomass each cycle (40-50 sites each year, with 47 in 2019) using methods dependent on the nature of the seabed (sulfide measurements in samples taken at 30 m and 125 m from the net pens in soft-bottom habitats, or videos and visual analysis up to 125 m from the net pens in hard-bottom habitats). DFO conducts enforcement audits, with 13 of the 47 sites (27.6%) reaching peak biomass audited in 2019[32]. It is noted that there is unlikely to be a specific "peak biomass" point in any one production cycle as partial harvesting can maintain high biomass levels for extended periods of time, therefore conducting benthic sampling at an "early" peak biomass timing could miss later cumulative impacts, however the repetitive cycles of production and monitoring will at least require long term compliance at each site.

Figure 3 shows the percentage of monitored sites each year that meet the regulatory thresholds, with typically 80-90% of sites below the thresholds each year and an average of 85% from 2011 to 2019. Most recently, the 2019 full year data show that 19.1% of sampled sites were above the regulatory threshold and were not permitted to re-stock until follow-up

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[31] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/mar-rep-rap-2019/index-eng.html#reports

[32] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/mar-rep-rap-2019/index-eng.html#environmental

monitoring indicated that the site had recovered (i.e., returned below threshold as opposed to fully recovered). Partial data to September 2020 shows 6% of sampled sites were above the thresholds. Disagreements with industry self-reported results at DFO audits are uncommon, with one in 2019 (i.e., one out of the 13 sites audited by DFO in 2019), one in 2017, and two in 2015.

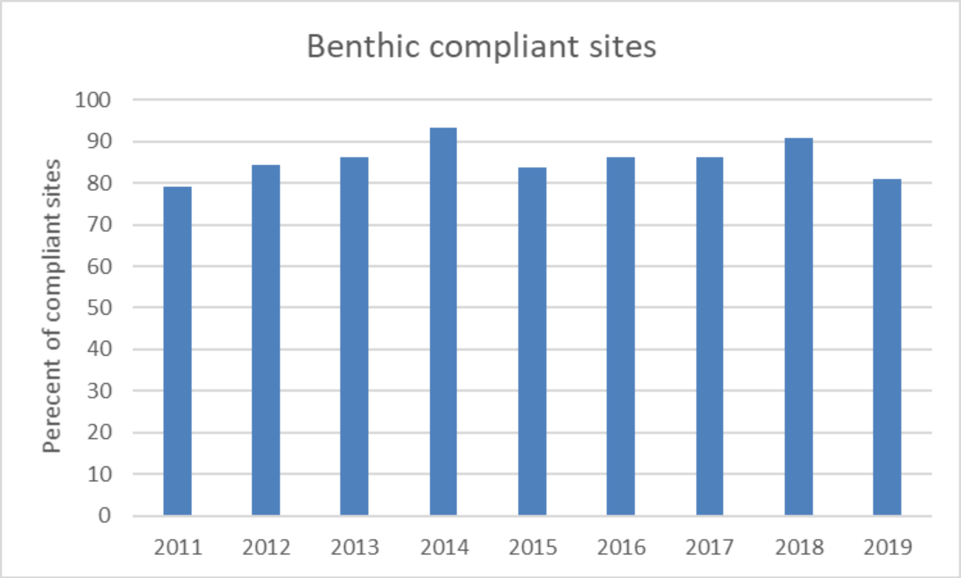

Figure 3: Benthic monitoring results from DFO from 2011 to 2019.

It is now a globally typical practice for salmon farm sites to be fallowed between production cycles for a variety of reasons (e.g., breaking parasite life cycles in addition to benthic recovery). The Aquaculture Activities Regulations do not mandate a fallow period in BC; instead, all sites must be shown to be compliant with the benthic sulfide thresholds before restocking. In a now-dated study, Brooks and Mahnken (2003) showed chemical and biological remediation in BC occurred naturally during fallow periods at every salmon farm studied. An analysis of DFO benthic monitoring data shows it took an average of 7.8 months for a failed site in BC to subsequently be re-sampled satisfactorily (noting that the subsequent sampling time may not be in any way related to the actual recovery, i.e., the site may have returned below the thresholds some time prior to the resampling date). As noted below, this does not mean a full recovery, but simply that the site can be restocked again.

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

With regard to potential cumulative impacts, the primary tool in BC is the separation distance between sites of 3 km. Samuelsen et al. (2015) reported particles containing pesticide residues have been found as far as 1,100 m (i.e., 1.1 km) from a treated salmon farm site, but Colombo et al. (2016) showed a limit of detection in BC at a maximum of approximately 750 m using novel methods to detect changes in the fatty acid composition of resident marine organisms consuming aquaculture feed waste and fecal particles. Using these studies to demonstrate the overlap potential of all materials – organic or chemical – discharged from a salmon farm site, it appears highly unlikely that there will be any significant overlap of impact zones from multiple farms, ultimately limiting – but not eliminating – the potential for cumulative impact.

Conclusions and Final Score

Salmon farms discharge large quantities of waste nutrients and – as net pen systems open to the environment – depend on coastal waterbodies to assimilate them. Using evidence from dated studies conducted in BC and more recent research and reviews from other major salmon farming regions, the potential for soluble nutrients from salmon farms in BC to exceed the local or waterbody carrying capacity is low. For seabed impacts, on average 85% of farms in BC comply with the regulatory thresholds (80% in 2019), but farms clearly have a substantial cyclical impact in the immediate farm area during the production/fallow cycle. There is no evidence of cumulative impact at the waterbody or regional scale, and the seabed impacts are temporary in the context that they could recover with an extended fallow or cessation of production (noting that they typically do not recover fully during normal fallow periods). In most years, more than 10% of the sampled farms in BC exceed the government-mandated benthic limits at peak biomass, and the sites in these cases are not allowed to be restocked until they return to compliance. With sufficient data available, the Evidence-Based Assessment method has been used, and while there is no evidence of cumulative impacts at the waterbody or regional scale, the number of sites exceeding the regulatory thresholds within an allowable zone of effect each year is considered to be more than occasional. The final score for Criterion 2 – Effluent 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

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

Brief Summary

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

The regulatory systems and their enforcement for siting, licensing, and managing impacts to the habitats in which salmon farms are located continues to be that set out by DFO in the Fishery (General) Regulations, the Pacific Aquaculture Regulations, and the Aquaculture Activities

Regulations. Nevertheless, recent movement toward more participatory decision-making includes the requirement for consent of First Nations to site salmon farms in their territory. Consultations have thus far resulted in the decision to review the long-term feasibility of 17 farms in the Broughton Archipelago and to close 19 farms in the Discovery Islands by mid-2022. With regard to the specific habitat impacts of the floating net pens considered here, the DFO system includes some aspects of the physical structure, but their application to all the potential impacts of the site infrastructure and operation, and particularly potential cumulative impacts across multiple sites, are not clear. The literature indicates that the realization of any or all of these potential impacts does not significantly impact the functionality of the ecosystems in which farms are sited, and more basically, the siting of net pen arrays does not result in habitat conversion in the same way that, for example, pond construction does. The removal of farm infrastructure would rapidly restore baseline biophysical processes. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management and enforcement system is broadly effective. The final score for Criterion 3 – Habitat is of 6.93 out of 10.

Justification of Rating

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

Factor 3.1. Habitat conversion and function

Data on site locational coordinates are available in various DFO data sets, and satellite images readily allow an overview of general salmon farm habitats. According to DFO (2012a), BC's total marine finfish aquaculture lease area (for 174 tenures at that time) covered 4,575 hectares of coastal area in 2010/2011. Without performing a specific calculation, this area (and that of today's industry) can be considered to be very small compared to the total area of BC's inshore waters; however, it must also be emphasized that the farms occupy areas highlighted as being particularly important habitats for the confined migration routes of wild salmon.

An example of three salmon farm sites on the west coast of Vancouver Island (only one of which is in production at the time of the image, as indicated by the presence of nets and predator nets in close up images) is shown in Figure 4. It is apparent from such images that the floating net pen containment system does not result in any gross functional conversion of surface habitats compared to (for example) the construction of ponds, but that is not to say there are no habitat impacts.

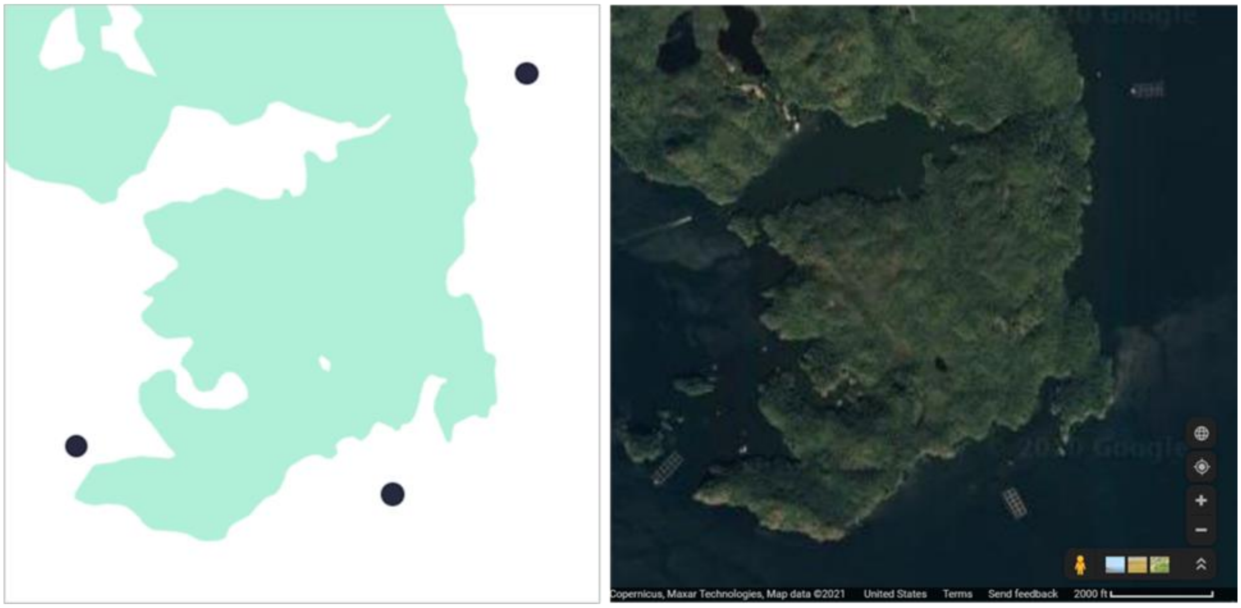

Figure 4: An example of three site locations from the BCSFA Interactive map (left image) and a satellite image of the same area from Google Earth (right image), providing an overview of the relevant surface habitats. In this image, only one site (upper right) is in production as indicated by installed nets.

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

Figure 5 shows a typical mooring pattern of anchor lines (at a Norwegian salmon farm randomly selected from the Directorate of Fisheries mapped database), and the positioning of the anchors (notably at approximately 1 km from southeast end of the net pen array in this example) shows the extent of the structures.

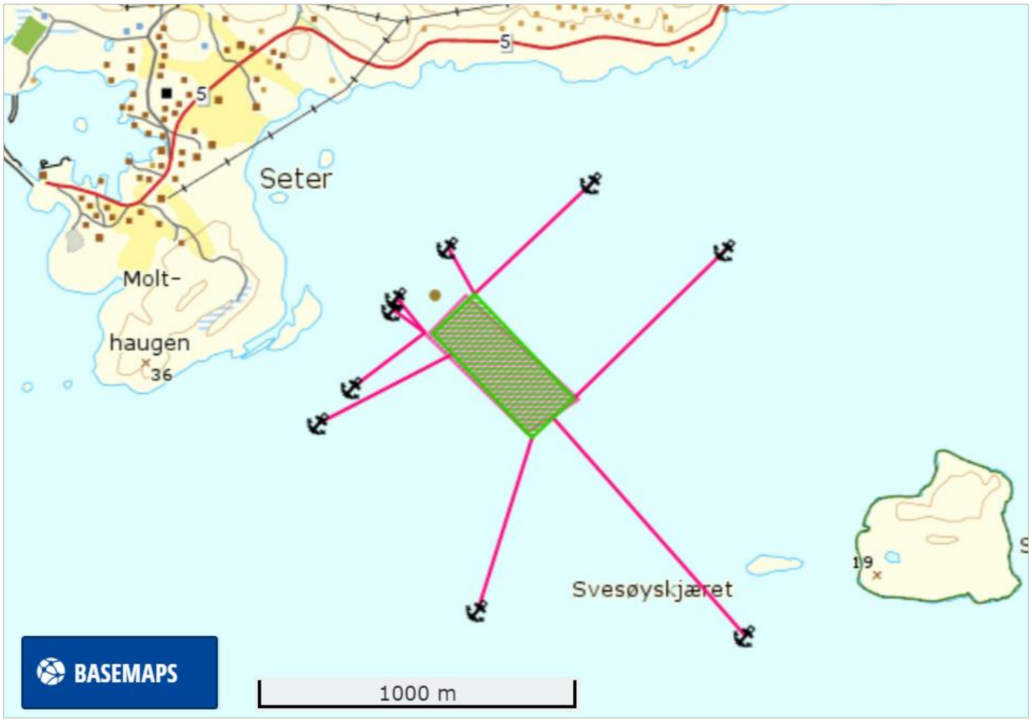

Figure 5: Illustration of the anchoring array of a salmon farm. Image copied from the Directorate of Fisheries' mapped database (https://kart.fiskeridir.no/)

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

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

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

A search for relevant literature since 2011 adds additional potential impacts. For example, DFO in a 2017 information webpage on the Alteration of Habitats[33] also notes the use of underwater lights may influence the behavior of wild fish by attracting them to—or causing them to avoid—farm sites, but also notes the lights do not penetrate more than a few meters beyond marine nets, suggesting that their use has minimal effect on the surrounding environment. Floerl et al. (2016) note a large number of fish (and mussel) farms in North America, Europe and New Zealand support extensive populations of biofouling invasive species, and the in-situ cleaning of fouled net pens may inadvertently support the persistence and distribution of such species within aquaculture regions by the localized dispersal of non-indigenous propagules and fragments, or by the use of farm structures as stepping-stones for range expansion (Bloecher and Floerl, 2020). In New Zealand, MPI (2013) also note the potential for impacts to benthic habitats due to shading, but in keeping with McKindsey (2011), they note that no studies exist that separate the effects of shading from that of benthic enrichment, presumably because they occur concurrently, and the latter is thought to be the dominant stressor. DFO requires farms to be located at sites with a minimum of 10 m depth, but those in BC (and other regions) are normally sited in greater than 30 m depth (BCSFA, pers. comm., 2021).

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

Uglem et al. (2020) also note salmon farms attract large amounts of wild fish which consume uneaten feed pellets. Dempster et al. (2009) estimated an average of 10.2 mt of wild fish aggregated around each salmon farm in Norway, and as specific examples, Otterå et al. (2014) and Skilbrei et al. (2016), note saithe (*Pollachius virens*) are by far the most numerous fish visitors to fish farms (on the Norwegian coast) and show evidence of establishing core residence areas close to fish farms such that the aquaculture industry is influencing the local saithe distribution. Again, Otterå et al. (2014) conclude large-scale population effects are difficult to prove, but note it is possible that the dynamic relationship between the coastal and oceanic phases of saithe has been altered. Uglem et al. (2020) also note the modified diet of the wild fish aggregating at salmon farms (i.e., the consumption of salmon feed pellets) may

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

reduce the flesh quality of the fish, influencing the local fisheries (although they noted the changes in flesh quality were small).

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

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

Factor 3.2. Farm siting regulation and management

Factor 3.2a: Content of habitat management measures

The Department of Fisheries and Oceans Canada (DFO) is responsible for regulating and managing the aquaculture industry in BC. The Fishery (General) Regulations (FGR), Pacific Aquaculture Regulations, and Aquaculture Activities Regulations (AAR) are the principal Fisheries Act regulations governing the activity of marine finfish aquaculture in BC. DFO’s responsibilities include the licensing of aquaculture sites and the conditions of licensure. Full details of the siting and monitoring requirements can be found in DFO’s Siting Guidelines for Marine Finfish Aquaculture in British Columbia[34].

With reference to the impacts of the physical structure, the siting guidelines require the applicant for new sites to conduct surveys, undertake analyses and submit a set of comprehensive reports detailing the physical and biological characteristics of the ecosystem

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[34] http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/docs/site-guide-direct-eng.html

beneath and around the proposed site location. Additionally, the placement and operation of an aquaculture facility should not impact Species at Risk Act (SARA) listed species. The siting guidelines specify that “the placement of farm infrastructure on the seafloor (e.g., anchor blocks)” must be considered in the siting process. The guidelines also state that a minimum distance of 10 m should be maintained between the bottom of the facility infrastructure (i.e., netting, predator nets etc.) and the seabed to mitigate potential impacts from direct contact.

Notably, there is significant debate in BC and Canada more broadly regarding who has authority – in whole or in part – in giving permission for farms to be sited BC is home to many First Nations some of which have farms sited within their territories. In 2016, the Government of Canada formally adopted the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)[35], which requests free and prior consent from Nations for activities within their territory. In 2018, an agreement was reached between the provincial government and three Nations in the Broughton Archipelago region (called the Broughton Letter of Understanding), from which the companies and the Nations reached an agreement which outlines several requirements ranging from Indigenous Monitoring Programs, reporting, and knowledge sharing. The companies currently have separate agreements with the three Nations and part of the process is determining the feasibility and potential closure of long-term salmon farming operations in the region. In 2020, DFO engaged in consultation with seven First Nations who have territory in the Discovery Islands region on the renewal of DFO-issued licenses for farms sited there. In December 2020, the Canadian Fisheries Minister announced that the 19 salmon farms in the region must close (i.e., be free of fish) by June 30, 2022[36],[37].

The authority for siting and license permission is indeed a topic of ongoing debate and will continue to be followed closely as it evolves, but currently, the framework for managing impact to the habitats in which salmon farms are sited continues to be that set out by DFO in the Fishery (General) Regulations, the Pacific Aquaculture Regulations, and the Aquaculture Activities Regulations. As such, the content of these regulations drives the score for this Factor.

Overall, the regulatory and management content governing salmon farms in BC is focused on benthic impacts from nutrient wastes, but the siting process does appear to consider at least some of the potential impacts outlined in Factor 3.1 but perhaps not all. Given the uncertainty attributed to these impacts and the apparent dominance of benthic impacts, this is perhaps not surprising, and overall, the management system is considered to require farms to be sited according to ecological principles or environmental considerations at the site level. There appears to be limited consideration of potential cumulative habitat impacts associated with the combined infrastructures of the industry, therefore the score for Factor 3.2a is 3 out of 10.

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[35] https://www.un.org/development/desa/indigenouspeoples/declaration-on-the-rights-of-indigenous-peoples.html

[36] https://www.canada.ca/en/fisheries-oceans/news/2020/12/government-of-canada-moves-to-phase-out-salmon-farming-licences-in-discovery-islands-following-consultations-with-first-nations.html?fbclid=IwAR2zcwTUEA3zustPQp7tz2muGGIoW4BoWhDMkVY2ZSvsNgHim2uZQvYavUM

[37] https://www.canada.ca/en/fisheries-oceans/news/2020/12/measures-to-phase-out-salmon-farming-in-the-discovery-islands-area.html

Factor 3.2b Enforcement of habitat management measures

DFO lists the “Aquaculture compliance and monitoring activities in British Columbia” on its website[38]. DFO conducts monitoring and compliance visits which assess compliance with farm operators' license conditions. With regard to the site licensing process, DFO’s “Applications and decisions” page[39] and the more detailed application review process[40] provide information on the review process, and the previously mentioned Applications and decisions page provides links to summary information for current applications under review. There is apparently little information with which to determine how robustly applications are scrutinized with regard to infrastructure installations, or penalties for subsequent infringements during installation or operation. As such, the score for Factor 3.2b Enforcement of effluent management measures is 4 out of 5.

The final score for Factor 3.2 combines the scores for the regulatory content (Factor 3.2a) with the effectiveness of the enforcement (Factor 3.2b) resulting in a Factor 3.2 score of 4.8 out of 10.

Conclusions and Final Score

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

The regulatory systems and their enforcement for siting, licensing, and managing impacts to the habitats in which salmon farms are located, continues to be that set out by DFO in the Fishery (General) Regulations, the Pacific Aquaculture Regulations, and the Aquaculture Activities Regulations. Nevertheless, with regard to the consent of First Nations to site salmon farms in

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[38] http://www.pac.dfo-mpo.gc.ca/aquaculture/regs-eng.html

[39] http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/index-eng.html

[40] http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/applications-demandes/process-eng.html

their territory, and following their consultation, 17 farms in the Broughton Archipelago and 19 farms in the Discovery Islands must move or close by 2023 and mid-2022 respectively. With regard to the specific habitat impacts of the floating net pens considered here, the DFO system includes some aspects of the physical structure, but their application to all the potential impacts of the site infrastructure and operation, and particularly potential cumulative impacts across multiple sites, are not clear. The literature indicates that the realization of any or all of these potential impacts does not significantly impact the functionality of the ecosystems in which farms are sited, and more basically, the siting of net pen arrays does not result in habitat conversion in the same way that, for example, pond construction does. The removal of farm infrastructure would rapidly restore baseline biophysical processes. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management and enforcement system is broadly effective. The final score for Criterion 3 – Habitat is of 6.93 out of 10.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

- Impact: 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

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

Brief Summary

Antimicrobial use varies each year according to treatment needs but has declined substantially since the peaks of the late 1990s (noting that much of this decline was due to the industry's transition from farming Chinook salmon to Atlantic salmon in the mid-2000s, with the former species requiring higher uses of antimicrobials). The publication of data by DFO is somewhat delayed (2019 data is the latest available as of September 2021) but GSI data show antimicrobial use in 2020 was relatively low at 53 g/mt of production, compared to approximately 140 g/mt in 2018. Approximately half of active sites are treated with antimicrobials each year in BC, with 52% and 54% of active sites receiving an antimicrobial treatment in 2018 and 2019 respectively (i.e., 48% and 46% of sites respectively received no antimicrobial treatments). Two antimicrobial types are used – oxytetracycline and florfenicol – both of which are listed as highly important for human medicine by the WHO. Approximately 1 in 10 active sites are treated each year with oxytetracycline, and half the sites are treated with florfenicol. A simple averaging across all active BC sites indicates a three-year average of 1.3 antimicrobial treatments per site per year from 2018 to 2020, but with a focus on treatments of small fish soon after entry to seawater (for mouth rot – *T. maritimum)* (and therefore relatively small amounts of antimicrobial used per treatment), the median treatment number per treated site was three treatments (using 2018 and 2019 DFO data). This indicates that while many sites are not treated, those that are treated have multiple treatments per year.

The industry follows prudent use guidelines for antimicrobials and complies with the recommendations of the WHO Guidelines on Use of Medically Important Antimicrobials in Food-producing Animals. However, the limited availability of data on antimicrobial resistance or efficacy monitoring, or other relevant research in BC, limits the ability to understand how the industry's antimicrobial use patterns (i.e., approximately half the sites receiving no treatments, and the other half receiving multiple treatments) drive or contribute to the presence or development (if any) of antimicrobial resistance. The industry considers the antimicrobial treatments to still be extremely efficacious after decades of antibiotic usage to treat fish when required.

The use of pesticides of environmental concern (i.e., emamectin benzoate, EB, and hydrogen peroxide) in BC is currently less than once per year per site. While the impacts of their use in BC are not yet fully understood, the available evidence indicates that significant impacts are likely to be constrained to an area commonly accepted as an “allowable zone of effect”, similar to that impacted by organic enrichment. While increased tolerance (i.e., resistance) to EB has been slow to develop in BC compared to other regions and the industry uses a variety of alternatives, reduced efficacy of EB treatments is increasingly being reported. It is an area of concern to follow. Overall, the open nature of the net pen production system provides no barrier to infection from environmental pathogens, and while many sites are not treated with antimicrobials, the three-year average number of treatments per site has been 1.3 and the median number of treatments at treated sites has been three in the most recent DFO data years (2018-2019). As such, the use of antimicrobials that are highly important for human medicine at >1 treatment per site per year is a high concern and the final score for Criterion 4 – Chemical Use is 2 out of 10.

Justification of Rating

This assessment focuses on antimicrobials and sea lice pesticides as the dominant veterinary chemicals applied to salmon farming. While other types of chemicals may be used in salmon aquaculture (e.g., antifoulants, anesthetics), they have seen significant reductions in use (e.g., many anti-foulants applied to nets) and/or the risk of impact to the ecosystems which receive them is widely acknowledged to be less than that for antimicrobials and pesticides. See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations.

Antimicrobials

Antimicrobial use industry-wide

Antimicrobial use data are available from DFO as part of the National Aquaculture Public Reporting Data[41], and include the total annual quantity by weight of active ingredient for each product administered for each site in the industry. Data on the number of treatments per site were available in 2018, but not 2019. Publication of the data is somewhat delayed with 2019 being the most recent available in August 2021. These data are available from 2016, but a longer time series of country-level aggregated data is available from DFO for 1995 to 2019[42], shown in Figure 6, combined with data from GSI for three companies[43] reporting from 2015 to 2020.

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[41] https://open.canada.ca/data/en/dataset/288b6dc4-16dc-43cc-80a4-2a45b1f93383#wb-auto-6

[42] https://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/therapeut/index-eng.html#wb-auto-9

[43] Mowi no longer reports through GSI, but a value has been used from their annual report.

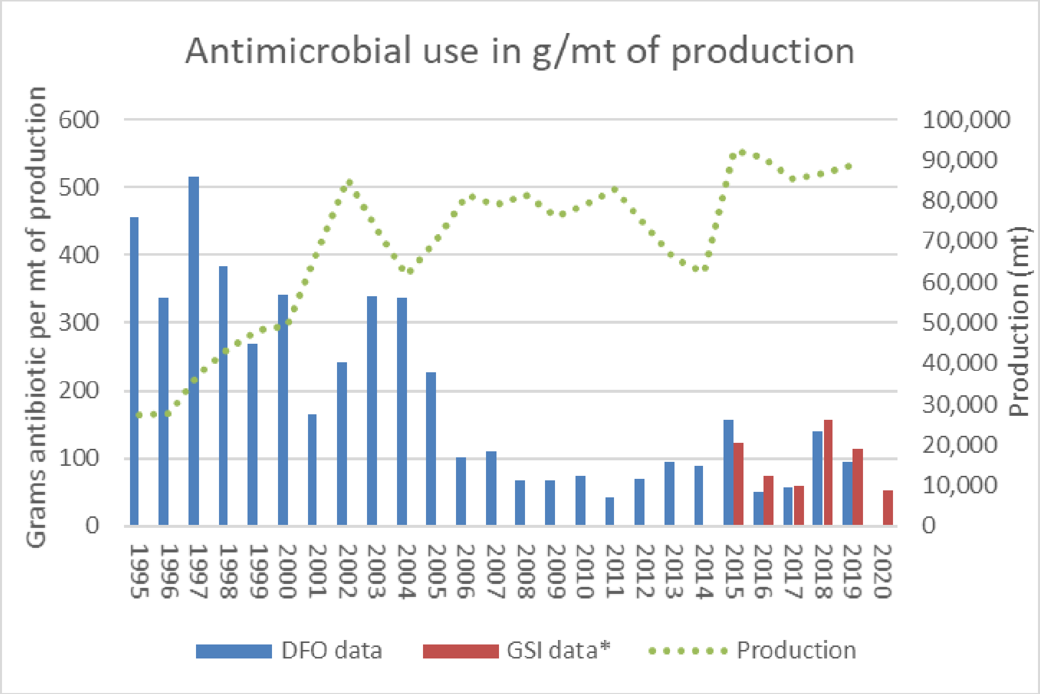

Figure 6: Antimicrobial use per ton of production and total farmed salmon production (all farmed salmon species – dotted line) in BC from 1995 to 2020. Blue bars show DFO country-level aggregated values. Data for two or three reporting companies per year from GSI are shown in red bars from 2015 to 2020 with (*) one company's 2019 and 2020 data obtained from an annual report (Mowi).

The data show a long-term decline in antimicrobial use from a peak in 1997, and more recently show considerable annual variability as the industry responds to varying disease pressures (see Criterion 7 – Disease). These data are for all farmed species in BC, and a substantial part of the earlier large decline in antimicrobial use was due the transition from the production of Chinook salmon (which used large quantities of antimicrobials to treat BKD) to Atlantic salmon in the mid-2000s (Morrison and Saksida, 2013). The large majority of current antimicrobial use is now for Atlantic salmon (for example, in 2016, only 2.9% of antimicrobials were used for other species[44]), but the decline in antimicrobial use for this species is likely to be less pronounced than appears in Figure 6. The GSI (plus one company's independent) data represent the three large salmon farming companies in BC (red bars in Figure 6) and indicate the antimicrobial use in 2020 (52.7 g/mt) had declined substantially compared to 2018 and 2019. The use of antimicrobials is now mostly related to the prevalence of *Tenacibaculum maritimum* (mouth rot) infections upon entry to seawater, with lesser use for Salmon Rickettsial Syndrome (SRS), and Moritella viscosa (winter ulcers) (see Criterion 7 – Disease).

Two types of antimicrobials, oxytetracycline and florfenicol, were used in similar quantities (4,180 kg and 4,134 kg respectively) by weight in 2019. Oxytetracycline has a lower potency and a much higher dose rate and total use per treatment than florfenicol (for the same biomass of treated fish), therefore the similar totals by weight reflect different numbers of treatments. For example, despite the similar total quantities, 8 sites in BC were treated with oxytetracycline in

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[44] 2016 data previously supplied by the BC Ministry of Agriculture through personal communication.

2019 compared to 40 sites treated with florfenicol (seven sites were treated with both). The DFO data for 2019 do not include the number of treatments at each site (this was included prior to 2019), but by using the 2018 data (i.e., both the number of treatments per site and the total quantity of antimicrobial used), an average quantity of each antimicrobial per treatment can be used to estimate the treatment frequency per site in 2019. DFO data show there were 76 active Atlantic salmon sites in 2019[45]. This appears straightforward for oxytetracycline; the average use in 2018 indicates there were 8 treatments in 2019 and eight sites were treated in 2019, indicating one treatment per treated site, or 0.1 treatments per site across all 76 sites. For florfenicol, using the average quantity per treatment in 2018, it is estimated that there were 107 florfenicol treatments in 2019 and a simple average concludes there were 1.4 treatments per site across the industry in 2019. But as only 52% of the 76 sites were treated with florfenicol in 2019, that equates to 2.7 florfenicol treatments that year at the treated sites.

However, it is important to note that the quantity of antimicrobials used per treatment is highly variable depending on the number of fish treated and their size; therefore, these 2019 estimates are a best approximation given the available data. For example, the average treatment quantity per site in 2018 for florfenicol varied from 11.5 kg to 335 kg, indicating that the average value of 1.4 treatments per site across all sites calculated above has a potential range of 0.16 to 4.7 treatments per site, and for the treated sites only, the range is 0.3 to 8.9 treatments per site in 2019. Therefore, the average calculated values for the number of treatments per treated site must be used with caution, yet these remain an important metric with which to consider antimicrobial use. By considering the approximate treatment frequencies in 2018 and 2019 using DFO data, the GSI relative use data for 2020 (53 g/mt) can also be converted to an estimated treatment frequency of 0.71 treatments per site in 2020. The three-year average number of antimicrobial treatments per site in BC from 2018 to 2020 is therefore estimated to be 1.3 treatments per site. It is noted that the GSI data are higher than the DFO data in four of the five comparable years (2015 to 2019 – see Figure 6), and while this represents another source of error (for which the reason is not immediately clear), the average variation over this period is 7.7% (higher) and not considered sufficient to further question the frequency-of-use calculations above.

For reference, the more detailed 2018 treatment frequency data are presented in Figure 7 (showing the number of treatments per site) and Figure 8 (showing the quantity of antimicrobials per site).

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[45] DFO data show 83 active and 33 inactive sites in 2019 of which 76 were considered to be active Atlantic salmon sites based on the exclusion of companies known to be producing other species.

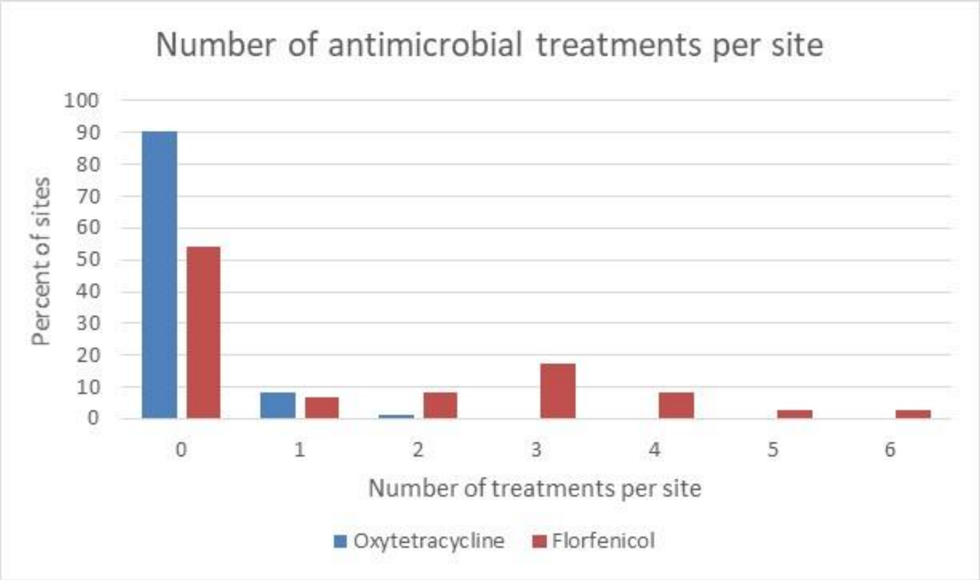

Figure 7: Percentage of sites receiving different <u>numbers</u> of antimicrobial treatments in 2018. Data from DFO.

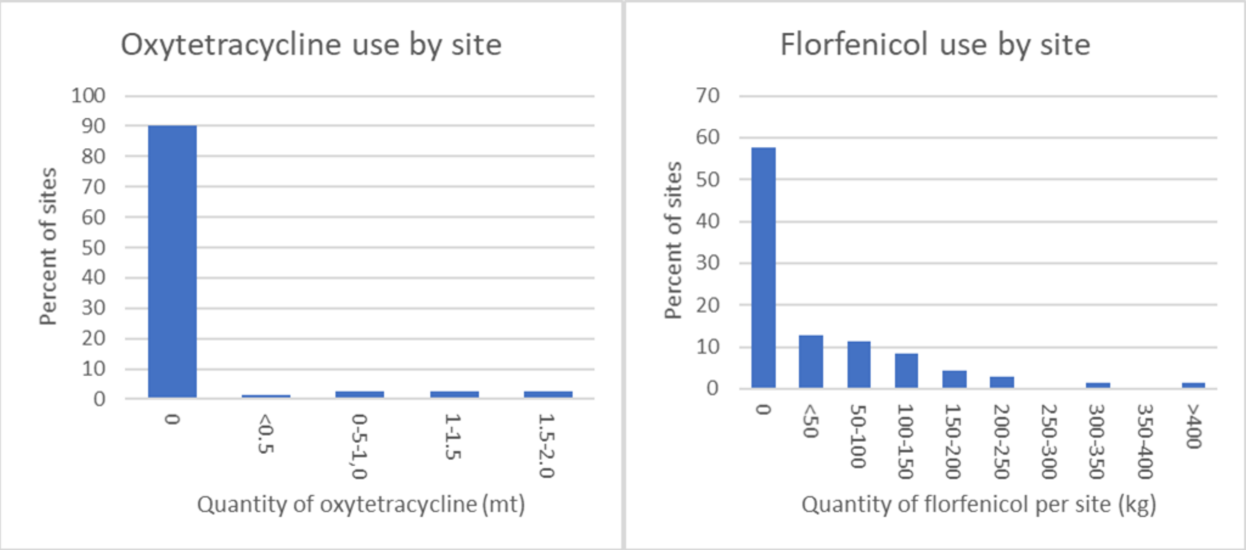

Figure 8: Percentage of sites receiving different <u>quantities</u> of antimicrobial treatments in 2018. Data from DFO.

Figure 7 shows 90.5% of sites in 2018 received zero oxytetracycline treatments, and of the 9.5% of sites that did receive treatment, one site received two treatments. Figure 8 also shows 54.1% of sites did not administer a florfenicol treatment, but the median number of florfenicol treatments at treated sites (17.6% of all sites) was three. Two sites received six florfenicol treatments, yet the total quantity was not high in either case, indicating either partial treatments or small size of treated fish (florfenicol usage is mainly due to treatments for mouth rot just after entering to sea from freshwater). An analysis of treatment data in DFO's fish heath reports shows that from 2018 to September 2020, 64% of treatments were applied to all fish on the site, and 36% of treatments were for part of the site.

Sites receiving oxytetracycline treatments varied in their total use by weight from <0.5 mt to 1.69 mt per site in 2018. For florfenicol, the majority of treated sites received low quantities (50.6% of the treated sites received <100 kg florfenicol), while some received higher amounts (13% of treated sites receiving more than 200 kg).

Company-level antimicrobial use

The GSI data show antimicrobial use has been highly variable by company in BC; these data (with some gaps filled with data from company annual reports) show Mowi has consistently low antimicrobial use when compared to Grieg and Cermaq (Figure 9), but it is important to note that small numbers of oxytetracycline treatments can dramatically change the use by weight in any one year or company. These variations mean BC-wide conclusions about average antimicrobial use must be made with caution, but it is also noted that the inter-company variability in recent years, particularly in 2020, is greatly reduced.

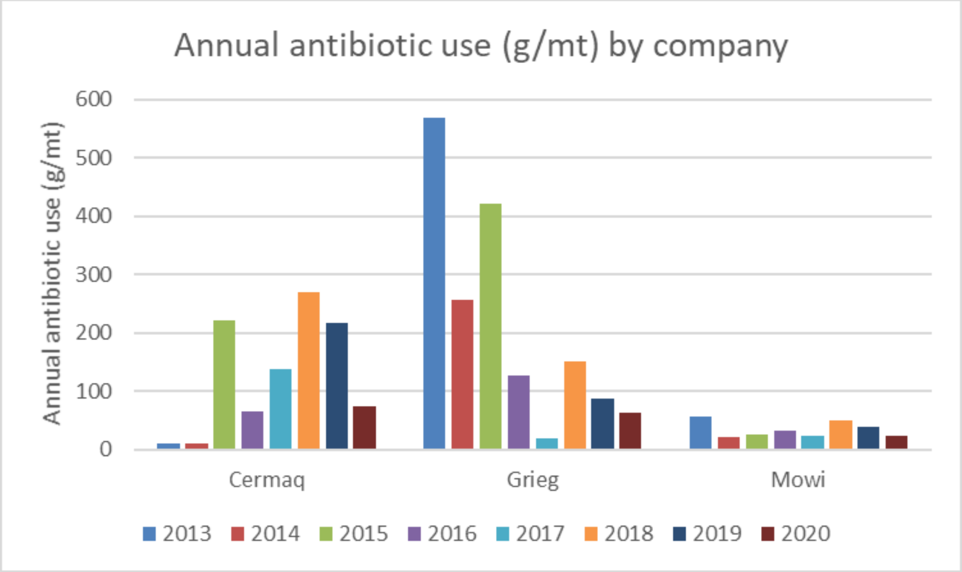

Figure 9: Relative antimicrobial use in g/ton of production for three major companies in BC between 2013 and 2020. Data from GSI and company annual reports.

Regulations and controls

Four antimicrobial products containing six active compounds are approved for use in food fish in BC: florfenicol, oxytetracycline, Romet-30 (a 5:1 combination of sulphadimethoxine and ormetoprim), and Tribrissen (sulphadiazine and trimethoprim; 5:1). All antimicrobial treatments are prescribed by a licensed veterinarian and administered following the policies and guidelines of the College of Veterinarians of British Columbia[46]. Of these six antimicrobials, five (including oxytetracycline and florfenicol) are listed as highly important for human medicine by the World Health Organization (WHO 2019). The DFO data include the occasional use of erythromycin which is listed as critically important by the WHO, but this is typically only used in small quantities (injected) in broodstock (i.e., non-food fish); for example, there was zero use in 2019 and only a single use of 820 g in 2018 (erythromycin is not listed explicitly for aquaculture but is

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[46] https://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/therapeut/index-eng.html#antibacterials

used legally according to Emergency Drug Registrations or when prescribed by a registered veterinarian for extra-label use[47]).

In addition to the WHO list, the World Organisation for Animal Health (OIE) has prepared a List of Antimicrobial Agents of Veterinary Importance[48], within which both florfenicol and oxytetracycline are listed as "Veterinary Critically Important Antimicrobial Agents". The OIE states: "The wide range of applications and the nature of the diseases treated make phenicols [and tetracyclines] extremely important for veterinary medicine. This class is of particular importance in treating some fish diseases, in which there are currently no or very few treatment alternatives." This emphasizes the need for responsible and prudent use (OIE, 2019).

Due to the need to treat sick fish for animal welfare reasons, none of the major salmon farming countries have limits in place for the frequency or total use of antimicrobials, but Lulijwa et al. (2019) note salmon farms (typically operating in developed countries) generally follow prudent use guidelines for antimicrobial use (i.e., veterinary oversight and prescription for diagnosed disease outbreaks, testing for efficacy/resistance, and no prophylactic use). In 2017, the WHO developed Guidelines on Use of Medically Important Antimicrobials in Food-producing Animals (WHO, 2017) with three recommendations and two suggestions:

> 1 - We recommend an overall reduction in use of all classes of medically important antimicrobials in food-producing animals.
> 2 - We recommend complete restriction of use of all classes of medically important antimicrobials in food-producing animals for growth promotion
> 3 - We recommend complete restriction of use of all classes of medically important antimicrobials in food-producing animals for prevention of infectious diseases that have not yet been clinically diagnosed.
> 4a - We suggest that antimicrobials classified as critically important for human medicine should not be used for control of the dissemination of a clinically diagnosed infectious disease identified within a group of food-producing animals.
> 4b - We suggest that antimicrobials classified as highest priority critically important for human medicine should not be used for treatment of food-producing animals with a clinically diagnosed infectious disease

It appears clear that the BC industry complies with these recommendations and suggestions (arguably, if a "whole net pen" population of fish was treated with the critically important antimicrobial erythromycin (e.g., via feed) after the initial diagnosis of disease in a smaller sample of fish, it would appear to not strictly comply with suggestion 4a[49], but it does not appear that this antimicrobial is used in this manner in BC salmon farms).

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[47] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/glossary-glossaire-eng.htm

[48] https://www.oie.int/fileadmin/Home/eng/Our_scientific_expertise/docs/pdf/AMR/A_OIE_List_antimicrobials_July2019.pdf

[49] It appears necessary to treat individual sick animals (e.g., by injection) to meet this WHO suggestion, which is more easily achieved with terrestrial livestock.

Antimicrobial resistance

The use of antimicrobials in open net pen production systems inherently links salmon farming to global concerns regarding the development of resistance and the passage of resistance genes from aquatic to terrestrial pathogens (Santos & Ramos, 2018; Lilijwa et al., 2019). The WHO (2017) states: extensive research into mechanisms of antimicrobial resistance, including the important role of horizontal gene transfer of antimicrobial resistance determinants, supports the conclusion that using antimicrobials in food-producing animals selects for antimicrobial resistance in bacteria isolated from food-producing animals, which then spread among food-producing animals, into their environment, and to humans.

The environmental risks include residue accumulation, aquatic biodiversity toxicity, microbial community selection for antimicrobial resistance, and the emergence of multi-antibacterial resistant strains (Lulijwa et al., 2019). Quinones et al. (2019) emphasize there is an urgent need for more comprehensive ecosystem (beyond farm) studies on the impacts of antimicrobials.

The subject of antimicrobial resistance is extremely complex and the subject of a voluminous and rapidly growing body of literature. In technical complexity, the details of this subject are beyond the scope of this Seafood Watch assessment, yet the appropriate level of concern is important to this Chemical Use criterion. Therefore, in addition to the limited available data from BC, the recent scientific literature has been relied upon.

Lulijwa et al.'s (2019) review indicates antimicrobial residues accumulate in sediments, and may drive change in microbial communities through selection for antimicrobial-resistant species (and antimicrobial resistance genes may persist in the environment for several years after actual use of the drugs). Further, the same review reports antimicrobials may impose toxic effects in wild non-target species, can affect phytoplankton and zooplankton diversity via bacterial intoxication, and have also been implicated in the disruption of zooplankton development and phytoplankton chlorophyll production. These changes, in turn, may result in alterations of food web dynamics with consequences throughout the ecosystem (Lulijwa et al. 2019); however, the known and potential impacts are poorly understood at different scales and locations (global, country, waterbody, site), and particularly the contributions that salmon farming's antimicrobial use makes in relation to other key users (i.e., terrestrial agriculture and human health). Therefore, understanding the complex potential impacts to food safety, occupational health hazards, antimicrobial resistance, and direct impacts to the local environment continues to be challenging to fully comprehend (Lulijwa et al., 2019).

There is evidence that antimicrobial resistance has occurred previously in BC. For example, Sheppard (1992) documented *Aeromonas salmonicida* resistance to oxytetracycline in BC, prior to the successful adoption of vaccination. Morrison and Saksida (2013) expressed concern with a need to repeat antimicrobial treatment for stomatitis (treated with florfenicol), though this could have been more indicative of the antimicrobial being less suitable to treat the disease than already-developed resistance. BC's Ministry of Agriculture's Animal Health Centre (AHC) assessed bacterial resistance in diagnostic salmon samples submitted between 2007 and 2015 and presented data on resistance to three antimicrobials: florfenicol, oxytetracycline, and trimethoprim-sulfadiazine, in two key bacteria (*Aeromonas salmonicida* which causes furunculosis, and *Yersinia ruckeri* which causes enteric redmouth disease) (AHC, 2016). While noting the data limitations expressed in the study (small sample sizes, passively collected samples likely to be of sick fish), the data showed antimicrobial resistance in *Y. ruckeri* was very uncommon, with only one isolate showing resistance to one antimicrobial in the nine-year sample history. For *A. salmonicida*, Figure 10 shows that although there were no trends of increasing or decreasing resistance to any antimicrobial over time, multiple isolates in some years showed resistance to one or more antimicrobials and frequently appeared to be resistant to multiple antimicrobials.

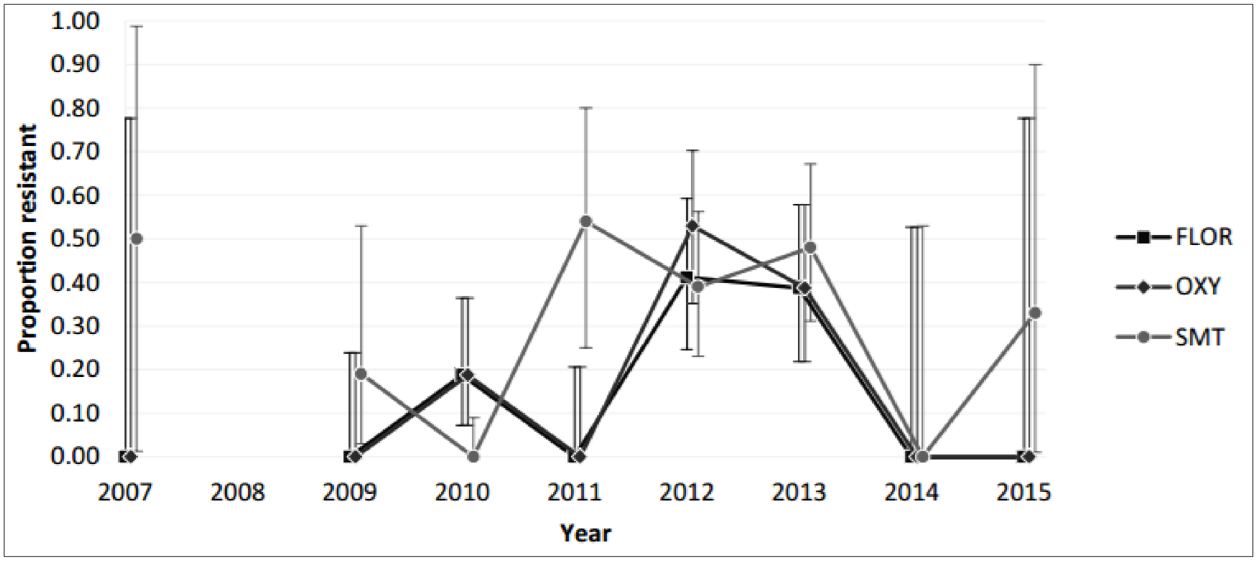

Figure 10: Proportion of *A. salmonicida* isolated from Atlantic salmon submissions to the Animal Health Centre resistant to florfenicol (FLOR), oxytetracycline (OXY) and sulfa-trimethoprim (SMT) by year. Error bars represent 95% confidence intervals for the proportion. Graph copied from AHC (2016). Note only two samples were taken in 2007 and zero in 2008.

Florfenicol is currently the most commonly used antimicrobial in BC, and despite not being used in human medicine, it is listed as highly important for human medicine by the World Health Organization. This is due to the presence of a mobile resistance gene (e.g., the FloR gene) which, though horizontal gene transfer (HGT), gives florfenicol the potential to co-select for a diversity of resistances (Fernandez-Alarcon et al., 2010). According to the BCSFA (pers. comm., 2021) a quantitative method of susceptibility testing (Minimum Inhibitory Concentration) is routinely used to help determine antibiotic efficacy, and the treatments used continue to be extremely efficacious with decades of antibiotic usage to treat fish when required.

Antimicrobial conclusions

The total antibiotic use varies each year according to treatment needs but declined to 53 g/mt in 2020 from >150 g/mt in 2018 and >100 g/mt in 2019. Approximately half of active sites are treated with antimicrobials each year in BC, with 52% and 54% of active sites received an antimicrobial treatment in 2018 and 2019 respectively. Two antimicrobial types are used – oxytetracycline and florfenicol – both of which are listed as highly important to human medicine by the WHO. Approximately 1 in 10 sites are treated each year with oxytetracycline, and one in two sites with florfenicol. With a focus on treatments of small fish soon after entry to seawater (for mouth rot – *T. maritimum)* and with approximately one-third of treatments applied to only part of the site, it is considered that the total amounts of florfenicol used at those sites that are treated represents multiple smaller treatments per year, with an estimate of 2.7 treatments per treated site in 2019. In 2018, the median treatment number per treated site was three treatments.

The industry follows prudent use guidelines for antimicrobials and complies with the recommendations of the WHO Guidelines on Use of Medically Important Antimicrobials in Food-producing Animals. However, the limited availability of data on antimicrobial resistance or efficacy monitoring, or other relevant research in BC, limits the ability to understand how the industry's antimicrobial use patterns (i.e., approximately half the sites receiving no treatments, and the other half likely receiving multiple treatments) drive or contribute to the presence or development (if any) of antimicrobial resistance. The industry considers the antimicrobial treatments to continue to be extremely efficacious with decades of antibiotic usage to treat fish when required.

Pesticides

The primary use for pesticide compounds in salmon farming is the treatment of parasitic sea lice with a lesser use (typically of hydrogen peroxide) to treat amoebic gill disease (AGD). The use of pesticides in BC to treat sea lice is primarily intended to reduce the risk of transmission to wild juvenile salmonids as the levels of sea lice rarely exceed the threshold for known health impacts on farmed fish (St-Hilaire et al., 2018; Aaen et al., 2015).

Emamectin benzoate (EB— trade name SLICE®), administered in feeds, has been the primary pesticide used since the year 2000, with hydrogen peroxide (trade name Interox® Paramove™ 50) administered as a bath in wellboats allowed as an alternative since 2014. Health Canada's Pest Management Regulatory Agency (PMRA) registered azamethiphos (trade name Salmosan Vet®) in 2017, but while this has been used in eastern Canada, it has not been used to date in BC (DFO data) and is not discussed further here. Similar to antimicrobials, pesticide data are available from DFO as part of the National Aquaculture Public Reporting Data and show site-specific treatment type, frequency of treatment (in 2018 but not 2019), and total quantity by weight of active ingredient.

The total use of EB in 2019 was 33.4 kg. The relative use in grams of active ingredient per ton of salmon production from 2000 to 2020 (from DFO and GSI data) is shown in Figure 11. The relative use has generally been increasing, and the 2019 total of 33.4 kg is the highest in the 2000 to 2019 DFO data. In 2019, 45 of the 76 active sites (59%) were treated with EB. In 2018, the DFO frequency data (not available in 2019) showed 41% of sites were treated with EB and two sites received multiple (two) treatments each. The average number of treatments in 2019 was therefore less than one per year (0.45). Extrapolating to the higher 2019 relative use gives an estimated 0.71 average treatments per site per year.

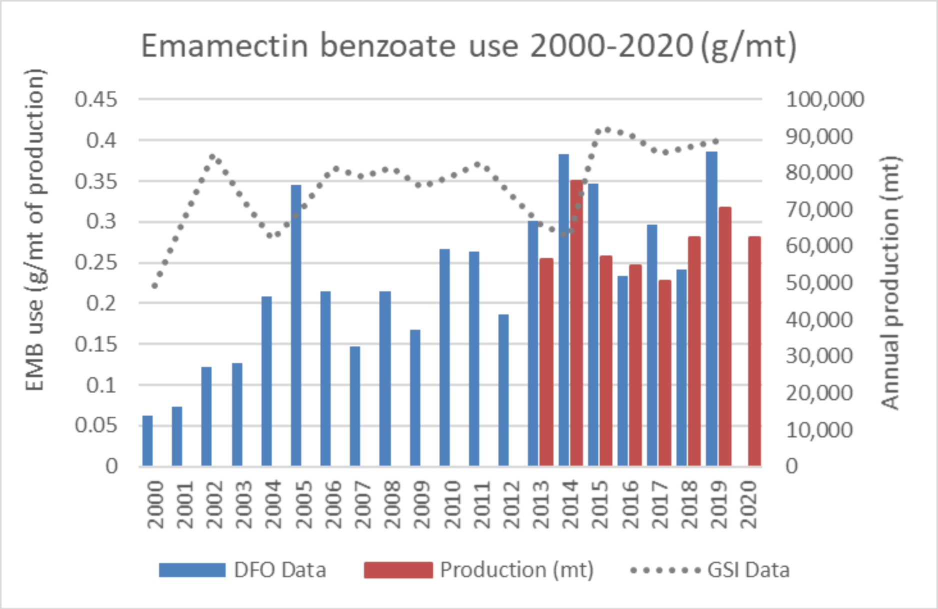

Figure 11: Use of emamectin benzoate (SLICE®) in grams per ton of production in BC between 2000 and 2020 (blue bars – data from DFO). Red bars show GSI data for three[50] large companies. The dashed line shows total salmon production.

The BCSFA (2019a) notes several alternatives or additions to EB treatment are currently used, including hydrogen peroxide, modifications to the net pens (sea lice skirts and snorkel nets), the use of freshwater baths, and hydrolicers (which use water pressure to dislodge lice). Hydrogen peroxide use as an alternative to EB has increased since its introduction in 2014. Twelve sites were treated in 2019 and the 2019 total of 314 mt was substantially higher than the 279 mt in 2018 (even though 22 were treated in 2018). Figure 12 shows the increasing use.

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[50] Mowi no longer reports through GSI, and values from company annual reports have been used.

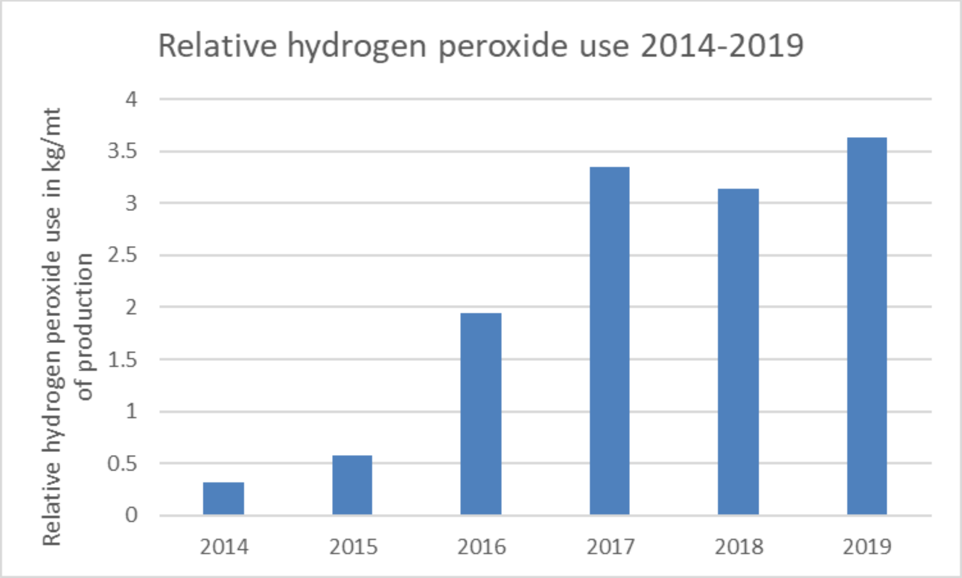

Figure 12: Relative use of hydrogen peroxide from 2014 to 2019 in kilograms per mt of production. Data from DFO.

Pesticide resistance

Most salmonid aquaculture industries globally have documented the emergence of EB resistant sea lice within 5 to 10 years of the product's introduction (Lam et al., 2020). There is widespread resistance in the Atlantic (e.g., Sommerset et al., 2021, in Norway), yet salmon farms in BC have not historically experienced the same issues with treatment efficacy, possibly due to the relatively large population of endemic salmonid hosts that serve to both redistribute surviving lice and dilute populations potentially under selection pressure by introducing naïve lice to farms (Messmer et al., 2018). That is, the migratory hosts maintain a refuge for naïve lice, and represent an ecosystem service to the salmon farming industry (Bateman et al., 2020; Kreitzman et al., 2020).

Nevertheless, although the 2015 testing by Bateman et al. (2016) showed no evidence of reduced sensitivity to EB in the Broughton region, Saksida (2016) reported "evidence of tolerance" in BC, and Messmer et al. (2018) described occasional clusters of lice in BC with increased tolerance to the pesticide, but are clear that these occurrences of higher tolerances remain as exceptions. In contrast, Wristen & Morton (2018) describe anecdotal evidence of developing resistance along the west coast of Vancouver Island, and in an analysis of 2018-2020 sea lice counts and treatment records, Wristen (2020) reported lice were resistant to EB in 39% of treatments and in 69% of treatments when EB was used in combination with bath and mechanical treatment. These numbers have not been independently verified and Wristen represents an NGO critical of the BC industry, but the results indicate that resistance may be developing in many regions of BC despite the relatively low frequency of use of EB with approximately half the sites treated each year, and at an average frequency of less than once per site per year.

With regard to hydrogen peroxide, while there are no apparent data or examples of resistance occurring in BC, it is of interest to note the Norwegian example where Helgesen et al. (2015) reported initial cases of resistance to hydrogen peroxide amongst sea lice populations in Norway, and Somerset et al. (2021) reported that reduced sensitivity to hydrogen peroxide was increasingly widespread. Helgesen et al. (2021) reported less resistance to hydrogen peroxide than the other medicines, but continued to note reduced hydrogen peroxide sensitivity in several areas.

The treatment records in the DFO sea lice counts show the industry uses a suite of chemical (and non-chemical) treatments, but any failure of sea lice treatments (due to increased tolerance in the lice or for any other reason) can allow lice levels to increase dramatically which may exacerbate impacts to wild salmonids (as discussed in Criterion 7 – Disease).

Pesticide impacts

In-feed treatments (i.e., EB) tend to be dispersed in uneaten feed and fecal particles that settle to the seabed (Burridge et al., 2010; Samuelsen et al., 2015). Sea lice pesticides are non-specific (i.e., their toxicity is not specific to the targeted sea lice) and therefore may affect non-target organisms, in particular crustaceans, in the water column and on the seabed in the vicinity of treated net pens (Burridge et al., 2010). The presence of a chemical in the environment does not necessarily mean that it is causing harm (SEPA, 2018), but while the impacts continue to be studied and reviewed, the real effects of these pharmaceuticals on the marine environment remain largely uncertain (Urbina et al., 2019).

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

In Scotland (where the average pesticide frequency was 3.2 treatments per site per year in 2020[51] compared to <1 in BC in 2019), the Scottish Environmental Protection Agency (SEPA) conducted an independent review of the environmental impact of emamectin benzoate on Scotland's seabed from its use on salmon farms, and the results of the analysis (published by SEPA, and in a peer-reviewed academic journal as Bloodworth et al., 2019) indicate that the impacts of farms may extend beyond their immediate vicinity and have confirmed that the existing Environmental Quality Standards (EQS) were not adequately protecting marine life (SEPA, 2018). Though similar in many ways, the Scottish and Canadian ecosystems are not the same, making direct comparison difficult.

In 2011, a Canadian Science Advisory Process was held to assess the impact of EB near aquaculture facilities in British Columbia and its effect on the native spot prawn *Pandalus*

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[51] Calculated from Scotland's Aquaculture database.

platyceros (DFO, 2012). The DFO study detected substantial levels of EB under the farm and a low level at the limit of detection up to 150 m from the farm. The study indicated the potential for EB to remain in sediments close to the farm for 1.5 years after treatment and, therefore, to accumulate if multiple treatments occurred at any one site. It concluded, "*(i) EB can remain and so potentially buildup in benthic sediments close to salmon farms, depending on the frequency and extent of SLICE® usage and the local site conditions; and (ii) EB is bioavailable and can be measured in the muscle tissues of spot prawns collected near salmon farms treated with SLICE®."* Similarly, Iknomou & Surridge (2013) reported a distinct concentration gradient within 50-100 m where EB was detected at low ng/g levels in shrimp tissue and sediments. With impacts restricted to the immediate farm area, significant impacts to spot prawn populations seem unlikely. Park (2013) also studied the biological effects of EB on spot prawn in the field and laboratory and showed that prawns seem to avoid pellets coated in EB when other food sources are available, and that mortality, molting success, and behavior only changed when short term EB exposure was 50-200 times greater than levels observed in the marine environment. However, Park (2013) also found that the size distribution of the prawns shifted at sites treated with EB, but not at reference sites, suggesting that some consideration should be placed on the potential effects of long-term chronic EB exposure rather than just its short-term acute toxicity.

Although hydrogen peroxide breaks down relatively rapidly in the environment, Grefsrud et al. (2021a,b) reviewed the available information (in Norway) on its presence in the environment (based on the volume used, its spread and dilution, and its decomposition) and its environmental effects on non-target species (based on the sensitivity of the non-target organisms and the seasonal overlap between its use and the presence of those non-target organisms). In both Norway and BC, hydrogen peroxide is administered as a bath typically in a well boat – allowing the discharge at appropriate locations potentially remote to the treated farm site. Nevertheless, (and noting that the use of hydrogen peroxide is much higher in Norway compared to BC at approximately 5,000 mt in 2020 compared to 314 mt in BC in 2019), Grefsrud et al. (2021a) concluded that the risk of environmental impact on non-target organisms through the use of hydrogen peroxide was "moderate", and thereby the same as deltamethrin, diflubenzuron and teflubenzuron, emamectin benzoate, and worse than azamethiphos.

Overall, the use of pesticides in BC is currently low (less than one treatment per site per year on average) and used in response to the need to control sea lice numbers during important periods for wild salmon migration. While the impacts of their use in BC are not yet fully understood, the available evidence indicates that significant impacts are likely to be constrained to an area commonly accepted as an "allowable zone of effect", similar to that impacted by organic enrichment. While there may be impacts to organisms within this area, there is little evidence for concern beyond the net pens.

Metals

The number of sites using copper antifoulants on net pens in BC is uncertain; for example, Marine Harvest Canada eliminated copper-treated nets in 2012[52], and BCSFA (2019) note the vast majority of BC salmon farms have eliminated the use of copper-based anti-foulant coatings. Regarding potential impacts, Russell et al. (2011) (in Scotland) showed sediment samples with concentrations of copper which might cause adverse effects in the environment were all samples from within 25 m of the net pens. In addition, the biochemistry of copper availability in fish farm sediments is complex; any copper accumulation beneath salmon farms occurs in conjunction with high organic loading and it becomes difficult to confirm that changes in populations or communities are related to concentrations of copper and zinc (Burridge et al. 2011) rather than confounding factors. Although monitoring of metal residues is no longer required in BC, the potential deposition of copper is not considered a high concern.

Chemical use management and governance in BC

While the types of antimicrobials and pesticides are regulated in BC, there are no limits in place on the frequency or total quantities of their use. In 2018, the Canadian Government conducted an independent audit focused on whether DFO and the Canadian Food Inspection Agency (CFIA) managed the risks associated with salmon aquaculture in a manner that protected wild fish (Gelfand, 2018). Overall, the audit found DFO did not conduct adequate analysis to know whether its rules for drug and pesticide deposits at salmon farms would minimize harm to wild fish, and DFO did not define limits on the amount of drugs or pesticides that could be deposited, or confirm the accuracy of information self-reported by aquaculture companies.

Conclusions and Final Score

Antimicrobial use varies each year according to treatment needs, but has declined substantially since the peaks of the late 1990s (noting that much of this decline was due to the industry's transition from farming Chinook salmon to Atlantic salmon in the mid-2000s, with the former species requiring higher uses of antimicrobials). The use in 2020 was relatively low at 53 g/mt of production, compared to approximately 140 g/mt in 2018. Approximately half of active sites are treated with antimicrobials each year in BC, with 52% and 54% of active sites receiving an antimicrobial treatment in 2018 and 2019 respectively (i.e., 48% and 46% of sites respectively received no antimicrobial treatments). Two antimicrobial types are used – oxytetracycline and florfenicol – both of which are listed as highly important to human medicine by the WHO. Approximately 1 in 10 active sites are treated each year with oxytetracycline, and half the sites are treated with florfenicol. A simple averaging across all active sites indicates a three-year average of 1.3 antimicrobial treatments per site per year from 2018 to 2020, but with a focus on treatments of small fish soon after entry to seawater (for mouth rot – *T. maritimum)* (and therefore relatively small amounts of antimicrobial used per treatment), the median treatment number per treated site was three treatments (using 2018 and 2019 DFO data). This indicates that while many sites are not treated, those that are treated have multiple treatments per year.

The industry follows prudent use guidelines for antimicrobials and complies with the recommendations of the WHO Guidelines on Use of Medically Important Antimicrobials in

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[52] http://www.marineharvest.ca/about/news-and-media/container2012/october-1-2012/

Food-producing Animals. However, the limited availability of data on antimicrobial resistance or efficacy monitoring, or other relevant research in BC, limits the ability to understand how the industry's antimicrobial use patterns (i.e., approximately half the sites receiving no treatments, and the other half receiving multiple treatments) drive or contribute to the presence or development (if any) of antimicrobial resistance. The industry considers the antimicrobial treatments to still be extremely efficacious after decades of antibiotic usage to treat fish when required.

The use of pesticides of environmental concern (i.e., emamectin benzoate - EB, and hydrogen peroxide) in BC is currently less than once per year per site. While the impacts of their use in BC are not yet fully understood, the available evidence indicates that significant impacts are likely to be constrained to an area commonly accepted as an "allowable zone of effect", similar to that impacted by organic enrichment. While increased tolerance (i.e., resistance) to EB has been slow to develop in BC compared to other regions and the industry uses a variety of alternatives, reduced efficacy of EB treatments is increasingly being reported. It is an area of concern to follow.

Overall, the open nature of the net pen production system provides no barrier to infection from environmental pathogens, and while many sites are not treated with antimicrobials, the three-year average number of treatments per site has been 1.3 and the median number of treatments at treated sites has been three in the most recent DFO data years (2018-2019). As such, the use of antimicrobials that are highly important for human medicine at >1 treatment per site per year is a high concern and the final score for Criterion 4 – Chemical Use is 2 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 the efficiency of conversion can result in net food gains or dramatic net losses of nutrients.
- Unit of sustainability: The amount and sustainability of wild fish caught for feeding to farmed fish, the global impacts of harvesting or cultivating feed ingredients, and the net nutritional gains or losses from the farming operation.
- Principle: Sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains

Criterion 5 Summary

C5 Feed parameters	**Value**	**Score**
F5.1a Forage Fish Efficiency Ratio	1.56	
F5.1b Source fishery sustainability score (0-10)		6
F5.1: Wild fish use score (0-10)		4.67
F5.2a Protein INPUT (kg/100kg fish harvested)	46.67	
F5.2b Protein OUT (kg/100kg fish harvested)	16.90	
F5.2: Net Protein Gain or Loss (%)	-63.79	3
F5.3: Species-specific kg CO2-eq kg-1 farmed seafood protein	23.54	4
C5 Feed Final Score (0-10)		**4.09**
Critical?	No	Yellow

Brief Summary

An approximate feed composition of key ingredients was supplied by two BC feed companies via the BCSFA. Additional data from salmon farming company reports and reference feeds in the academic literature were also used to represent BC salmon feeds. Performance results were verified against public reporting where possible (e.g., GSI). With total fishmeal and fish oil inclusions of 5.2% and 10.5% respectively, modest use of fish oil from by-product sources, and an eFCR of 1.3, from first principles 1.56 mt of wild fish must be caught to produce the fish oil needed to grow 1.0 mt of farmed salmon. Information on the sustainability of source fisheries obtained directly from one BC company and from two additional major feed companies from the Ocean Disclosure Project showed a moderate overall sustainability and resulted in a Wild Fish Use score of 4.67 out of 10. There is a net loss of 63.8% of feed protein (score 3 out of 10) and an estimated feed ingredient footprint (global warming potential) of 23.54 kg CO_2-eq. per kg of harvested protein (score of 4 out of 10). Overall, the three factors combine to result in a final Criterion 5 – Feed score of 4.09 out of 10.

Justification of Rating
The Seafood Watch Feed Criterion assesses three factors: wild fish use (including the sustainability of the source), net protein gain or loss, and the feed "footprint" based on the climate change impact (CCI, in units of in CO_2-eq/kg including land use change) of the feed ingredients

necessary to grow one kilogram of farmed salmon protein. See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations.

Feed composition
An approximate feed composition of key ingredients was supplied by two BC feed companies via the BCSFA. Other data sources were also considered, such as global and regional data from Mowi's Salmon Industry Handbook (Mowi, 2020), and specific ingredients in two salmon reference diets in Mørkøre et al. (2020) and Aas et al. (2019). The ingredient inclusion in the two feed formulations provided by the BCSFA totaled 71.7%, and while key figures for marine ingredients (required for Factor 5.1) were present, estimating the remaining 28.3% of the formulation is important for Factor 5.3. Therefore, the remaining 29% was allocated (based on the reference diets noted above) to soy protein concentrate as it has a relatively high climate change impact potential value on a precautionary basis.

As such, a best-fit feed composition has been compiled from the available data as shown in Table 1, along with each ingredient's Global Feed Lifecycle Institute (GFLI) Climate Change (CC)/mt value (see Factor 5.3). Country-of-origin data were not available for the ingredients, with the exception of the marine ingredients articulated further in Factor 5.1b. While this composition might not reflect the exact ingredients and their inclusions, it is considered to be sufficiently representative of a typical BC salmon feed for this assessment.

Table 1: Best-fit feed composition and GFLI values from the available data.

Feed Ingredient	Inclusion (% of total feed)	GFLI value
Fishmeal	4.6	1.1843
Fishmeal byproducts	0.6	1.1843
Fish oil	8.9	0.8176
Fish oil byproducts	1.6	0.8176
Wheat gluten	3.6	3.9989
Soy protein concentrate	28.3	6.417
Corn gluten	6.7	1.5647
Rapeseed (canola) Oil	15.3	2.9154
Poultry meal	23.9	1.2334
Poultry oil	3.5	3.1717
Vitamin/minerals/other	3.0	No data
Total	100.0	

Economic feed conversion ratio (FCR)
General eFCR values in the academic literature for Atlantic salmon (i.e., not specific to any region) are 1.3 (Tacon et al., 2021; Naylor et al., 2021; Tacon, 2020). The BCSFA (2019) state BC farmed salmon "now require as little as 1.15 – 1.2 kg of feed to gain 1 kg of body weight". The

phrasing here implies this is perhaps the best-case scenario, and also perhaps a biological FCR[53]. The BCSFA dashboard[54] states 1.2 to 1.5. While Mowi's 2019 annual company report states an eFCR of 1.14, the global values from Mowi's Industry Handbook (Mowi, 2020) (i.e., representing all salmon farming companies globally) and Aas et al (2019) are 1.3, and this value is used here. It is recognized that these are primarily industry-generated data.

Factor 5.1. Wild Fish Use

Factor 5.1a – Feed Fish Efficiency Ratio (FFER)

Using the data in Table 1, the eFCR value of 1.3, and the yield values for fishmeal and fish oil (22.5% and 7.5% respectively, provided by the feed ompanies), the Forage Fish Efficiency Ratio (FFER) is 0.27 for fishmeal and 1.56 for fish oil. This means that from first principles, 1.56 mt of wild fish must be caught to supply the fish oil needed to produce 1.00 mt of farmed salmon. The 0.27 value for fishmeal is lower than the three-year average (2018-2020) of two BC companies (Grieg and Cermaq) that report FFDR[55] for fishmeal of 0.51. However, the 1.56 value calculated here is higher than the same 3-year GSI average of 1.32, but the same as the 2020 average of the two companies (1.57).

Factor 5.1b –Sustainability of the Source of Wild Fish

Aggregated data on the certification status of source fisheries supplying fishmeal and fish oil for salmon feeds was provided by one feed company in BC. The source fisheries and their status for BC feeds are otherwise unknown. While the single company's data were used, the global data for three major feed companies (Biomar, Ewos-Cargill, and Skretting) reporting through the Ocean Disclosure Project were also used[56]. While each of these three companies has a sustainable sourcing policy, the fisheries used are the more practical manifestation of their sourcing policies.

The Ocean Disclosure Project data covered approximately 38 different fisheries used by the three companies, and report the management status of the fishery (certified, well-managed, managed, needs improvement, and not rated[57]). It is not known which fisheries supplied fishmeal, fish oil, or both, nor are the weightings of each source known (i.e., which sources are most commonly used in BC feeds and how much). Therefore, an aggregated sustainability score for fishmeal and fish oil has been generated across all three feed companies (incorporating the single company's data) and used here for BC. Again, this may not reflect the exact fisheries sources used in all BC salmon feeds but is considered to be acceptably representative.

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[53] The calculation for economic FCR takes account of mortalities and other losses during a production cycle.

[54] https://dashboard.bcsalmonfarmers.ca/kgs-of-feed-required-per-kg-of-protein

[55] FFDR - Forage Fish Dependency Ratio is the same as FFER

[56] https://oceandisclosureproject.org/

[57] Additional sub-categories of partly certified and Fishery Improvement Project are provided by the ODP, but these were not considered relevant to the SFW scoring and the primary management category was used by default.

Table 2: Source fishery sustainability categories from the Ocean Disclosure Project

Fishery status	Percent of fisheries	SFW Sustainability score	Weighted score
Certified	59.2	7	4.2
Well Managed	7.8	6	0.5
Managed	11.5	4	0.5
In need of improvement	14.4	3	0.3
Not rated	7.0	2	0.1
		Weighted sustainability score (0-10)	**5.6**

The weight-calculated sustainability score is 5.6 out of 10. Rounding this score to the nearest integer, the final Factor 5.1b sustainability score is 6 out of 10, and in combination with the FFER value of 1.56, results in a final score for Factor 5.1 - Wild Fish Use of 4.67 out of 10.

Factor 5.2. Net Protein Gain or Loss

A value for the total protein content of BC feeds was not supplied by the feed companies, but values for typical salmon feeds from the suite of references stated above average to 35.9% (with a range of 35% to 36.4%). Aas et al. (2019) specify a whole-body composition of farmed salmon of 16.9% crude protein.

Therefore, one ton of feed contains 359 kg of protein; 1.3 tons of feed are used to produce 1.00 ton of farmed salmon (eFCR), so the net protein input per ton of farmed salmon production is 466.7 kg. With only 169 kg of protein in one ton of harvested whole salmon, there is a net loss of 63.8% of protein. This results in a score of 3 out of 10 for Factor 5.2.

Factor 5.3 Feed Footprint

This factor is an approximation of the embedded climate change impact (CCI, in units of kg CO_2-eq) of the feed ingredients required to grow one kilogram of farmed seafood protein. The calculation is performed by mapping the ingredient composition of a feed used against the Global Feed Lifecycle Institute (GFLI) database[58] to estimate the climate change impact (CCI) of one metric ton of feed, followed by multiplying this value by the eFCR and the protein content of whole harvested salmon. If an ingredient of unknown or unlisted origin is found in the GFLI database, an average value between the listed global “GLO” value and worst listed value for that ingredient is applied; this approach is intended to incentivize data transparency and provision. Detailed calculation methodology can be found in Appendix 3 of the Seafood Watch Aquaculture Standard.

Calculations based on the GFLI values presented in Table 1 above and following the methodology in the Seafood Watch Aquaculture Standard indicate the CCI is 23.54 kg CO_2-eq per kg of farmed salmon protein. This results in a score of 4 out of 10 for Factor 5.3.

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

Conclusions and Final Score

The final score is a combination of the three factors with a double weighting for the Wild Fish Use factor. Factors 5.1 (4.67 out of 10), 5.2 (3 out of 10), and 5.3 (4 out of 10) combine to result in a final score of 4.09 out of 10 for Criterion 5 – Feed.

Criterion 6: Escapes

Impact, unit of sustainability and principle

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

Criterion 6 Summary

C6 Escape parameters		Value	Score
F6.1 System escape risk (0-10)		4	
F6.1 Recapture adjustment (0-10)		0	
F6.1 Final escape risk score (0-10)			4
F6.2 Competitive and genetic interactions score (0-10)			6
C6 Escape Final Score (0-10)			**5**
	Critical?	No	Yellow

Brief Summary

After eight years of very low reported escape numbers of Atlantic salmon in BC, the escape of nearly 21,000 fish at the end of 2019 (and those continually occurring in every other salmon farming region globally) highlighted the inherent risk of escapes from net pen production systems. Large escape events affect a very small proportion of sites in BC, but the ten-year average loss of Atlantic salmon is 2,229 fish per year. Significant undetected or unreported trickle escapes may also occur. With the exception of the recapture of many Atlantic salmon in BC in 2017 after an escape from Washington state in the US (just south of the BC industry), the numbers of Atlantic salmon detected in the wild in BC are low. Atlantic salmon are non-native in BC but there have been hundreds of deliberate efforts over more than a century to establish the species for sportfishing in BC. Evidence increasingly shows the species to be a poor colonizer outside of its native range, and despite the large numbers of escapes over recent decades, there is currently no evidence of establishment and Atlantic salmon are considered highly unlikely to become established in BC. The moderate-high risk of escapes combined with the low risk of competitive or genetic impacts results in a final score for Criterion 6 – Escapes of 5 out of 10.

Justification of Rating

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

Factor 6.1 Escape Risk

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

The 2018 Spring Reports of the Commissioner of the Environment and Sustainable Development to the Parliament of Canada (Galfand, 2018) noted that although DFO did not set a national standard for nets and other equipment to prevent fish escapes, the Department did require aquaculture companies in BC to follow its standard for net support structures and anchoring systems, and to properly maintain equipment under the Pacific Aquaculture Regulations. In BC, when there is evidence that an escape has occurred (even of only one fish), salmon farms are required to report the incident to DFO within 24 hours, detailing the cause, time, and location of the event, the species, size, number of fish involved, and any recent therapeutant treatments administered to the escapees; a more detailed written report must be submitted to DFO within seven days[59].

DFO has published (industry-reported) escape data for Atlantic and Pacific salmon since 1987[60] (Figure 13). The number of industry-wide reported escapes of Atlantic salmon since 2010 has been very low (a maximum of 23 fish in 2016) until a large escape of 20,973 fish at the end of 2019. The ten-year average is 2,229 Atlantic salmon escapes per year.

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[59] Public Reports on Aquaculture – Escapes http://www.dfo-mpo.gc.ca/aquaculture/protect-protege/escape-prevention-evasions-eng.html

[60] https://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/escapes-evasions/index-eng.html#wb-auto-4

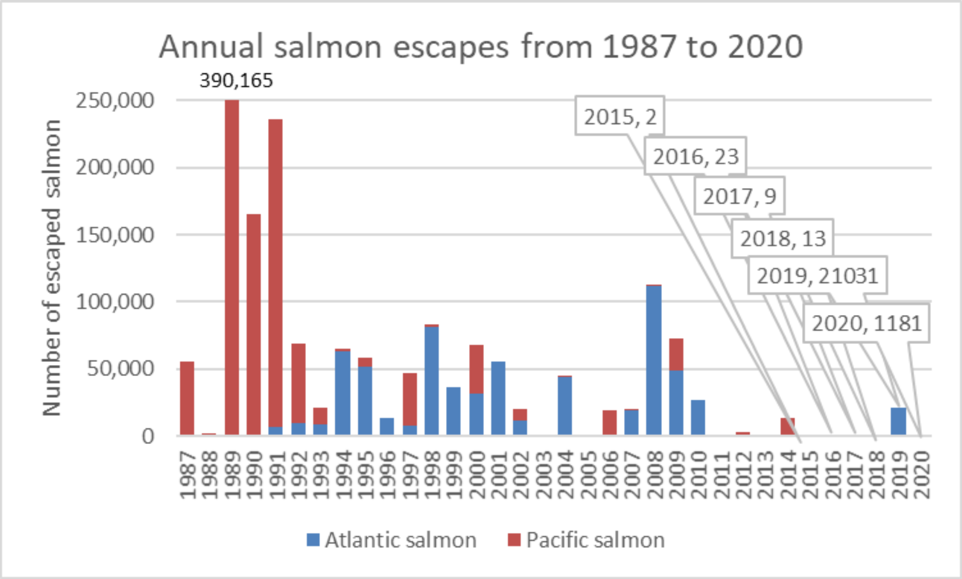

Figure 13: Industry-reported escape figures in British Columbia. Data labels indicate the escapes of Atlantic salmon from 2015 to 2020. Data from DFO.

The BCSFA attribute the low frequency of escapes since 2010 to better containment technology, particularly the use of HDPE netting. Large escape events are limited to a small number of sites. For example, in 2007, an escape of 19,168 fish dominated the total of 19,223, in 2009, an escape of 47,000 fish dominated the total of 48,858, and an escape of 15,000 fish was dominant in 2010 (more escape events happened in 2008, but were still dominated by a small number of large events) (Gillespie, 2013; Anderson, 2008). Therefore, preventing a very small number of large escape events leads to low numbers of reported escapes overall in recent years, and it can be seen that the vast majority of sites in BC have not had any reported escape events for many years until 2019.

While these isolated catastrophic escape events are clearly limited to a very small number and small proportion of the salmon farms in BC, it is considered that lesser-reported trickle losses can also be significant and potentially not detected or reported (Leggatt et al., 2010; Taranger et al., 2011). For example, Sistiaga et al. (2020) noted the escape of small smolts through farm netting is a major challenge faced by the Norwegian salmon farming industry when the smolts placed in the net pens are smaller than the size estimated by the farmers, and this is considered to be a similar risk in BC. Escape statistics are usually based on reports by the farmers themselves and are likely to underestimate, significantly in some circumstances, the actual number of fish escaping from farms (Glover et al., 2017). In Norway, where significant research has taken place, Skilbrei and Wennevik (2006) note small-scale undetected or unreported escape events may make up a large portion of the total number of escaped fish, and a modelling analysis by Skilbrei et al. (2015) suggests that the total numbers of post-smolt and adult escapees have been two- to four-fold higher than the numbers reported to the authorities by farmers. ICES (2016) also support the notion that the true number of escapees is likely to be significantly higher than reported figures.

The challenge to accurately count the large numbers of fish in any one cage is shown by the concept of "unexplained loss"; for example, public reporting by salmon farming companies in BC as part of the ASC certification requirements (e.g., Cermaq[61]) demonstrates that the realistic counting accuracy available to salmon farming companies (e.g., +/- <2% of the actual number) allows large differences in inventory counts – both positive and negative. In their reporting from 2017 to 2019, Cermaq report differences in the expected counts at harvest (i.e., the difference between the count at stocking minus any known removals, and the count at harvest) of between -13,925 and +6,218 fish. Therefore, it cannot be known if these "unexplained losses" are true loss (i.e., escapes), or simply due to the inherent inaccuracy of the counting system, but they highlight the potential for undetected escapes of smaller numbers of fish to occur.

With regard to the detection of escaped farmed salmon in the wild in BC, Price et al. (2017) reported monitoring efforts had declined steadily since the 1980s, while since the 2017 Cypress Island escape (more details below), Blasco (2019) reported there had been high surveillance. Volpe et al. (2000) reported escaped farmed salmon had been found in more than 80 BC rivers (sampled during a multi-year period of sustained high escapes), but a survey conducted by DFO in 2011 and 2012 (Andres, 2015) did not observe any Atlantic salmon in the rivers sampled – rivers considered most likely to contain escapes. The majority of the non-targeted sightings or captures have been reported through the Atlantic Salmon Watch Program (ASWP)[62] but the level of activity within the program is unclear. In August 2017, between 243,000 and 263,000 Atlantic salmon (of which 57,000 were recovered) escaped from the Cypress Island farm site just south of the Canada-US border in Washington State (Blasco, 2019). Prior to this event (from 2011 to 2017), the ASWP program confirmed only three captures of Atlantic salmon in BC[63]. After it, there were 78 confirmed Atlantic salmon caught in BC, and further examination confirmed 98% were from Cypress Island. Blasco (2019) reported that in 2018, the number of confirmed Atlantic salmon in BC fell to only two, and fourteen river surveys returned no observations of Atlantic salmon in 2018; as such, Blasco (2019) concluded that there had been few sightings in rivers in recent years despite high surveillance.

While the available monitoring data indicate only the occasional detection of low numbers of escapees in the wild, the escape event of nearly 21,000 fish in 2019 and the likelihood of trickle losses demonstrate the inherent vulnerability of the net pen production system to such events. Ultimately, the initial score for Factor 6.1 – Escape Risk is 4 out of 10.

Recaptures

Noakes (2011) reported a small percentage (less than 5% on average) of the escaped Atlantic salmon to be observed or reported being caught in ocean fisheries or in freshwater in BC, while largely incomplete data in Piccolo and Orlikowska (2012) show highly sporadic recaptures of

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[61] https://www.cermaq.com/wps/wcm/connect/cermaq-ca/cermaq-canada/our+sustainable+choice/public-reporting

[62] http://www.pac.dfo-mpo.gc.ca/fm-gp/rec/species-especes/atlant-eng.html

[63] https://open.canada.ca/data/en/dataset/f0299fb3-73b9-4977-b96a-c83bd84ebdc4

Atlantic salmon in Washington State, BC, and Alaska. Although these recaptures were most substantial in BC (for example, 7,834 fish in the year 2000), the last figures included were from 2002. Pacific aquaculture licenses do not require recapture efforts. This is considered to be due to a reduced number of escapes, and a reduced concern of potential impacts from competition or establishment (Dolmage, pers. comm., 2017). After the 2017 Cypress Island escape just south of the BC industry approximately 22% of fish were recovered (Blasco et al., 2019) including some in BC, but this cannot be assumed to be the case in a similar event in BC. There is no robust justification for a recapture adjustment, and the final score for Factor 6.1 – Escape Risk is 4 out of 10.

Factor 6.2 Competitive and Genetic Interactions

Atlantic salmon are a non-native species on the Pacific coast of Canada, and as such, have the theoretical potential to cause considerable harm to ecosystems in BC and further afield. Atlantic salmon (presumed to be from BC or Washington State farms in the US) have in the past been caught in southeast and even northern Alaska (Piccolo and Orlikowska 2012), and have also been caught or observed in many rivers and streams in BC and Puget Sound (Bisson, 2006; Korman, 2011, Fisher et al., 2014; Noakes, 2011; Blanco, 2019).

The successful natural spawning of Atlantic salmon was reported in the Tsitika River on Vancouver Island in 1997 and 1998 (Volpe et al., 2000), and 20 years ago, three river systems in BC were reported to support wild-spawned juvenile Atlantic salmon (Volpe et al., 2001).

Since then, there has been no further evidence of spawning of Atlantic salmon in BC (or anywhere else in the Pacific Ocean), and while not specifically looking for Atlantic salmon, it is important to note that there have been no reports of juvenile Atlantic salmon being caught in the extensive annual sampling of juvenile Pacific salmon in various locations in BC (see Criterion 7 – Disease). Similarly, annual surveys of juvenile Pacific salmon migrations by DFO from 2010 to 2017 reported zero Atlantic salmon amongst 229,000 salmonids captured via purse seine and trawl (Neville et al. 2016; BCSFA, 2020 – based on personal communication with Neville).

There have been many deliberate attempts to establish Atlantic salmon across North America (and elsewhere), and a review by the OECD (2017) summarized the following:

> During the early 1900s attempts were made to introduce Atlantic salmon to some British Columbia (Canadian Pacific coast) watersheds in a deliberate attempt to establish runs for sport fishing. Nearly 200 introductions were made into 52 different water bodies and a total of 13.9 million eggs, alevins, fry or smolts were introduced. None of these introductions was successful in terms of establishing runs of Atlantic salmon on the British Columbia coast. In the United States there have been at least 170 attempts in 34 different states where Atlantic salmon were not native, including Washington, Oregon, and California. None of these efforts was successful. For example, in Washington State attempts were made from 1904 to 1991 by U.S. agencies to introduce and establish Atlantic salmon and not a single self-sustaining population was established. Similar results have occurred with Atlantic salmon introductions in

> Australia, New Zealand, South Africa, Chile and many other countries. There has never been a documented successful introduction (i.e. resulting in a self-sustainable population) of sea run Atlantic salmon outside of their natural territory where other native salmon species were present.

Yet, a theoretical concern for establishment remains with increasing generations of Pacific-raised farm stocks; for example, Bisson (2006) states: "Despite a long history of failure to establish Atlantic salmon from single or a few deliberate introductions, it seems possible that continuous recruitment of fish escaping from farming operations may eventually lead to locally-adapted stocks. At that point, the species may rapidly become a dangerous invasive—a pattern that is often seen in other aquatic plants and animals where a prolonged early colonization period is followed by a rapid phase of exponential growth."

Alternatively, it could be argued that the continuing domestication of farmed salmon would make them less likely to establish in the wild; Jonsson and Jonsson (2006) list a number of genetic, morphological, and physiological characteristics of farmed salmon (also quoting Gross et al., 1998) that result in less competitive and reproductive potential. One likely demonstration of this phenomenon was when Noakes (2011) reported that of 1,584 recaptured salmon in BC, 80% had empty stomachs, leading the author to conclude that "most escaped Atlantic salmon do not successfully feed and survive for any extended period of time."

Overall, while considered to occasionally be present in the wild – a result of farm escapement – Atlantic salmon are considered highly unlikely to establish in BC, and currently there is no evidence of any significant ecological impacts of their escape. The score for Factor 6.2 – Competitive and Genetic Interactions is 6 out of 10.

Conclusions and Final Score

After eight years of very low reported escape numbers of Atlantic salmon in BC, the escape of nearly 21,000 fish at the end of 2019 (and those continually occurring in every other salmon farming region globally) highlighted the inherent risk of escapes from net pen production systems. Large escape events affect a very small proportion of sites in BC, but the ten-year average loss of Atlantic salmon is 2,229 fish per year. Significant undetected or unreported trickle escapes may also occur. With the exception of the recapture of many Atlantic salmon in BC in 2017 after an escape from Washington state in the US (just south of the BC industry), the numbers of Atlantic salmon detected in the wild in BC are low. Atlantic salmon are non-native in BC but there have been hundreds of deliberate efforts over more than a century to establish the species for sportfishing in BC. Evidence increasingly shows the species to be a poor colonizer outside of its native range, and despite the large numbers of escapes over recent decades, there is currently no evidence of establishment and Atlantic salmon are considered highly unlikely to become established in BC. The moderate-high risk of escapes combined with the low risk of competitive or genetic impacts results in a final score for Criterion 6 – Escapes of 5 out of 10.

Criterion 7. Disease; Pathogen and Parasite Interactions

Impact, unit of sustainability and principle

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

Criterion 7 Summary

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

Brief Summary

Many species of Pacific salmon are in decline over large geographical areas, including areas with and without salmon farms or salmon farming industries. As such, it is clear that pathogens or parasites from salmon farms have not caused the widespread decline, but given the importance of wild salmon (considered essential to life by indigenous communities in BC), any substantial contributions to their local declines or inhibitions of their recovery must be considered. The consequences of pathogen infection are highly variable depending on the individual, the strain of the pathogen, and the circumstances, thus driving the challenge of studying their impacts effectively in wild populations. The DFO risk assessments (for the risk of nine pathogens from farms in the Discovery Islands impacting the abundance or diversity of Fraser River sockeye salmon) are important studies with which to frame the components to be considered, yet despite their findings that all nine viral and bacterial pathogens had a “minimal” risk of impact when considered individually, the limitations in their scope are apparent with regard to other pathogens and parasites (both individually and in combination), and to other species of salmon in other areas of BC. Recent research continues to develop rapidly on many fronts and is making many associations between farm viruses and wild salmon, yet with few robust conclusions on transmission, infection, morbidity, or mortality in wild salmon. This challenge of drawing conclusions is perhaps best illustrated by a 2021 publication from the Strategic Salmon Health Initiative that notes (emphasis added here) “the <u>risk</u> of disease transmission from farmed to wild fish has increased, with <u>potential to contribute</u> to declines in wild fish populations, but <u>the probability and magnitude of this transmission has not been determined</u>” (note the use of this statement here is not intended to imply any particular level of impact or concern, but is simply utilized to highlight the challenge in drawing conclusions and in determining the appropriate level of concern). It therefore currently remains largely impossible to clearly differentiate between the speculation that viruses are driving or significantly contributing to the declines of wild salmon and the contrasting position reflected in the DFO risk assessments and other recent studies that bacterial and viral pathogens from Atlantic salmon farms are of minimal concern to wild salmon in BC.

With regard to parasitic sea lice, the large amount of data available indicates high geographic and temporal variability in lice levels on farms in most regions. In contrast to a period of stability in sea lice numbers up to 2015, there have been substantial outbreaks (e.g., average lice levels above the three-lice treatment threshold) in one or more reporting regions in most of the last five years, and frequent high lice levels in some regions, particularly the west and northwest coasts of Vancouver Island. The regulations allow lice to increase to high levels on farms (above the treatment threshold) without breaching the conditions of license. The numbers of lice observed on out-migrating juvenile wild salmon are also highly variable both geographically and temporally. The tolerance of juvenile Pacific salmon to sea lice infection varies considerably by species and particularly by size. For some, even low abundances of lice on very small juvenile salmon may cause mortality or sublethal effects on physiology and behavior, but susceptibility in young fish changes rapidly with age, and therefore their risk of being impacted by on-farm lice changes substantially during the four-month outmigration period. Therefore, the prevalence and intensity of lice seen on wild fish does not necessarily imply mortality or significant impact to individual fish, yet given the high regional and temporal variability, it is likely that there will be substantial mortality in some areas in some years. Sub-lethal impacts and increased risk of predation may also be important. Like bacterial and viral pathogens, the ongoing controversy regarding the impacts of sea lice highlights the lack of conclusive outcomes to date, but with repeated lice outbreaks in some areas during the outmigration period, the level of concern has increased.

The analysis here has been limited to a simplistic overview and highlights the ongoing uncertainty in the cumulative impacts of pathogens and parasites from farms to wild salmon populations across BC, but given the status of wild salmon populations, the uncertainties largely define the need for a precautionary approach. While the volumes of data and research on this topic are large and continually increasing, the complexities (highlighted by the research) mean the impacts of salmon farming alone cannot be quantified robustly; as such, the Risk-Based Assessment method is used. Overall, the potential pathogen and parasite interactions between farmed and wild salmon in BC, and particularly the repeated sea lice outbreaks in some areas during the outmigration period, must be considered a high concern until further evidence indicates otherwise. With open production systems discharging viral, bacterial, and parasitic pathogens into waterbodies shared with vulnerable and endangered wild salmon populations, there is a high concern and the final score for Criterion 7 – Disease is 0 out of 10.

Justification of Rating

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

Acknowledging that pathogen detection alone is insufficient to allow inferences of the overall health status of wild fish populations and requires the context of host susceptibility, virulence of pathogen strains, and environmental conditions (Jia et al., 2020), the expansion of salmon aquaculture has brought conservation concerns into regions (such as BC) where the areas occupied by salmon farms are often important migratory corridors for wild salmon (Peacock et al., 2014).

This Disease Criterion is split into two sections: first, bacterial and viral pathogens, and second, parasitic sea lice. Due to the significant challenge in robustly quantifying the impacts to wild salmon (despite the considerable body of data and literature available), the Risk-Based Assessment method has been used.

Bacterial and Viral Pathogens

There is a large and rapidly developing body of scientific literature on bacterial and viral pathogens on salmon farms and their potential impacts to wild fish, particularly wild salmon, in BC. Given the complexity and highly specialized nature of many different aspects of this research, the methodology used in nine assessments of the risk to Fraser River sockeye salmon from the transfer of pathogens from Atlantic salmon farms in the Discovery Islands area of BC (conducted by DFO[64]) are used here as a framework for discussion. Figure 14 provides an overview of the risk assessment methodology for reference (in this case referring to Infectious Hematopoietic Necrosis Virus - IHNV, but the model is the same for all nine pathogens). It is noted here that the basic methodology used by DFO is similar to that used by the Institute of Marine Research in Norway to assess the risk of changes in the incidence of disease in wild salmon as a result of virus transmission from fish farming (in Grefsrud et al., 2021a). These are at the global leading edge of research to understand the dynamics of pathogen- and parastite-related interactions between farmed species and wild species. However, the narrow scope of the DFO risk assessments (i.e., nine pathogens, assessed individually, one population of wild fish, and one area of farms) is noted and discussed below.

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

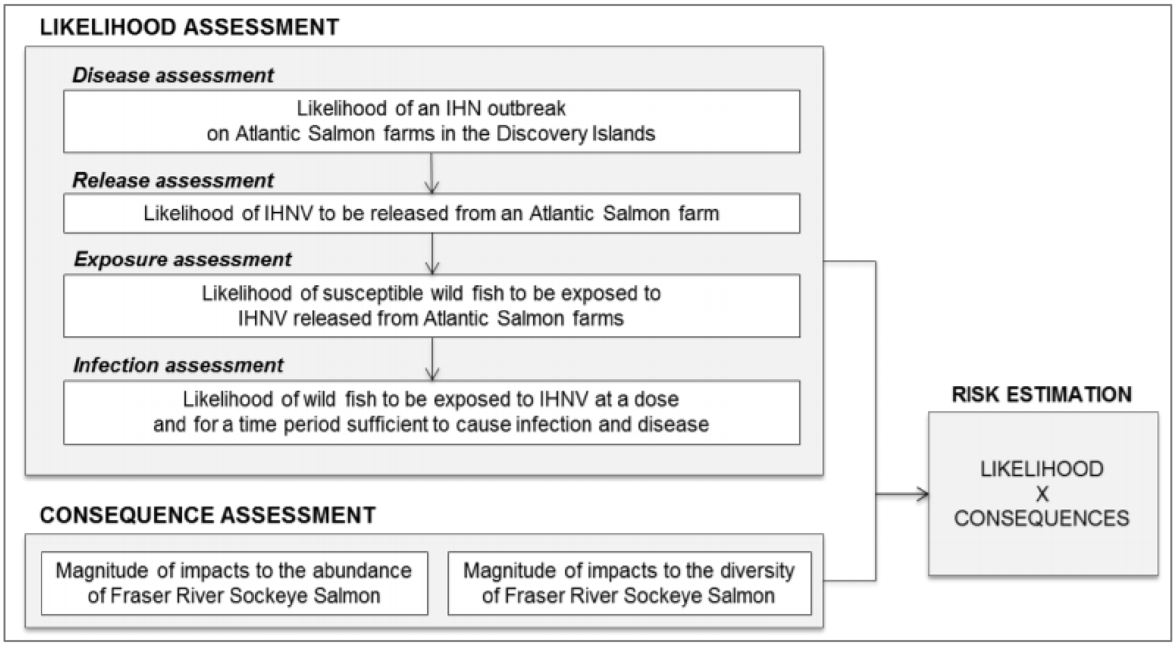

Figure 14: Conceptual model for risk assessment of IHN virus to Fraser River Sockeye salmon attributable to Atlantic Salmon farms located in the Discovery Islands, BC. Image and title copied from DFO (2017).

Bacterial and viral pathogens on fish farms

With regard to disease outbreaks on Atlantic salmon farms, DFO publishes data on fish health events[65], average monthly mortality by health zone[66], carcass classifications[67], and site-level data on the causes of mortality events and contributing factors[68]. The data on fish health events, defined by DFO as "any suspected or active disease that occurs within an aquaculture facility that requires the involvement of a veterinarian and warrants mitigation measures (e.g., treatment, quarantine, reduction in density)" show an average of 39 fish health events per year industry-wide between 2017 and 2019, with 24 to September in 2020 (the latest data available as of August 2021). With 76 active sites in 2019, a simple averaging shows 0.51 fish health events per site (or, approximately one fish health event at half of all active sites). Looking more closely at 2019 (the most recent complete data year), there were 44 fish health events, with an average of 0.57 events per active site, but one site (1.3% of active sites) had three events, eight sites (10.5% of active sites) had two events, 25 sites (32.9% of active sites had one event, and 42 sites (55.3% of active sites) had zero events. Figure 15 shows approximately 60% of events (from 2017 to March 2020) were caused by mouth rot (causative agent *Tenacibaculum maritimum)* and 15% by salmonid rickettsial septicemia (SRS – caused by *Piscirickettsia salmonis*).

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

[66] A map of the nine fish health zones is provided in the sea lice section below – Figure 18

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

[68] More information and the DFO mortality event data are available at: https://open.canada.ca/data/en/dataset/7fbb2662-391a-4df7-99b4-3343fa68fc93

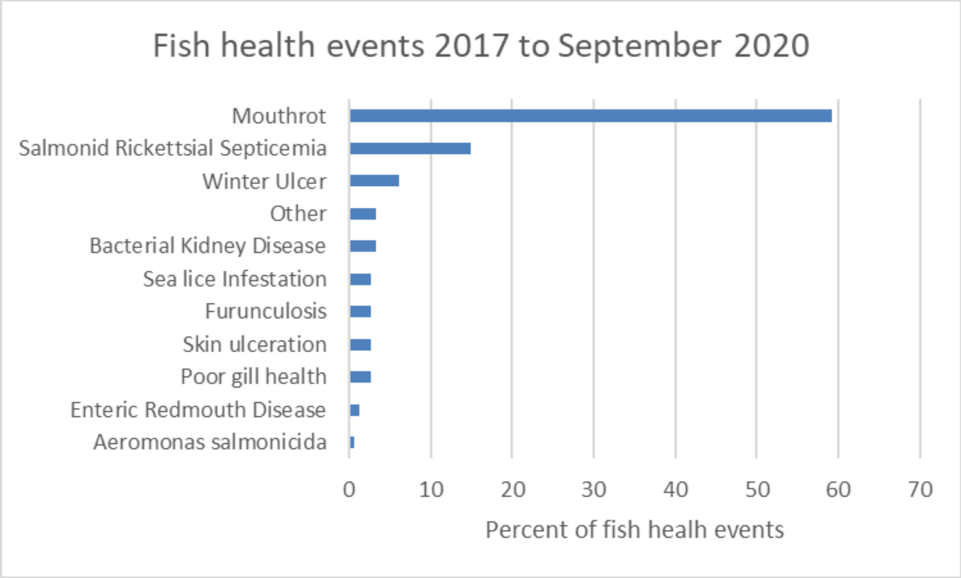

Figure 15: Fish health events at BC Atlantic salmon farms between 2017 and March 2020 by percentage cause. Data from DFO.

Figure 16 shows the average annual mortality from all causes (of which infectious disease is just one) varies between approximately 11% and 17% with a higher rate of 25% in 2018. In 2020, there were 109 reported mortality events (defined by DFO as when the amount of dead fish at a farm exceeds thresholds outlined in the conditions of license), of which five were attributed to “infectious disease”. However, diseases (including non-infectious diseases) and particularly poor gill health, were listed as contributing factors in another 28 mortality events associated with sea lice treatments, low oxygen levels, algal or jelly fish blooms or handling. While it is challenging to calculate the percentage of total annual mortality resulting from infectious diseases, from these data it appears to be small.

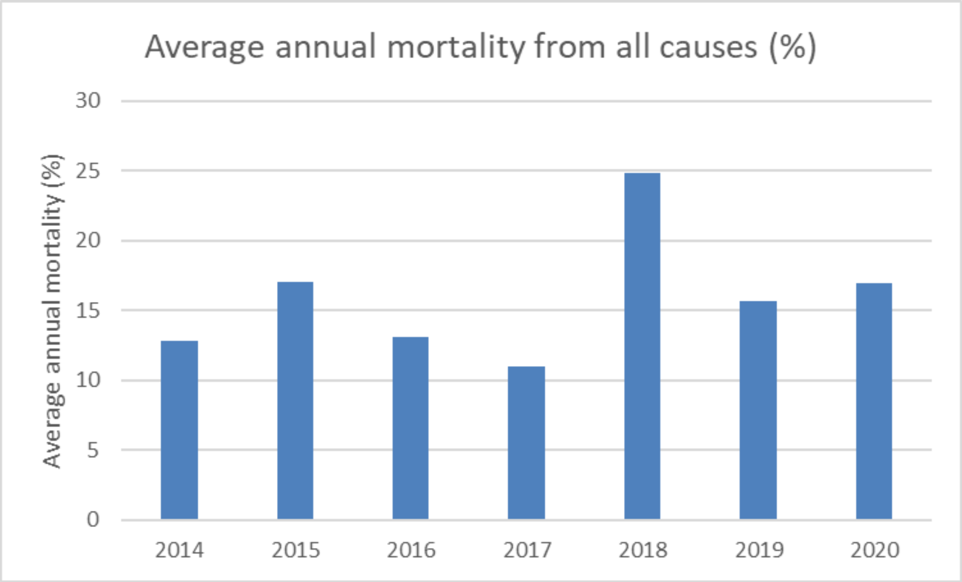

Figure 16: Average annual mortality rates from all causes for all active salmon farms in BC from 2014 to 2019. Data from DFO.

Due to the ability to treat diseased fish, mortality is not always a useful indicator with which to understand the potential transfer of pathogens to wild fish throughout the pathogen cycle. Infective agents can be present long before—or long after—clinical symptoms (Bateman et al., 2021), and therefore farmed fish can be vectors of pathogen discharge into the marine environment prior to any disease-related mortality (e.g., Shea et al., 2020). This is discussed in the next section.

Salmon farms as reservoirs of pathogens

Bacteria and viruses are ubiquitous in seawater[69] (Bergh et al., 1989). Farmed salmon are associated with a wide variety of bacteria and viruses (e.g., in recent publications: Bateman et al., 2021a,b; Shea et al., 2020; Mordecai et al., 2019, 2021a,b) and salmon farms are associated with elevated pathogen environmental DNA (eDNA) suggesting that salmon farms serve as a potential reservoir for a number of infectious agents (Shea et al., 2020). In the "farm infection" component of the DFO risk assessments (Figure 14), the likelihood that farmed Atlantic salmon infected with each pathogen were present on one or more farms varied from highly unlikely (e.g., for the bacteria *Yersinia ruckeri*) to extremely likely (e.g., for Piscine reovirus-1; PRV).

Following the DFO "farm infection" assessment, the "release assessment" (see Figure 14) determined the likelihood that a pathogen would be released from an infected Atlantic salmon farm located in an environment accessible to wild salmon (via infected farmed Atlantic salmon or via mechanical vectors such as personnel, wildlife, farm equipment or vessels). For all nine pathogens (three viruses and six bacteria) the assessment outcome was that the release of pathogens was expected and/or extremely likely. That is, it is extremely likely that the

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

pathogens would be released from a net pen Atlantic salmon farm were it to contain infected fish.

Although the DFO risk assessments only considered nine pathogens from farms only in the Discovery Islands, it is assumed here that net pen Atlantic salmon farms throughout BC represent a reservoir of a variety of bacterial and viral pathogens which will be released into environments that are at times shared with wild fish. The potential impacts to those wild fish (if any) are considered in the next sections.

Exposure, infection, and disease in wild fish

Pathogens released from salmon farms can only cause an impact to wild fish if the wild fish are exposed to them in the conditions allowing for infection. Following the pathogen “release assessment” described above, the DFO risk assessment process considered the “exposure” of wild salmon to the released pathogens. The exposure assessment determined the likelihood that a susceptible wild fish would be exposed to a pathogen released from Atlantic salmon farms, and “exposure” was defined as one wild fish encountering a single viral particle released from any of the Atlantic salmon farms operating in the Discovery Islands.

It is of relevance here to note the recent research by Rechisky et al. (2021) using biotelemetry to show tagged sockeye salmon were within 80-200 m of a farm site for on average less than 20 minutes, and only about one-third of the population used a migration route that took them past a salmon farm site in the Discovery Islands. For reference, Grefsrud et al. (2021b) provide a theoretical scenario in Figure 17 showing how migrating salmon may be affected after passing through an area of infection such as a farm, and they also caution that a) the presence of a pathogen does not mean infection, b) infection does not mean the development of disease or the spread of infection, and c) illness does not mean death.

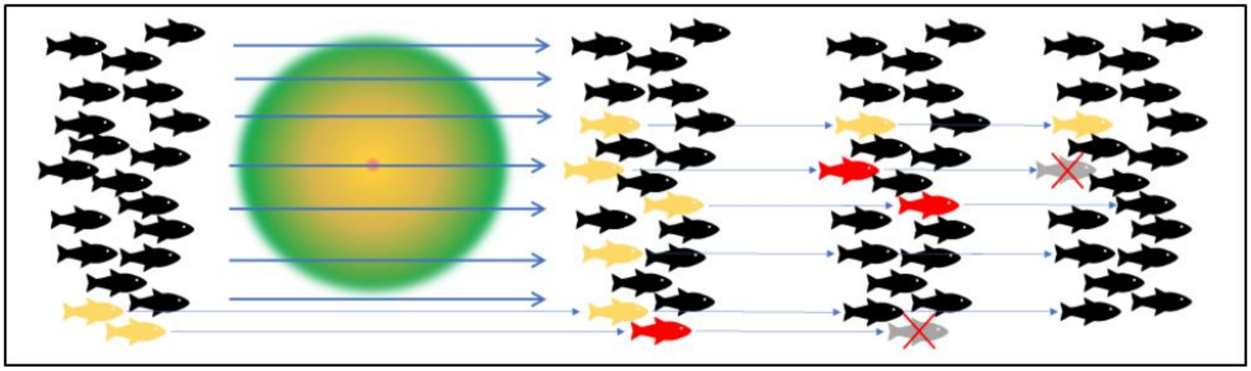
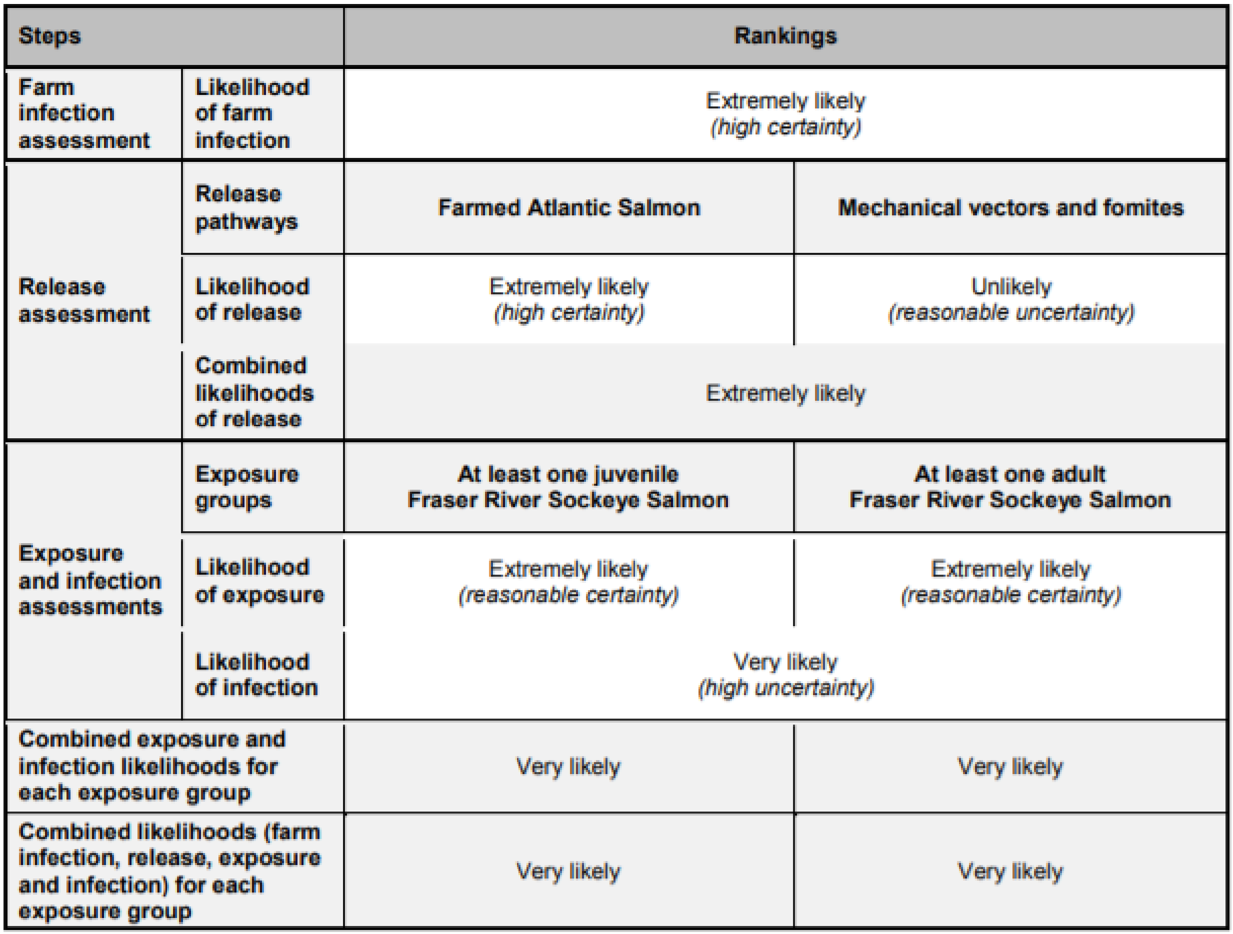


Figure 17: A theoretical scenario of migrating salmon smolts or sea trout in a fjord passing through areas with infection from farming. In such an area the exposure varies a lot. Upon exposure, some individuals may become infected (yellow fish). Some infected individuals may become ill (red fish). Some sick fish may die (grey fish), some may recover, and some may become chronically infected (carriers). Some of the wild fish may be naturally infected regardless of farming, and some of them may also become ill and die. Image copied from Grefsrud et al. (2021b).

The DFO “infection assessment” determined the likelihood that susceptible wild fish would be exposed to the pathogen at a dose and for a period of time sufficient to cause infection and disease (on the assumption that susceptible fish have been exposed to the pathogen released from a farm). Thus, the overall “likelihood” that wild fish become infected and diseased by pathogens attributable to Atlantic salmon farms depends on the sequential likelihoods of disease, release, exposure, and infection. In the specific case of the Fraser River sockeye salmon and the farms in the Discovery Islands, the combined likelihood outcomes (i.e., farm infection, release, exposure, and infection) for the nine pathogens were highly variable, ranging from extremely unlikely (e.g., for IHN virus) to very likely (for PRV). Figure 18 shows an outcome example for PRV, and it is of relevance to note the high/reasonable certainty in the farm infection, release, and exposure, but high uncertainty in the likelihood of infection of wild fish with PRV.



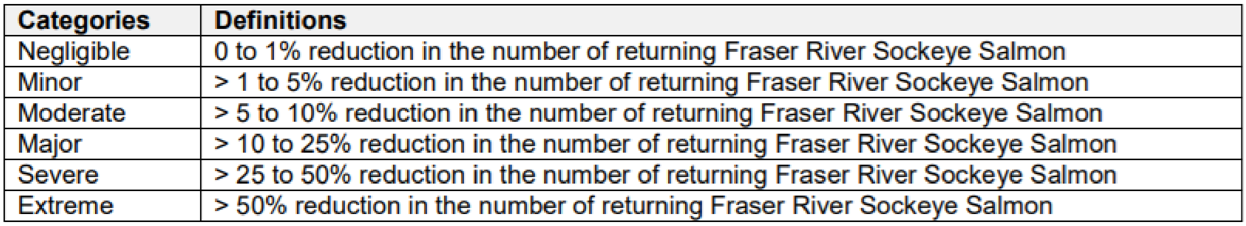
Steps		**Rankings**	
Farm infection assessment	**Likelihood of farm infection**	Extremely likely *(high certainty)*	
Release assessment	**Release pathways**	**Farmed Atlantic Salmon**	**Mechanical vectors and fomites**
	Likelihood of release	Extremely likely *(high certainty)*	Unlikely *(reasonable uncertainty)*
	Combined likelihoods of release	Extremely likely	
Exposure and infection assessments	**Exposure groups**	**At least one juvenile Fraser River Sockeye Salmon**	**At least one adult Fraser River Sockeye Salmon**
	Likelihood of exposure	Extremely likely *(reasonable certainty)*	Extremely likely *(reasonable certainty)*
	Likelihood of infection	Very likely *(high uncertainty)*	
Combined exposure and infection likelihoods for each exposure group		Very likely	Very likely
Combined likelihoods (farm infection, release, exposure and infection) for each exposure group		Very likely	Very likely

Figure 18: Example of the “likelihood assessment’ outcomes for PRV. Image copied from DFO (2019). Note the high and reasonable certainty in the farm infection, release, and exposure, but high uncertainty in the likelihood of infection of wild fish with PRV.

Impacts to wild fish

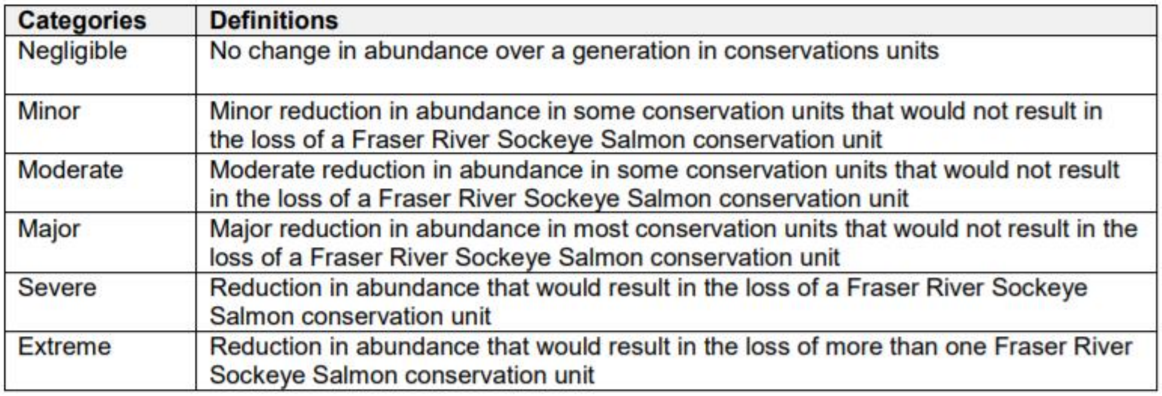
The consequences of pathogen infection with pathogens are highly variable depending on the individual, the strain of the pathogen, and the circumstances. Assessing the impacts of pathogens to wild fish, which are challenging to monitor in the wild, is extremely complex. Using the DFO risk assessment process again as a framework for discussion, the "Consequence assessment" considers what happens if only one or a few fish are infected[70] or if there is significant infection and spread within the population. It considers the consequences to wild salmon abundance and diversity. Tables 3, 4 and 5 show the categories used for both aspects, and the likelihood definitions.

Table 3: Categories and definitions used to describe the potential consequences to the abundance of Fraser River Sockeye Salmon in the DFO risk assessments. Table copied from DFO (2017).



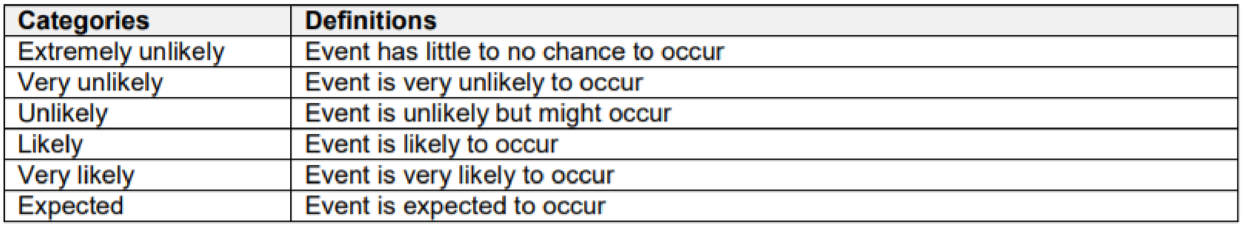
Categories	Definitions
Negligible	0 to 1% reduction in the number of returning Fraser River Sockeye Salmon
Minor	> 1 to 5% reduction in the number of returning Fraser River Sockeye Salmon
Moderate	> 5 to 10% reduction in the number of returning Fraser River Sockeye Salmon
Major	> 10 to 25% reduction in the number of returning Fraser River Sockeye Salmon
Severe	> 25 to 50% reduction in the number of returning Fraser River Sockeye Salmon
Extreme	> 50% reduction in the number of returning Fraser River Sockeye Salmon

Table 4: Categories and definitions used to describe the potential consequences to the diversity of Fraser River Sockeye Salmon in the DFO risk assessments. Table copied from DFO (2017).



Categories	Definitions
Negligible	No change in abundance over a generation in conservations units
Minor	Minor reduction in abundance in some conservation units that would not result in the loss of a Fraser River Sockeye Salmon conservation unit
Moderate	Moderate reduction in abundance in some conservation units that would not result in the loss of a Fraser River Sockeye Salmon conservation unit
Major	Major reduction in abundance in most conservation units that would not result in the loss of a Fraser River Sockeye Salmon conservation unit
Severe	Reduction in abundance that would result in the loss of a Fraser River Sockeye Salmon conservation unit
Extreme	Reduction in abundance that would result in the loss of more than one Fraser River Sockeye Salmon conservation unit

Table 5: Categories and definitions used to describe the likelihood of an event over a period of a year. Table copied from DFO (2017).



Categories	Definitions
Extremely unlikely	Event has little to no chance to occur
Very unlikely	Event is very unlikely to occur
Unlikely	Event is unlikely but might occur
Likely	Event is likely to occur
Very likely	Event is very likely to occur
Expected	Event is expected to occur

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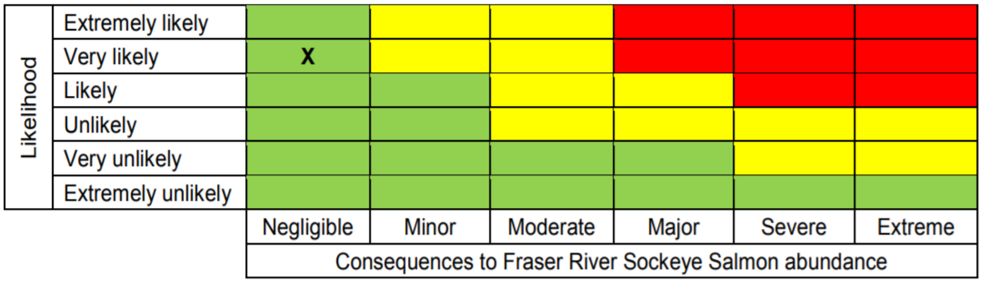
[70] It is important to note that the outcome of the "likelihood" assessment is in terms of the risk of a single fish being exposed and infected (a single wild sockeye salmon in this case) by the relevant pathogen. That is, in Figure 18 above, it is "very likely" that a single Fraser River juvenile and a single Fraser River adult sockeye salmon will each be infected by PRV-1 from a salmon farm in the Discovery Islands.

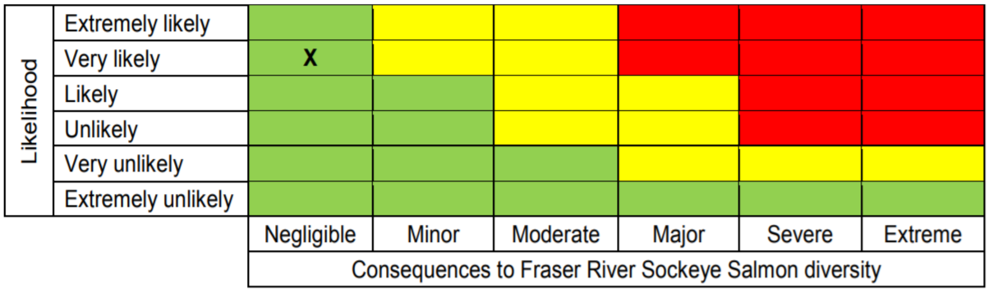
For example, for PRV in which the infection of wild sockeye salmon was very likely (Figure 18), the consequences of those infections to their abundance and diversity were considered negligible (i.e., the infection was considered to have little impact to the individuals infected and thereby to the populations). As such, the PRV risk assessment concluded that the risk to the abundance and diversity of Fraser River sockeye salmon was minimal – shown in Figures 19 and 20.

The likelihood/consequence combinations varied across the nine pathogens assessed by DFO (for example, while the consequences of a VHS infection were "moderate" for abundance and diversity, the likelihood of that happening was "extremely unlikely"), but the DFO assessments all concluded that the risk to the abundance and diversity of Fraser River sockeye salmon for each of the nine pathogens from Atlantic salmon farms in the Discovery Islands was "minimal" (i.e., in the green sections of Figures 19 and 20).



Likelihood	Extremely likely	🟩	🟨	🟨	🟥	🟥	🟥
	Very likely	🟩 X	🟨	🟨	🟥	🟥	🟥
	Likely	🟩	🟩	🟨	🟨	🟥	🟥
	Unlikely	🟩	🟩	🟨	🟨	🟨	🟨
	Very unlikely	🟩	🟩	🟩	🟩	🟨	🟨
	Extremely unlikely	🟩	🟩	🟩	🟩	🟩	🟩
		Negligible	Minor	Moderate	Major	Severe	Extreme
		Consequences to Fraser River Sockeye Salmon abundance					

Figure 19: Risk matrix for combining the results of the assessment of the likelihood and consequences to Fraser River Sockeye Salmon <u>abundance</u> from PRV. Green, yellow and red, respectively, represent minimal, moderate and high risk. The "X" indicates the estimated risk.



Likelihood	Extremely likely	🟩	🟨	🟨	🟥	🟥	🟥
	Very likely	🟩 X	🟨	🟨	🟥	🟥	🟥
	Likely	🟩	🟩	🟨	🟨	🟥	🟥
	Unlikely	🟩	🟩	🟨	🟨	🟥	🟥
	Very unlikely	🟩	🟩	🟩	🟨	🟨	🟨
	Extremely unlikely	🟩	🟩	🟩	🟩	🟩	🟩
		Negligible	Minor	Moderate	Major	Severe	Extreme
		Consequences to Fraser River Sockeye Salmon diversity					

Figure 20: Risk matrix for combining the results of the assessment of the likelihood and consequences to Fraser River Sockeye Salmon <u>diversity</u> from PRV. Green, yellow, and red, respectively, represent minimal, moderate, and high risk. The "X" indicates the estimated risk.

<u>Beyond the DFO Risk Assessments</u>

Beyond the narrow scope of the DFO risk assessments – that is, with consideration of the potential impacts of other pathogens (both singularly and cumulatively), potential impacts to other species of wild salmon, and of other farming areas across BC – the literature is extremely complex and developing rapidly (including since the DFO risk assessments were published from 2017-2020).

For example, PRV is a focus of interest yet its origin (and that of other parasites and pathogens) in BC continues to be debated (Marty et al., 2015; Miller et al., 2020; Kibenge et al., 2017; Kibenge, 2019; Siah et al.,2020; Mordecai et al., 2021; Thakur et al., 2019). While DiCiccio et al. (2018) suggest migratory Chinook salmon may be at more than a minimal risk of disease from exposure to the high levels of PRV occurring in salmon farms, the virulence and impact to farmed and wild salmon in BC continues to be debated and the mechanisms of PRV pathogenesis have been suggested to be highly variable with regard to the host species, host strain (and possibly even the individual), and to the PRV isolate involved (reviewed by Polinski et al., 2020). Polinski et al. (2020) note that in controlled experimental trials, the BC strain of PRV has (as yet) never caused clinical morbidity or mortality in salmon even during extreme blood infections.

The specific impacts to wild salmon in the field (i.e., beyond laboratory challenge tests) also remain uncertain. Miller et al. (2014) and Morton et al. (2017) negatively associated the PRV-positive proportions of return-migrating wild adult salmon with increases in their success against migratory challenges (i.e., fewer fish with PRV were successfully migrating to higher elevations in their natal rivers, implying reduced fitness in infected fish). However, the salmon species sampled by Morton et al. (2017) and thereby in their correction (Morton et al., 2020) were substantially different before and after the migratory challenge and limited the relevance of the findings. Other recent studies show a minimal impact of PRV on Chinook and coho salmon (Purcell et al.,2020), or on the respiratory performance of sockeye salmon when infected, leading to the conclusion that PRV infection did not reduce their fitness (Zhang et al., 2019, Polinski et al., 2021, Zhang, 2021).

More broadly, Jia et al. (2020) reviewed the distribution of infectious agents reported in wild Pacific salmonid populations, focusing on ten pathogens considered to potentially cause severe economic losses in Atlantic salmon or be of conservation concern for wild salmon in BC[71]. Their findings indicated that while the occurrence and prevalence of the ten selected agents in wild salmonids in BC varied among species, and in some cases among life stages, locations, and habitat type, overall, there was a low frequency of occurrence of nine of the ten pathogens, and no positive results for the tenth pathogen.

Jia et al. (2020) also note that given the connectivity among vast watercourses in BC, the population-level impact of infectious agents on the survival of wild salmonids remains speculative; the uncertainty is exacerbated by the complexity of salmonid populations and diverse biotic and abiotic factors that interact, including pathogens, changes in marine environments, and anthropogenic activities. Studying disease in wild populations is exceedingly complex; in the ocean, mortality events are rarely observed, sampling efforts solely capture live fish, and it has been suggested that weak and dying fish may be predated before the disease progresses to mortality (Miller et al., 2014, 2017; Mordecai et al., 2019). Such examples do

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[71] Infectious hematopoietic necrosis virus (IHNV), piscine orthoreovirus (PRV), viral haemorrhagic septicaemia virus (VHSV), *Aeromonas salmonicida*, *Renibacterium salmoninarum*, *Piscirickettsia salmonis* and other Rickettsia-like organisms, *Yersinia ruckeri*, *Tenacibaculum maritimum*, *Moritella viscosa* and *Paramoeba perurans*.

exist. For example, Furey et al. (2021) showed mortality from predatory bull trout (*Salvelinus confluentus*) of out-migrating sockeye salmon in the Fraser River in BC was 15-26 times higher (in one of two years studied[72]) for fish that screened positive for IHN virus (a naturally occurring pathogen in the studied population) although the mechanism of increased predation was not determined.

The developing research techniques allow the detection of large numbers of viruses (e.g., Shea et al., 2020; Mordecai et al., 2021a, Bateman et al., 2021a), and imply many associations between salmon farm pathogens and wild salmonids, yet they provide little conclusive proof of any transmission, infection, morbidity, or mortality in wild salmon. Returning briefly to PRV, Mordecai et al. (2021b) note that despite potential impacts of viral pathogens such as PRV on endangered wild salmon populations, their epidemiology in wild fish populations remains obscure. Pathogens such as *Tenacibaculum maritimum* (which causes mouth rot in Atlantic salmon soon after entry to sea water, and other forms of tenacibaculosis in other species) have also been highlighted as a cause for concern (e.g., Bateman et al., 2021b), yet with similar limitations on robust conclusions. For example, Bateman et al. (2021) showed a clear peak in *T. maritimum* detections in sockeye salmon in the Discovery Islands region of BC, where they migrate close to salmon farms, but were unable to resolve important epidemiological features of the system such as the relative roles of post infection mortality and recovery. Similarly, the DFO risk assessment concluded it was very likely that Atlantic salmon farms would be infected with *T. maritimum*, extremely likely that the pathogen would be released, very likely that juvenile sockeye salmon would be exposed, but unlikely that they would be infected due to the concentration of the pathogen necessary for infection (DFO, 2020). The DFO assessment concluded the risk to migrating sockeye salmon from *T. maritimum* was minimal, but it must be noted that the DFO assessment had high uncertainty in the risk of infection.

Noting the ability of the developing genetic techniques to identify large numbers of viruses, many new potential pathogens continue to be associated with salmon farms and wild salmonids in BC. For example, the SSHI has identified over 50 infectious agents in wild Pacific salmon, including fifteen previously uncharacterized viruses, and associations continue to be made with salmon farms (e.g., Mordecai et al., 2021a,b; Bateman et al., 2021a). Yet, the nature of their pathogenicity and therefore the nature of these associations is largely unknown. With regard to interactions between multiple pathogens (and as noted previously, a potential weakness of the DFO risk assessments), Bateman et al. (2021b) showed many correlations between multiple agents in Atlantic salmon in BC, but they caution that apparent mortality signatures (e.g., high levels of *T. maritimum* in dead and dying fish) may be due to secondary infections of opportunistic bacteria rather than a direct cause of mortality or other underlying interaction. As a result, no conclusions can currently be made with regard to the cumulative impacts of multiple pathogens, but overall, the discharge of on-farm pathogens (singularly or of multiple species) clearly justifies some level of concern given the status of many wild Pacific salmon populations (discussed further below), and Bateman et al. (2021b) continue to urge a more precautionary approach to managing farm/wild interactions in sockeye salmon.

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[72] In the second study year (2015) IHN virus was not present in the sampled fish.

In conclusion (with regard to bacterial and viral pathogens), the DFO risk assessments for nine pathogens are important studies with which to frame the components to be considered. Yet despite their findings that all nine pathogens had a "minimal" risk of impact to Fraser River sockeye salmon, their limitations in scope are apparent: for each, they assessed the risk of a single pathogen to a single wild salmon species from a single river in a single salmon farming area. Recent research continues to develop rapidly on many fronts, making many associations between farm viruses and wild salmon, but with few new robust conclusions. This is perhaps best illustrated by Mordecai et al. (2021b) who note (emphasis added here) that "the <u>risk</u> of disease transmission from farmed to wild fish has <u>increased</u>, with <u>potential</u> to <u>contribute</u> to <u>declines</u> in wild fish populations, but the <u>probability and magnitude of this transmission has not been determined</u>" (note the use of this statement here is not intended to imply any particular level of impact or concern, but is simply utilized to highlight the challenge in drawing conclusions and in determining the appropriate level of concern).. It therefore currently remains largely impossible to clearly differentiate between the speculation (summarized by Zhang, 2021) that "viruses found on farmed fish are a ticking time bomb that could collapse wild Pacific salmon populations, particularly sockeye salmon, by preventing a once-in-a-lifetime spawning event and resulting in zero lifetime fitness", and the contrasting position broadly drawn from the DFO risk assessments and other recent studies that bacterial and viral pathogens from Atlantic salmon farms are of minimal concern to wild salmon in BC.

Status of wild salmon populations

Salmon production in the north Pacific has fluctuated widely (and there is some evidence to suggest that such fluctuations have occurred naturally for hundreds and perhaps thousands of years) and the most recent increase in production started in 1977 and coincided with significant shifts in climate and the ecosystem of the north Pacific (Noakes et al., 2000). By the mid-1980s, total Pacific salmon catch was at record high levels exceeding 900,000 tons annually, but catches in Canada began to decline sharply around 1990, coincidentally with a significant shift in the climate/ocean environment of the north Pacific (Noakes et al., 2000). For reference, salmon farming began in British Columbia in the late 1980's with production exceeding 1,000 mt for the first time in 1987 (see Figure 1). According to Noakes et al. (2000), the most likely reasons for the large-scale declines in Pacific salmon stocks include a combination of climate change, overfishing, and freshwater habitat destruction.

The current status of wild salmon is highly variable across species, Conservation Units[73] (CU), and discreet populations; for example, according to Welch et al. (2021), essentially all west coast North American Chinook populations are now performing poorly with dramatically reduced productivity. Welch et al. (2021) note that Chinook have declined across essentially all of Alaska and the Canadian portion of the Yukon River, a vast swathe of relatively pristine

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[73] A Conservation Unit (CU) is a group of wild Pacific salmon sufficiently isolated from other groups that, if extirpated, is very unlikely to recolonize naturally within an acceptable timeframe, such as a human lifetime or a specified number of salmon generations. https://open.canada.ca/data/en/dataset/1ac00a39-4770-443d-8a6b-9656c06df6a3

territory where anthropogenic habitat impacts (including salmon farming) are negligible. The Smolt-Adult Return rate (SAR) has declined over a very large geographic range (i.e., in large areas with and without salmon farms). Grant et al. (2019) note Chinook salmon are also returning to spawn at younger ages, their sizes are decreasing for a given age, and egg numbers and egg sizes are decreasing. The DFO Canadian status of four salmon species is shown in Table 6, with >70% of the assessed Chinook populations ranked "Red" (i.e., 32 of the 44 assessed stocks).

Welch et al. (2021) consider the reduced productivity to be similar for most BC populations of coho, sockeye and steelhead trout (*O. mykiss*), but with some exceptions (e.g., in the Skeena and Nass rivers) pink and chum salmon populations are generally more robust than other salmon species throughout their ranges. Boldt et al. (2020) compiled over 60 papers on the state of the physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2019, and these mention a large array of potential impacts or secondary factors that may potentially affect wild salmon populations in BC's inshore and outer coast environments. It is interesting to note that salmon farms or aquaculture in general are not mentioned in any of the 60+ papers. While ocean conditions appear important (e.g., Grant et al., 2019), Finn et al. (2021) highlighted anthropogenic impacts to salmonid freshwater environments, showing access to floodplains and stream habitat in the lower Fraser River (Canada's most productive salmon river) have declined dramatically with only 15% of historic flood plains remaining accessible, and 1,700 km of stream length that have been completely lost.

A number of BC populations are considered Endangered or Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC[74]). According to COSEWIC, of sixteen south coast Chinook populations, eight are Endangered, four are Threatened, one is a Special Concern, one is Not at Risk, and two are Data Deficient. For Fraser River sockeye population, eight stocks are Endangered, two are Threatened, five are Special Concern, and nine are Not at Risk according to COSEWIC.

Table 6: Status of wild salmon Conservation Units based on the available DFO data. Red = considered at risk of extinction by COSEWIC, Amber = at low risk of loss, however there will be a degree of lost production, Green = given existing conditions, there would not be a high probability of losing the CU, TBD = To be determined, DD = Data deficient. Odd and Even Pink salmon CUs are combined. No status data were available for Chum salmon. Data from DFO[75]

Species	DFO Status as a percentage of each species' Conservation Units						
	Red	Red/Amber	Amber	Amber/green	Green	TBD	DD
Chinook	32	3	3	0	6	32	23
Coho	0	0	60	40	0	0	0
Sockeye	26	9	22	26	17	0	0
Pink	7	13	1	39	12	0	27

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[74] http://www.cosewic.ca/

[75] https://open.canada.ca/data/en/dataset/1ac00a39-4770-443d-8a6b-9656c06df6a3

Parasitic Sea Lice

The dominant focus of research on the interactions between farmed and wild salmon in BC has been the parasitic sea lice *Lepeoptheirus salmonis* and (to a lesser extent) *Caligus clemensi*. For an overview of sea lice population ecology and epidemiology in BC, see Saksida et al. (2015).

Sea lice numbers on farms

With improving industry sea lice control, Peacock et al. (2013) reported that after four years of sea lice epizootics in the early 2000s, the changes in parasite management (including the establishment of treatment thresholds and the use of pesticide treatments to control lice) reduced these epizootics. Morton et al. (2011) reported a 100-fold decrease in sea lice on juvenile wild fish in 2007 compared to previous epizootics, Jones and Beamish (2011) reported a large drop between 2004 and 2008 and that the low numbers of lice on wild fish continued in 2009 and 2010, Marty et al. (2010) reported a large decrease from 2005 to 2008, and Saksida et al. (2012) reported low lice numbers in 2007 and 2008 with 0% lethal infections in 2008 (based on the references of Jones et al. (2008), Nendick et al. (2011), and Sutherland et al. (2011)). With some exceptions, the lower lice levels continued until 2015, when lice levels increased dramatically in many areas of BC. Considered at the time to potentially be an anomaly due to extreme water temperatures, more recent data, up to and including most of the 2021 outmigration period are discussed below.

Sea lice count data[76] from farms (as monthly averages) are available since 2011 from DFO (though Open Canada[77]). Industry-performed counts are conducted bi-weekly during the March-June period of smolt outmigration and monthly during the rest of the year. These industry-reported counts are checked in approximately 50 audits per year by DFO. The audits are conducted throughout the year but are concentrated in the wild salmon outmigration period; for example, in 2019, 30 of the 51 of the annual audits (59%) occurred in the March-June period. The DFO audit data[78] show 92% agreement with industry counts in 2019, and an average of 87.5% agreement from 2017 to 2019. Godwin et al. (2020) studied potential bias in these counts and concluded that the industry's counts of *Caligus* and *Lepeophtheirus* sea lice increased by a factor of 1.95 and 1.18 respectively in months when counts were audited by the federal fisheries department, i.e., the lice counts were on the low side at times when DFO was not auditing (for which the cause was not clear). As the analysis below shows, sea lice counts can be highly variable, and as the focus of this assessment is on the sea lice counts in the outmigration period, the potential for some inaccuracies in the data is an underlying consideration (e.g., what if the counts were up to 18% higher than the data suggests?).

The sea lice count data show numbers on farmed fish are highly variable geographically and temporally. DFO provides simple aggregated monthly sea lice count data by health zone (and

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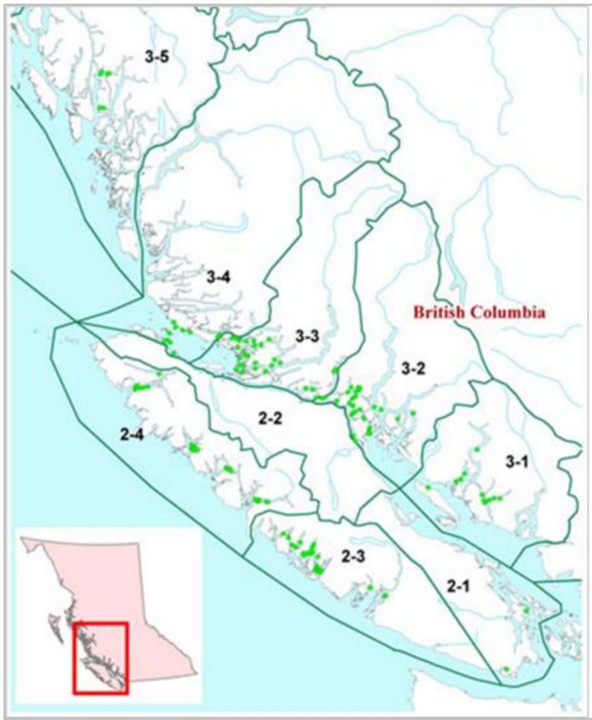
[76] Note all sea lice count data presented here, unless otherwise indicated, refer to "motile" lice. This includes both male and female sub-adult and adult sea lice, including egg-bearing mature female lice.

[77] https://open.canada.ca/data/en/dataset/3cafbe89-c98b-4b44-88f1-594e8d28838d

[78] https://open.canada.ca/data/en/dataset/5cfd93bd-b3ee-4b0b-8816-33d388f6811d

subzones, and since 2019 by reporting areas, corresponding to the same health zones and subzones). A map of health zones and reporting areas in BC is shown in Figure 21.



DFO reporting regions

- Clayoquot Sound – 2.3
- NW Coast of Vancouver Island (combining data from Esperanza Inlet, Nootka Sound, Quatsino Sound) – 2.4
- Sunshine Coast – 3.1
- Discovery Passage/Islands – 3.2
- Broughton Archipelago – 3.3
- Port Hardy – 3.4
- Central Coast - 3.5

Figure 21: Map of fish health zones 2 and 3 in BC, and DFO reporting regions (used since 2019). Also see Figure 1 for an annotated map of production areas. Image and text copied from DFO.

Two examples of a time series of average monthly sea lice counts (of motile *L. salmonis* only) across all farms in a health zone are shown in Figure 22. As discussed further below, it is important to note that the farm level data are highly variable and therefore these averages across multiple farms and multiple counts hide large variations in local sea lice levels, but the data are useful for giving an overview of sea lice trends from year to year and between regions. The first example in Figure 22 is from the Broughton Archipelago farming area where lice on farms appear to be controlled below the treatment threshold (of three motile lice per fish) consistently each year, particularly during the wild salmon outmigration period (shown as pale green bars). The second example (selected to highlight a peak event) is from Clayoquot Sound on Vancouver Island which had a large lice outbreak in 2018. In May 2018, the complete DFO data show every farm in Clayoquot Sound exceeded the treatment threshold.

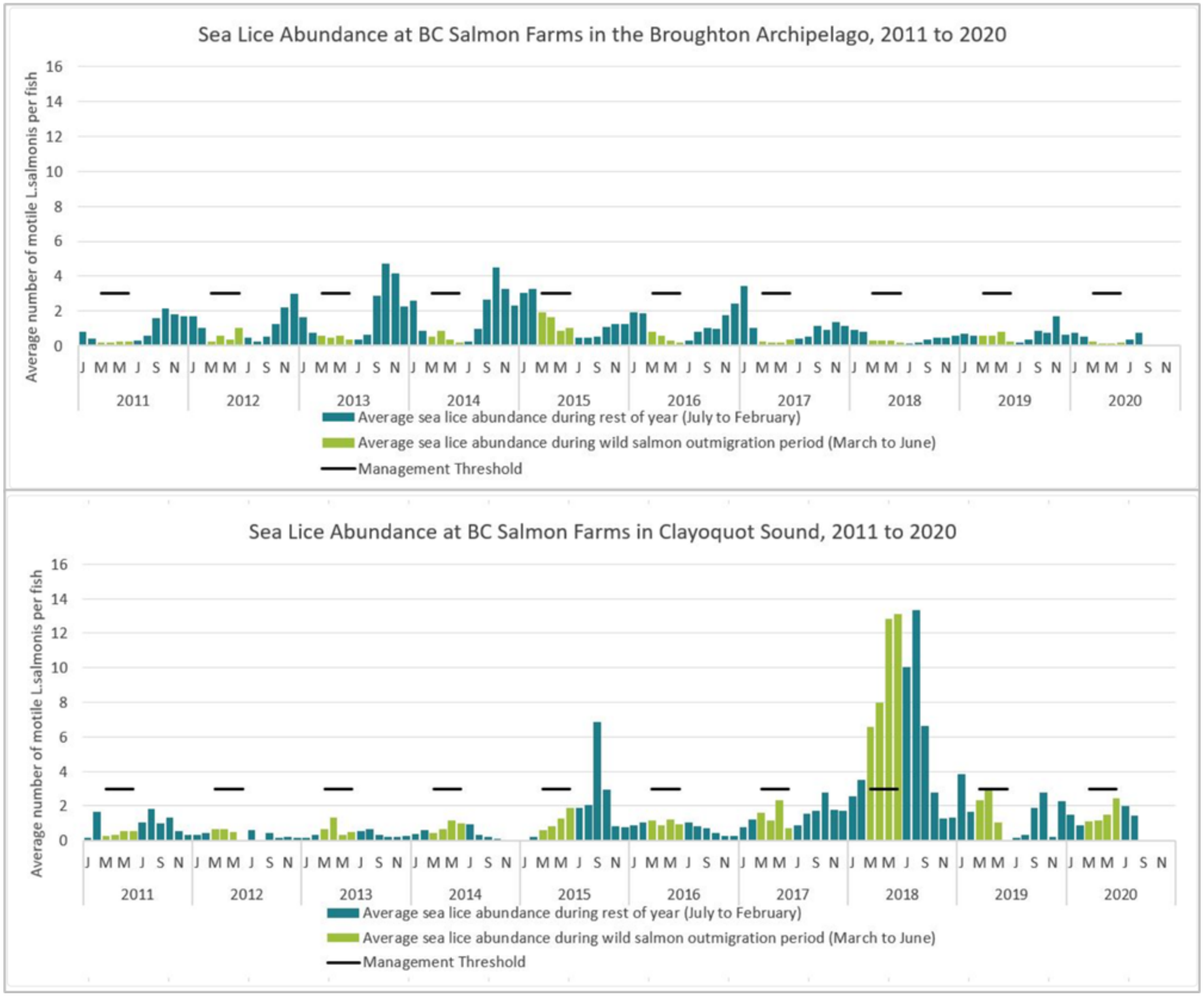


Figure 22: Average monthly sea lice counts per farmed fish from 2011 to August 2020. Pale green bars highlight the March-June wild salmon outmigration period and the 3 lice treatment threshold at these times (black horizontal lines). The top image is Zone 3.3 and the lower is Zone 2.3. Images copied from DFO.

The focus of this assessment is on the dominant outmigration period for wild Pacific salmon, stipulated as March-June (noting that some species will remain in inshore waters beyond this period, for example, coho and Chinook salmon are known to overwinter in inshore waters and may spend up to a year in estuaries; Nekouei et al., 2018; Chalifour et al., 2021; R. Dunlop, pers. comm., 2021). Figure 23 shows average monthly sea lice counts on salmon farms during the March-June period in each reporting region from 2011 to 2021 (only to May in 2021 using the latest available data). Figure 23 shows that average lice levels are generally below the treatment threshold of three motile lice per fish in most regions in most years, but there are higher counts of lice in some regions in most years.

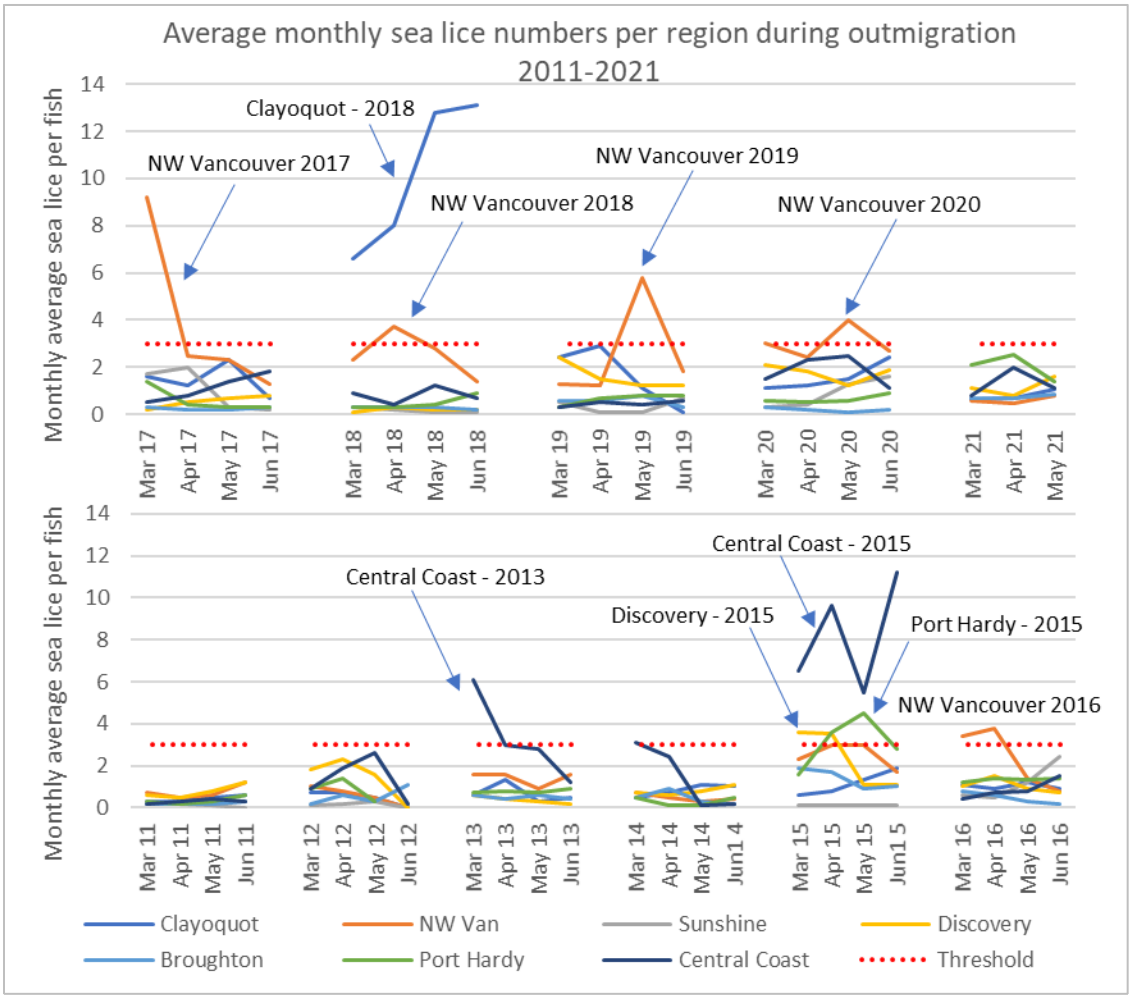


Figure 23: Average monthly sea lice counts during the March-June outmigration period for each DFO reporting region, from 2011 to May 2021. Data from 2011 to 2020 from DFO[79], and for 2021 analyzed from DFO raw data[80]

As can be seen in both Figures 22 and 23, Clayoquot Sound had a large outbreak in 2018 with average lice counts of 13.1 per fish. The average counts in four regions approached or exceeded the three-lice level in 2015 with the Central Coast having a large outbreak. The NW Vancouver Island area (comprising the Nootka Sound, Esperanza Inlet and Quatsino Sound farming areas) have repeatedly had average lice levels greater than three from 2016 to 2020. The available data (to May only) show 2021 to be a relatively low lice year for all regions based on these average regional monthly data.

It is emphasized again that while these aggregated and averaged values provided useful trend information, they hide substantial geographical and temporal variation between farming areas and between farms in each region. For example, during the 2020 outmigration period, the average sea lice count (of *L. salmonis*) in NW Vancouver Island (Region 2.3) was 3.03 but Figure 24 shows the specific counts during this period are highly variable with many above the three-

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[79] https://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/lice-ab-pou/index-eng.html#wb-auto-25

[80] https://open.canada.ca/data/en/dataset/3cafbe89-c98b-4b44-88f1-594e8d28838d

lice treatment threshold, including a maximum of 16.1 lice per fish in the middle of the outmigration period.

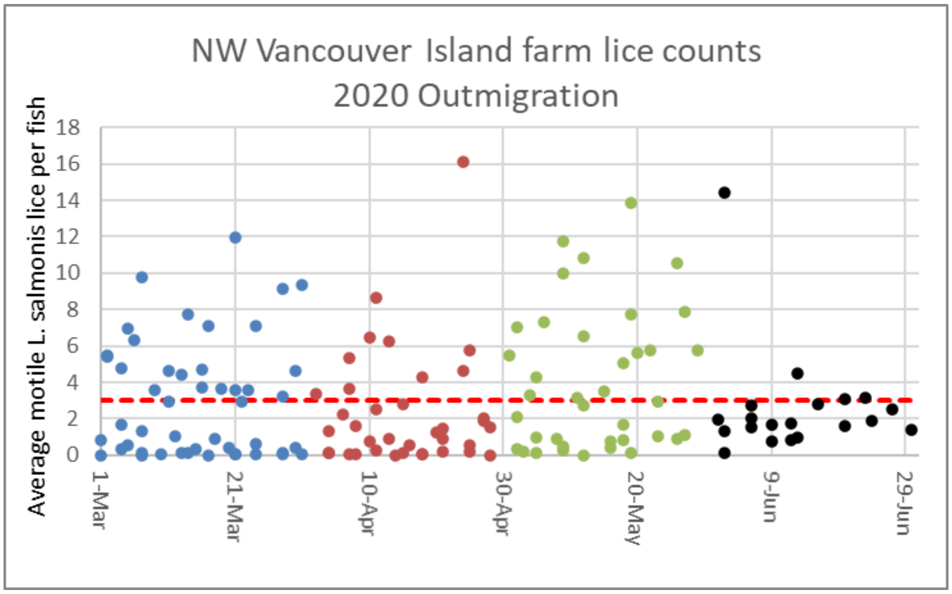

Figure 24**:** Farm lice counts during March-June 2020 in NW Vancouver Island**.** Different colors represent different months. The average sea lice count during this period was 3.03 lice per fish. The red dotted line shows the three-lice treatment threshold. Data from DFO.

In addition to the broad temporal and geographical variability, smaller scale geographical variability can also be seen by considering the discreet farming areas within the larger NW Vancouver Island reporting region. Figure 25 below shows how the regional data for NW Vancouver Island (i.e., the data in Figure 24 above) varies across the three discreet production areas of Quatsino Sound, Nootka Sound, and the Esperanza Inlet. This shows that while lice levels in Esperanza were low throughout the 2020 outmigration period (increasing at the end of this period), most of the higher lice counts were in the Nootka Sound area. Figure 26 shows that only 2.2% of lice counts in Esperanza during March-June 2020 were >3 lice per fish, while 68% of the counts were >3 in the Nootka Sound area.

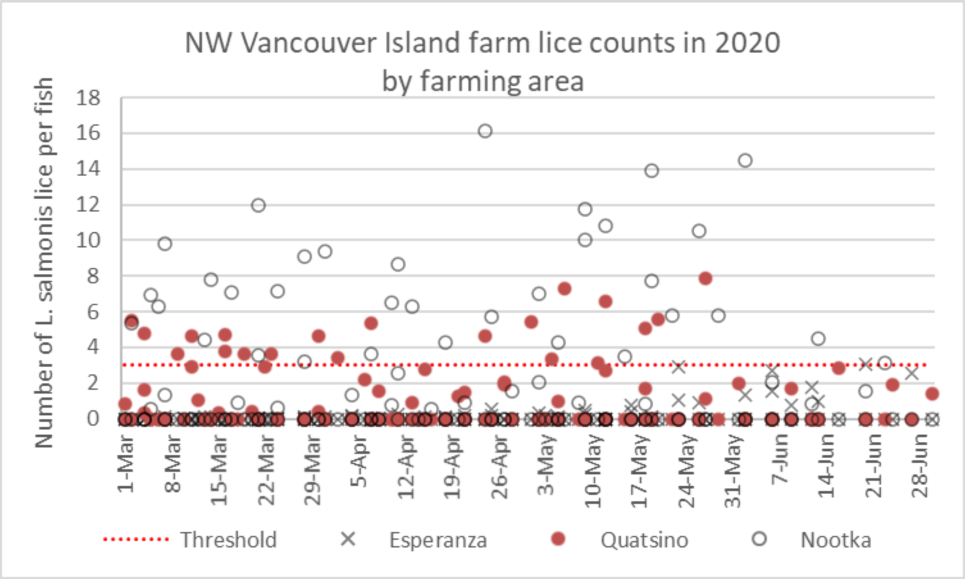

Figure 25: All farm sea lice counts (*L. salmonis* species) in the NW Vancouver Island reporting region during the 2020 outmigration period, separated by the three main production areas. The three lice per fish treatment threshold is shown by the dotted red line. Data from DFO.

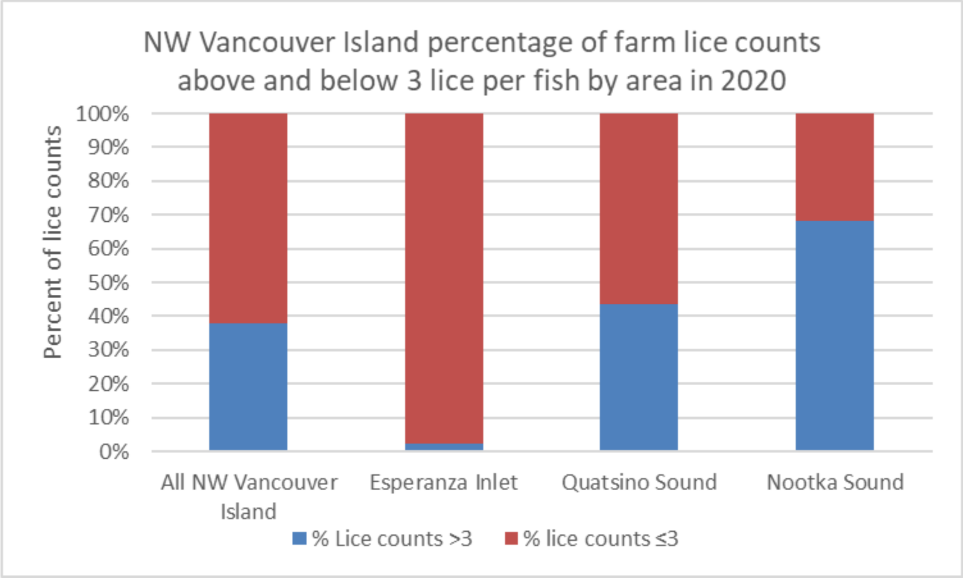

Figure 26: Percentage of farm sea lice counts (*L. salmonis* species) above or below the 3 lice per fish treatment threshold by production area within the NW Vancouver Island reporting region. Data from DFO.

Returning to data covering the whole of BC, Figure 27 shows that at the aggregated industry level, there is an apparent pattern of a low percentage of lice counts >3 lice per fish in most years, with larger peaks every few years The average number of lice per farmed fish during outmigration (red line in Figure 27) shows a similar pattern.

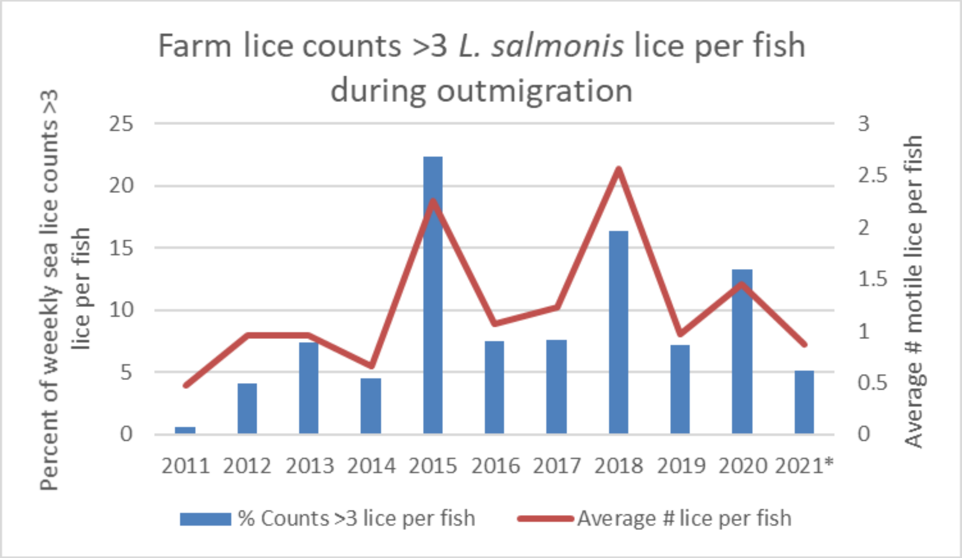

Figure 27: Percentage of farm sea lice counts between March and June inclusive each year that exceed the three-lice per fish treatment threshold (blue bars against primary y-axis). Also shown is the average number of lice per fish on farms between March-June each year (red line against secondary y-axis). 2021* is partial data to May only. Data from DFO.

The simplistic analysis and selective examples shown above highlight the large temporal and geographic variability in sea lice numbers on farms. The simple conclusion is that many discreet production areas are managing lice well in most years, while a small number of areas see substantial outbreaks with potentially very high lice numbers. This agrees with peer reviewed studies such as Nekouie at el. (2018) (who studied the Muchalet Inlet in the Nootka Sound) that found sea lice abundance in both farmed and wild populations shows prominent temporal and geographic variability. While there is some variability in the different regions seeing large outbreaks, it is important (from the perspective of potential impacts to wild salmon) to note the NW coast of Vancouver Island that has repeatedly had higher lice levels in five of the last six years (i.e., 2016 to 2020). The factors affecting lice dynamics (on wild and farmed fish) are complex, and in addition to the stochastic environmental and ecological variables, the farm lice numbers analyzed here are substantially affected by production variables such as year class of the fish and control treatments. While the potential reduction in efficacy of the primary sea lice treatment (emamectin benzoate) is a concern with regard to the industry's ability to treat sea lice (as noted in Criterion 4 – Chemical Use), the industry continues to develop and invest in alternatives such as modifications to the net pens (sea lice skirts and snorkel nets), and the use of non-chemical treatments such as freshwater baths and hydrolicers (which use water pressure to dislodge lice).

Salmon farms are also infected by *Caligus* sea lice species, but similar count data from DFO show low levels on farms; in 2019, 2020 and 2021, the average numbers of *Caligus* lice were 0.52, 0.33 and 0.82 lice per fish respectively. *Caligus* have a variety of hosts, and also infect wild salmonids with differences in host specialization and transmission dynamics between louse species (Godwin et al., 2015, 2017,2018; Brookson et al., 2020). The generalist louse, *C.*

clemensi, was many times more abundant than the salmonid specialist, *L. salmonis*, on wild pink, chum, and sockeye salmon, and with the focus of farm-wild salmon interactions the ongoing focus here is on the salmonid specialist *L. salmonis* lice.

Finally, it is important to note that these data discussed above are all based on counts of lice per individual (farmed) fish, and the total load of lice and therefore the infection pressure to wild salmon in any one waterbody is greatly influenced by the scale of production (i.e., the number of fish on any one farm, and the number of farms) and other complex variables such as the survival rates of sea lice nauplii.

Impacts to wild fish

The evidence involving interactions between farmed and wild salmon with regard to sea lice is controversial; Nekouie et al. (2018) aptly describe the situation where a large group of researchers, environmental activists, and indigenous people believe that sea lice originating on Atlantic salmon farms are a key component in the putative decline in some Pacific salmon stocks in BC, in contrast to a number of studies that present contradictory evidence. Nekouie et al.'s own 2018 study highlights the challenge; their results suggest that Atlantic salmon farms may be an important source for the introduction of sea lice to wild Pacific salmon populations, but they did not see a significant dose-response relationship between increased abundance of lice on farms and the levels of infestation observed on wild chum salmon. They concluded that any estimate of farm impact on wild salmon requires more careful evaluation of causal inference than is typically seen in the extant scientific literature. Interestingly, their study period was 2011 to 2016 and was conducted in the Muchalet Inlet in the Nootka Sound area, and while they noted higher lice levels (on farms and on wild fish) in 2016, their study period was followed by repeated high lice levels (on farms) for the next four years in the region (see Figure 23 and the subsequent analysis above of NW Vancouver Island and Nootka Sound – again noting that higher average lice on a regional basis likely indicate very high lice levels in one or more smaller areas within the region).

Monitoring of sea lice numbers on juvenile wild salmon during the outmigration period is conducted by several groups in different regions of BC. It is noted here that the results of different sampling groups even in the same area can (and do) vary substantially for many reasons. As a single source, the data collected each year from multiple regions by Mainstream Biological Consulting (MBC)[81],[82] can be used to give a simplistic overview of lice levels on wild fish. Figure 28 shows an approximate collation of data from different regions from 2015 to 2021[83] (note it is considered "approximate" because the summary reporting by MBC may be separated by lice species in any one region, or they may be combined; in most cases the combined figures have been used, and *L. salmonis* has been selected in the remainder as they typically represent the majority and are most commonly associated with farm sources as

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[81] https://www.mainstreambio.ca/. Monitoring reports are available from farming company websites.

[82] MBC is considered to be somewhat independent, but is employed by salmon farming companies to conduct the monitoring, primarily for compliance with the certification requirements of the Aquaculture Stewardship Council.

[83] These years selected to give the most sampling locations using the available data from MBC, and to increase clarity in the graphs by ignoring earlier parts of the few datasets that extend back to 2004.

opposed to wild hosts). These figures include all stages of sea lice from copepodids to adults. Figure 28A shows the lice prevalence, i.e., the percentage of fish in the sample that carries one or more lice, and Figure 28B shows the lice intensity, i.e., the average number of lice per infected fish.

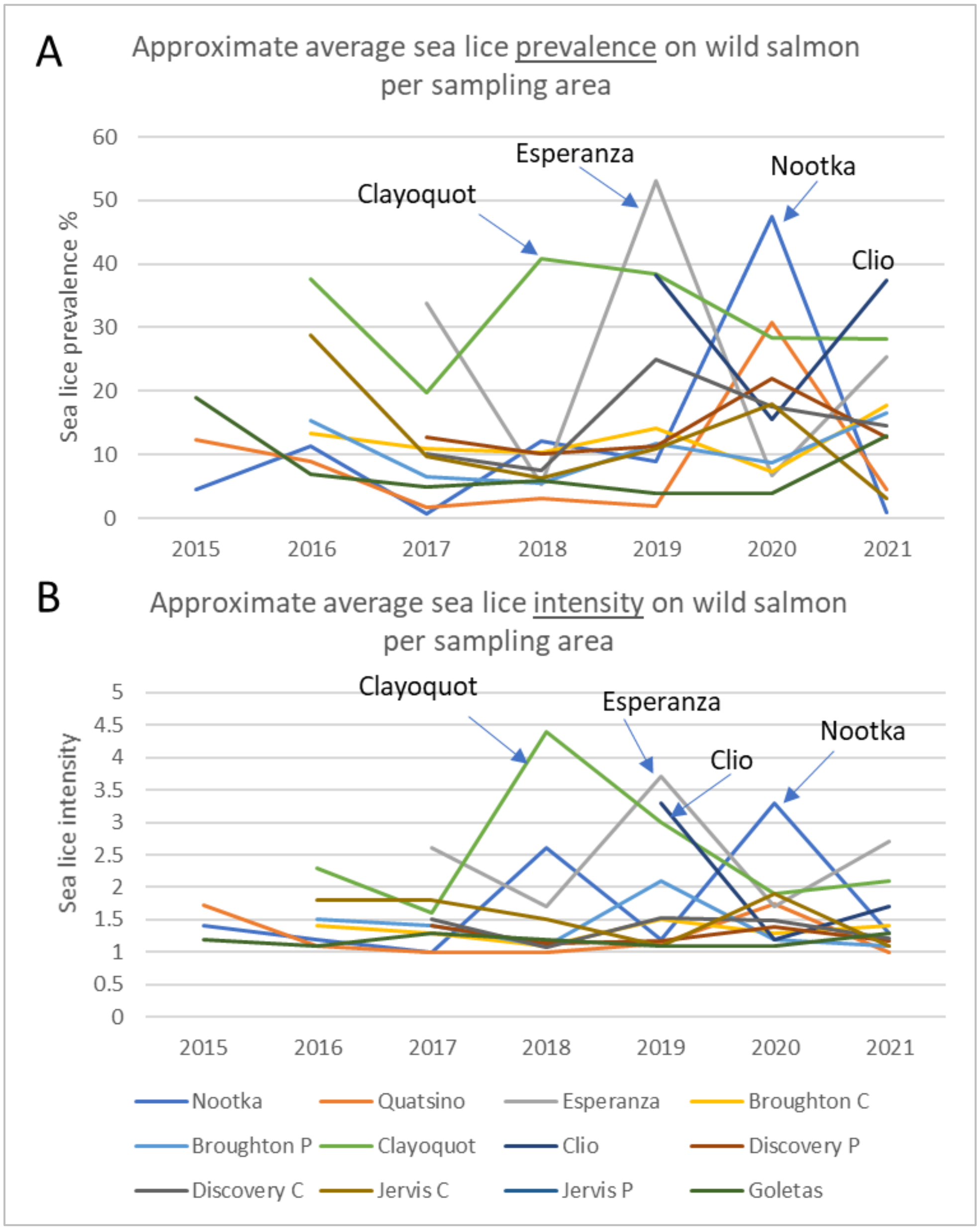

Figure 28: Sea lice counts on wild juvenile salmon during the outmigration period from 2015 to 2021, as sampled by Mainstream Biological Consulting. Graph A shows the prevalence of lice (i.e., the percentage of fish sampled that had one or more lice) and graph B shows the lice intensity, i.e., the average number of lice on those fish that are infected. Labels refer to the sampling areas (Nootka Sound, Quatsino Sound, Esperanza Inlet, Broughton Archipelago, Clayoquot Sound, Clio Channel and Chatham Channel, Discovery Islands, Jervis and Sechelt Inlets, Goletas Channel) and "P" and "C" refer to Pink or Chum salmon. Selected peak values are labelled.

In these MBC data, the maximum prevalence is >50% (i.e., more than half of the wild juvenile salmon sampled have one or more sea lice) and the intensity peaks at >4 lice per fish. Again, these averaged data hide substantial temporal and geographic variation; the lice levels on wild fish can be highly variable at different sampling sites within an area and at different sampling times during the four-month outmigration period. For example, Morton (2020) reported that juvenile wild salmon caught in 2020 at the monitoring site in Nootka that was most distant from salmon farms had 39% prevalence of sea lice (i.e., 39% of wild salmon were infected by one or more lice), while at the three monitoring sites near salmon farms, 97% of juvenile wild salmon were infected with an average of 9.3 sea lice per fish. A very simplistic conclusion is that the lice levels on wild juvenile salmon in BC are also highly variable both temporally and geographically. In some cases (e.g., those labelled in Figure 28), higher lice prevalence is also accompanied by high intensity, and in many cases it is not.

The controversy surrounding the potential impacts of sea lice to wild salmon (described by Nekouie et al., 2018, and noted above) stems initially from the temptation to draw correlations between the lice levels on farms and the lice levels on juvenile wild salmon in the same areas (or by extension, to the productivity of wild salmon populations). Indeed, there are clear examples such as the general higher lice levels on both farms and wild fish on the W and NW coasts of Vancouver Island (see Figure 23) and the specific examples highlighted above (e.g., high lice levels on farms and wild fish in Nootka Sound in 2020) that imply a correlation. But more broadly, it is clear overall (as warned by Nekouie et al., 2018) that any estimate of farm impact on wild salmon requires more careful evaluation than this kind of causal inference.

It is notable that the nine assessments of the risk to Fraser River sockeye salmon from the transfer of pathogens from Atlantic salmon farms in the Discovery Islands (conducted by DFO[84]) did not include an assessment of sea lice. With considerable similarity to the methods used by DFO for the other pathogens, the Norwegian Institute of Marine Research annually considers the "risk associated with mortality of migrating post-smolt salmon (Atlantic salmon – *Salmo salar*) as a result of salmon lice discharges from salmon farms" (Grefsrud et al., 2021a). This considers two primary factors: A) Wild fish are infected by sea lice, and B) The wild fish's tolerance to sea lice. Factor A has three sub-factors of 1) The environmental conditions for lice, 2) Emissions of salmon lice larvae from farms, and 3) Overlap between wild fish and sea lice in space and time (see Figure 29).

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

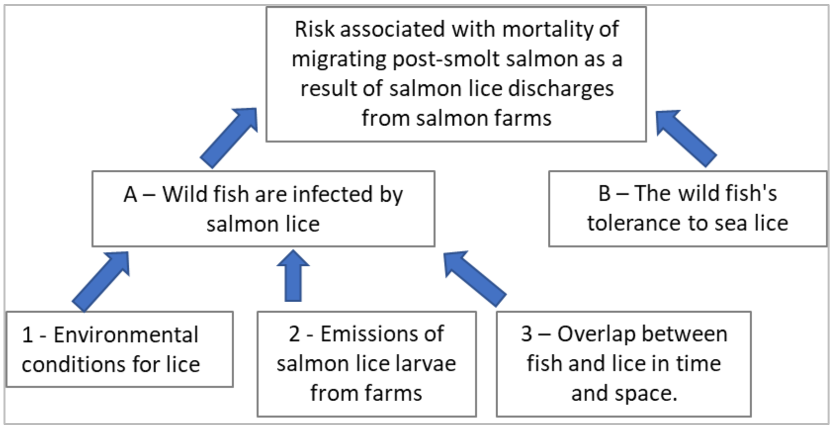

Figure 29: Factors and subfactors of the Norwegian Institute for Marine Research's annual risk assessment for sea lice impacts resulting from salmon farms. Translated from Grefsrud et al. (2021).

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

The tolerance of juvenile Pacific salmon to sea lice is also highly complex and varies considerably by species and particularly by size. Braden et al. (2020) describe over 30 years of research on louse biology, control, host responses and the host-parasite relationship that has provided a plethora of information on the intricacies of host resistance and parasite adaptation. Figure 30 shows an image copied from Braden et al. (2020) showing susceptibility of the main salmonid species, with sockeye salmon (*O. nerka*) being susceptible and coho salmon (*O. kisutch*) being largely resistant. For all species, even low abundances of lice on very small juvenile salmon may cause mortality or sublethal effects on physiology and behavior (Peacock et al., 2020, and references therein), but susceptibility changes rapidly with age for young fish (Sutherland et al., 2011) and therefore it changes rapidly during the four-month outmigration period as growing fish (also affected by temperature, food availability and various other factors) become more resistant.

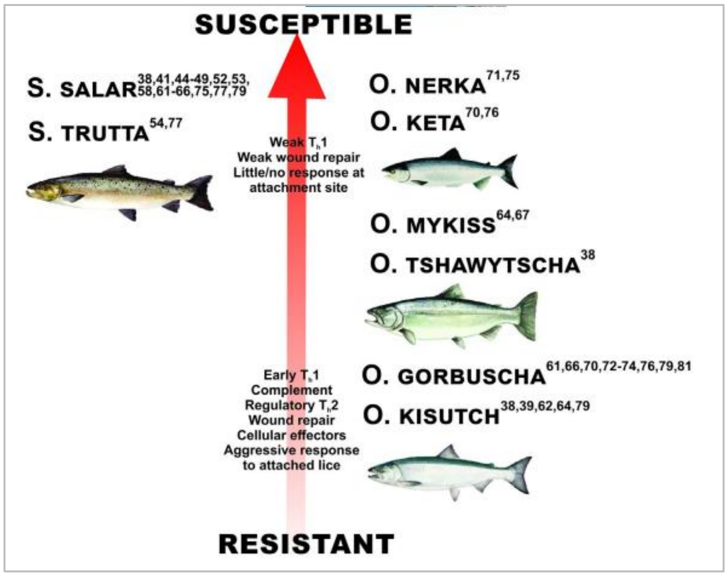

Figure 30: Overview of the susceptibility/resistance of Pacific (and Atlantic) salmonid species to sea lice. Image copied from Braden et al. (2020), and numbers refer to references quoted by Braden et al.

Many sub-lethal impacts of sea lice infection (e.g., reduced swimming speed, reduced feeding, and other changes in behavior) increase the likelihood of predation, including by other Pacific salmon species (Peacock et al., 2014; Godwin et al., 2018, 2019, Long et al., 2019), and the indirect ecological effects of parasites on host predation and competition may be the primary mode by which parasites affect wildlife populations in these situations (Peacock et al., 2020 and references therein).

By referring again to the risk factors used by Grefsrud et al. (2021a), it can be seen that there are large variations across all factors, thereby implying that the impacts may be severe when all the factors align, but that there may be few circumstances where they actually do in reality (i.e., there are large numbers of lice emitted by a farm and high survival of the lice larvae, at the same time as juveniles of a susceptible species and susceptible size are migrating through the infection zone). Further, research in Norway shows the impact of sea lice on wild salmonids (at the population level) is context-sensitive; that is, the effect of lice is directly correlated with the overall survival in the ocean, so that in years of poor survival the effect of lice is large, while in years of good survival the effect of lice is almost not measurable (Vollset et al., 2015, 2019; Bøhn et al., 2020). It is also interesting to note that the Norwegian risk assessment follows the mortality categories of the Norwegian "traffic light system"[85] where 0-10% mortality of wild out-migrating salmon as a consequence of lice infection is considered a low risk, 10-30% mortality is a moderate risk, and >30% mortality is a high risk. This is broadly similar to DFO's bacterial and viral risk assessments where a "likely" impact of 10-25% mortality is a yellow "moderate" risk outcome. As Pacific salmon species are considered essential to life by indigenous communities in BC (e.g., Massey et al., 2021), it is challenging to determine if these Norwegian mortality rates would be deemed acceptable in BC.

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[85] The traffic light system in Norway currently controls the scale of each region's production, based on the calculated mortality of wild Atlantic salmon due to sea lice from salmon farms. See Vollset et al. (2020).

This deliberately simplistic overview therefore highlights the fact that the prevalence and intensity of lice on wild fish (e.g., Figure 28) does not necessarily imply mortality or significant impact to individual fish, yet given the high regional and temporal variability, it is likely that there will be substantial mortality in some areas in some years. The ongoing controversy regarding the impacts (again referring to Nekouie et al., 2018) highlights the lack of conclusive outcomes to date, but given the repeated sea lice outbreaks in some areas during the outmigration period, the level of concern has increased in recent years.

Sea lice management and governance

Bateman et al. (2016) recognized nearly a decade of effective sea lice control up to 2015, but the increases in lice levels in that year plus subsequent outbreaks (in addition to the potential development of resistance to lice treatments (Messmer et al. 2018) and potentially increasingly frequent higher water temperatures (Godwin et al. (2020b)) shows the need for adaptive management from the industry and regulators.

DFO's Conditions of License for salmon farms (updated March 1, 2020) set a threshold of an average of 3.0 motile *L. salmonis* lice per farmed fish during the outmigration period (March-June). The license holder must ensure that sea lice numbers are below the threshold at the time of the first counting event of the out-migration window (all stocked pens must now be sampled in February). However, if the threshold is exceeded during the outmigration period, farms have a period of 42 days to bring the count below the threshold (based on the practical requirements to prescribe, obtain, and administer medicated feeds, and see a response). In reality, this means that (in a worst-case scenario) a lice outbreak at just under three lice per fish threshold can increase for 56 days before being brought back under the threshold (i.e., 14 days until the first bi-weekly count over three lice per fish plus 42 days to return to less than three). In theory, the lice levels could again exceed the threshold and trigger a second period of 42 days, thereby maintaining high lice loads (with no upper ceiling) throughout the outmigration period. It is emphasized that this is a worst-case scenario, and it is not known how many times (if any) it has occurred. The treatment thresholds are applied at the farm level, but with consideration of cumulative lice loads (and therefore to the total infection pressure experienced by wild fish), BC does not have an area-based approach to sea lice management (i.e., considering the connectivity and cumulative impacts of multiple farm sites in a shared waterbody), and is the only major salmon farming region not to do so (Tardiff, 2019[86]).

Sea lice and their treatment are important economically to the industry. As noted in Criterion 4 - Chemical Use, the use of pesticides continues, and is increasingly supplemented by non-chemical alternatives as the industry evolves. There is a clear potential to improve sea lice management across the industry and Peacock et al. (2020) emphasize the benefits of early and coordinated treatments to reduce lice ahead of the outmigration period. More drastically, five farms in the Broughton Archipelago in 2019 were the first of 17 farms to be decommissioned

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[86] https://www.asc-aqua.org/the-current-state-of-sea-lice-management/

up to 2023 as part of an agreement between the aquaculture industry and First Nations to protect wild salmon under the Indigenous Monitoring and Inspection Plan (IMIP)[87]. Also as noted previously, in December 2020, the Canadian Fisheries Minister announced 19 fish farms in the Discovery Islands must close by June 30, 2022, but given ongoing legal cases, this is not considered further at this time.

Conclusions and Final Score

Many species of Pacific salmon are in decline over large geographical areas, including areas with and without salmon farms or salmon farming industries. As such, it is clear that pathogens or parasites from salmon farms have not caused the widespread decline, but given the importance of wild salmon (considered essential to life by indigenous communities in BC), any substantial contributions to their local declines or inhibitions of their recovery must be considered. The consequences of pathogen infection are highly variable depending on the individual, the strain of the pathogen, and the circumstances, thus driving the challenge of studying their impacts effectively in wild populations. The DFO risk assessments (for the risk of nine pathogens from farms in the Discovery Islands impacting the abundance or diversity of Fraser River sockeye salmon) are important studies with which to frame the components to be considered, yet despite their findings that all nine viral and bacterial pathogens had a "minimal" risk of impact when considered individually, the limitations in their scope are apparent with regard to other pathogens and parasites (both individually and in combination), and to other species of salmon in other areas of BC. Recent research continues to develop rapidly on many fronts and is making many associations between farm viruses and wild salmon, yet with few robust conclusions on transmission, infection, morbidity, or mortality in wild salmon. This challenge of drawing conclusions is perhaps best illustrated by a 2021 publication from the Strategic Salmon Health Initiative that notes (emphasis added here) "the <u>risk</u> of disease transmission from farmed to wild fish has increased, with <u>potential to contribute</u> to declines in wild fish populations, but <u>the probability and magnitude of this transmission has not been determined</u>" (note the use of this statement here is not intended to imply any particular level of impact or concern, but is simply utilized to highlight the challenge in drawing conclusions and in determining the appropriate level of concern). It therefore currently remains largely impossible to clearly differentiate between the speculation that viruses are driving or significantly contributing to the declines of wild salmon and the contrasting position reflected in the DFO risk assessments and other recent studies that bacterial and viral pathogens from Atlantic salmon farms are of minimal concern to wild salmon in BC.

With regard to parasitic sea lice, the large amount of data available indicates high geographic and temporal variability in lice levels on farms in most regions. In contrast to a period of stability in sea lice numbers up to 2015, there have been substantial outbreaks (e.g., average lice levels above the three-lice treatment threshold) in one or more reporting regions in most of the last five years, and frequent high lice levels in some regions, particularly the west and northwest coasts of Vancouver Island. The regulations allow lice to increase to high levels on farms (above the treatment threshold) without breaching the conditions of license. The

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[87] Reported by Fish Farming Expert, September 20, 2019. BC First Nations to oversee phase-out of up to 17 sites.

numbers of lice observed on out-migrating juvenile wild salmon are also highly variable both geographically and temporally. The tolerance of juvenile Pacific salmon to sea lice infection varies considerably by species and particularly by size. For some, even low abundances of lice on very small juvenile salmon may cause mortality or sublethal effects on physiology and behavior, but susceptibility in young fish changes rapidly with age, and therefore their risk of being impacted by on-farm lice changes substantially during the four-month outmigration period. Therefore, the prevalence and intensity of lice seen on wild fish does not necessarily imply mortality or significant impact to individual fish, yet given the high regional and temporal variability, it is likely that there will be substantial mortality in some areas in some years. Sub-lethal impacts and increased risk of predation may also be important. Like bacterial and viral pathogens, the ongoing controversy regarding the impacts of sea lice highlights the lack of conclusive outcomes to date, but with repeated lice outbreaks in some areas during the outmigration period, the level of concern has increased.

The analysis here has been limited to a simplistic overview and highlights the ongoing uncertainty in the cumulative impacts of pathogens and parasites from farms to wild salmon populations across BC, but given the status of wild salmon populations, the uncertainties largely define the need for a precautionary approach. While the volumes of data and research on this topic are large and continually increasing, the complexities (highlighted by the research) mean the impacts of salmon farming alone cannot be quantified robustly; as such, the Risk-Based Assessment method is used. Overall, the potential pathogen and parasite interactions between farmed and wild salmon in BC, and particularly the repeated sea lice outbreaks in some areas during the outmigration period, must be considered a high concern until further evidence indicates otherwise. With open production systems discharging viral, bacterial, and parasitic pathogens into waterbodies shared with vulnerable and endangered wild salmon populations, there is a high concern and the final score for Criterion 7 – Disease is 0 out of 10.

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

Impact, unit of sustainability and principle

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

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

Criterion 8X Summary

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

Brief Summary

Due to the industry-wide use of domesticated broodstock, the BC salmon farming industry is considered to be independent of wild salmon fisheries for the supply of adult or juvenile fish or eggs. The final score for Criterion 8X – Source of Stock is a deduction of 0 out of -10.

Justification of Rating

Atlantic salmon aquaculture has seen a multi-decadal establishment of breeding programs, aimed at selection for traits advantageous to farming (e.g., fast growth, disease resistance), which has been integral in the rapid growth of the industry (Asche et al., 2013; Heino et al., 2015; Gutierrez et al., 2016). Of the finfish species farmed for food, Atlantic salmon is among those that have been subject to the longest and most intense domestication regimes (Skaala et al., 2019); for example, Norwegian farmed salmon (from which Atlantic salmon populations in BC originated) have now undergone approximately 15 generations of targeted breeding and are now considered to be partially domesticated and adapted to a life in captivity (Grefsrud et al., 2020).

Conclusions and Final Scores

Due to the industry-wide use of domesticated broodstocks globally, 100% of eggs, juveniles and smolts are considered to be independent of wild salmon populations. The final score for Criterion 8X – Source of Stock is a deduction of 0 out of -10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Criterion 9X: Wildlife Mortalities

Impact, unit of sustainability and principle

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

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

Criterion 9X Summary

Evidence-Based Assessment

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

Brief Summary

Detailed data from DFO allow for a robust understanding of the impact that wildlife interactions with salmon farms has on wildlife populations and allow the use of the Evidence-Based Assessment method. Accidental mortalities of harbor seals and California sea lions have continued to decline to an average of three (total) per year since 2016, and 2016 was the last time lethal control of seals was used. Two humpback whales died as a result of entanglement and one was released alive in 2016, with an additional entanglement and live release in 2018, but none since. A small number of birds are also entangled or drowned in farm infrastructure each year. Substantial numbers of fish are caught as "incidental catch" in salmon farms, most of which are Pacific herring, but the total caught is very small compared to the commercial fishery quota. These data, together with an understanding of the population sizes of affected species, demonstrate that wildlife mortalities are limited to exceptional cases, and do not significantly affect any of these species' population size. The final score for Criterion 9X – Wildlife and Predator Mortalities is -2 out of -10.

Justification of Rating

With a robust understanding of the impact that wildlife interactions on salmon farms has on wildlife populations, the corresponding Criterion 1 – Data score is 7.5 out of 10. As such, the Evidence-Based Assessment method was used.

The presence of farmed salmon in net pens at high density inevitably constitutes a powerful food attractant to opportunistic coastal marine mammals, seabirds, and fish that normally feed on native fish stocks (Sepulveda et al., 2015). These predators can threaten production and have historically been lethally controlled. They can also become entangled in nets and other farm infrastructure, resulting in mortality.

DFO provides industry-reported data on reported marine mammal fatalities at marine finfish aquaculture facilities in BC[88] (note this includes the small number of non-Atlantic salmon farms). Figure 31 shows that a variety of marine mammal species have had fatal interactions with farms, but after a peak in lethal control in the mid- to late-1990s of over 600 harbor seals and sea lions per year, the numbers have declined dramatically.

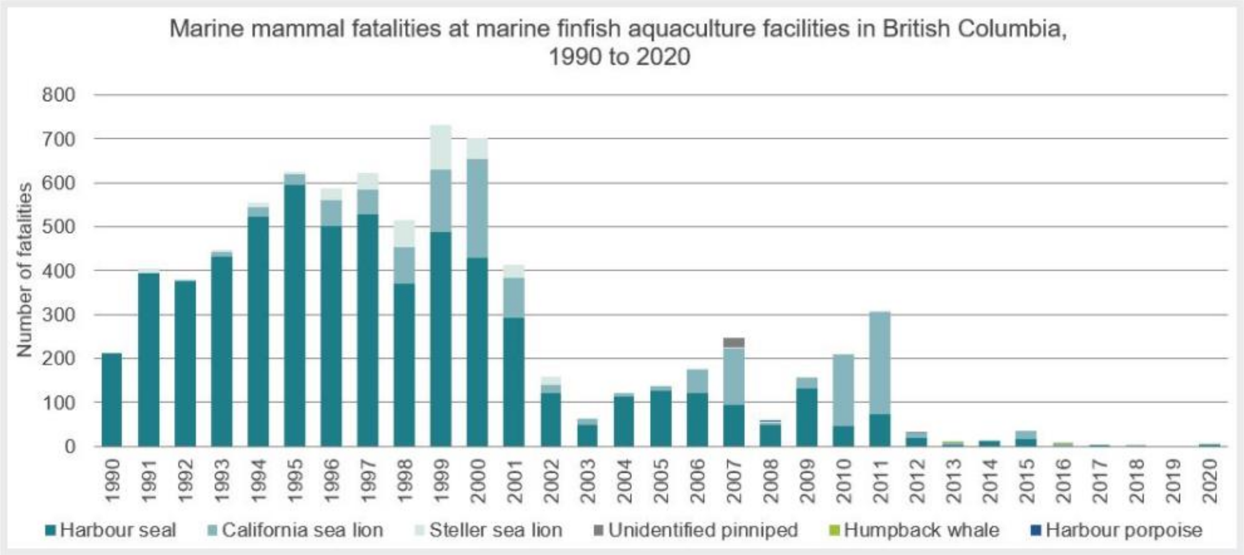

Figure 31: Reported marine mammal fatalities in BC. Image copied from DFO.

Seals and sea lions

In the last five data years (2016 to 2020), there have been 16 accidental mortalities with an annual maximum of six incidents in 2016: one harbor seal (*Phoca vituline)* and five California sea lions (*Zalophus californianus*). The last use of lethal control was in February 2016.

Having been depleted by over-hunting prior to the species being protected in 1970, the BC harbor seal population has increased considerably from approximately 10,000 in 1970 to about 105,000 in 2009 (DFO, 2010). Surveys conducted in 2008 estimated Stellar sea lion (*Eumetopias jubatus*) populations to be between 20,000 and 28,000 (DFO 2008). California sea lions in BC waters are migrants from more southerly breeding populations; the abundance of the US stock, estimated to be 300,000, is considered to be at its carrying capacity (WDFW, 2016[89]). While any mortality is distasteful from an anthropomorphic perspective, from an ecological perspective, the apparently stable population gives confidence that the current low mortality numbers do not impact the population size of these species.

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[88] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/mar-mam/index-eng.html

[89] Washington Department of Fish & Wildlife; California Sea Lion Fact Sheet. http://wdfw.wa.gov/conservation/sealions/facts.html

Humpback whales

The DFO data show three humpback whales became entangled in fish farm equipment in BC in 2016, with another in 2018; two of the whales in 2016 died, and the other two were released alive. One dead whale was found at a salmon farm in 2013, but after investigation, its death was found not to be associated with the farm (DFO marine mammal data as above). The DFO data show no whale mortalities since then (i.e., from 2017 to 2019), and no other reports (e.g., in the media) are readily apparent.

Humpback whales are listed as "threatened" under Canada's Species at Risk Act (SARA) and as "Special Concern" (i.e., lesser concern than "threatened") by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC)[90]. According to the SARA species profile[91], the most recent population estimate (2011) for the North Pacific Humpback whale was 18,302 individuals, suggesting the population is making a strong recovery, increasing at a rate of 4.9 to 6.8 percent annually since their commercial harvesting was banned by the International Whaling Commission in the North Pacific in 1965. Despite this increase, current numbers are low compared to pre-whaling population estimates. The mortality of a threatened species is a serious concern, but the growing population size indicates that the two mortalities in 2016 (and none since) will not contribute to further declines or prohibit recovery.

Birds

Data from GSI show small numbers of birds are entangled and/or drowned in salmon farms in BC, with an average of 0.3 birds per site per year from 2015 to 2020. Company reported data (e.g., Grieg[92]) show the species affected are mostly gulls with occasional crows and very occasional blue herons. These mortalities are not considered to have any impact on the populations of these species.

Fish

Wild fish of a variety of species may enter the salmon farm net pens at a small size and then grow to a size where they cannot escape, or that are otherwise killed during harvest or other farm activities. DFO publishes data on "incidental catch"[93], and in the 2011 to 2021 data (to May 2021), 750,150 fish have been caught as incidental catch in BC salmon farms, of 49 species. The large majority, 89.7% or 673,301 fish, were Pacific herring (*Clupea pallassi*), with Pacific cod the second most common at 4.6%. The remaining 47 species are caught in small numbers in isolated incidents. In the last three years (May 2018 to May 2021), 48,958 Pacific herring were caught. At a typical weight of 116 g (calculated according to the common length data and the length-weight relationships in Fishbase[94]), this equates to approximately 5.7 mt. This is a

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[90] Species at risk public registry. http://www.registrelep-sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=148

[91] http://www.registrelep-sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=148

[92] https://www.griegseafoodcanada.com/fish-farms/

[93] https://open.canada.ca/data/en/dataset/0bf04c4e-d2b0-4188-9053-08dc4a7a2b03

[94] https://fishbase.mnhn.fr/summary/Clupea-pallasii.html

substantial quantity, but relative to the 2020-2021 annual quota of 19,000 mt in BC[95], the incidental catch is minor.

Conclusions and Final Score

The very low numbers of seals, sea lions, whales, and birds experiencing accidental mortality at salmon farms in BC in recent years (plus considerable numbers of fish) while distasteful from a human perspective, are not considered to significantly affect the population size of these species. The mortality data allow the Evidence-Based Assessment method to be used, and show wildlife mortalities are limited to exceptional cases[96] that do not significantly affect the population sizes The final score for Criterion 9X – Wildlife and Predators is -2 out of -10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

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[95] https://www.cbc.ca/news/canada/british-columbia/bc-herring-quota-too-high-scientist-says-1.5920291

[96] While the capture of wild fish in general may not be limited to exceptional cases, significant events with large captures are considered exceptional

Criterion 10X: Introduction of Secondary Species

Impact, unit of sustainability and principle

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

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

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	75.9	2
Biosecurity score of the source of animal movements (0-10)		6
Biosecurity score of the farm destination of animal movements (0-10)		2
Species-specific score 10X Score		-3.2
Multi-species assessment score if applicable		n/a
C10X Introduction of Secondary Species Final Score		**-3.2**
Critical?	No	Yellow

Brief Summary

Although there are no longer considered to be any salmon egg imports into BC, the industry is dependent on the movements of live salmon from hatcheries to marine grow-out sites, and to a lesser extent between marine grow-out sites. These movements mostly take place within one large Salmonid Transfer Zone under transfer licenses, but approximately three-quarters of them in recent years cross Fish Health Zones. As systems open to the environment, the net pen sites that are the destination of most movements have inherently low biosecurity, so the tank-based freshwater hatcheries as the source of most salmon movements drives the overall risk. These systems typically have higher biosecurity (than net pens) and only a small proportion of movements from hatcheries to marine sites have designated fish health concerns. However, recent screening research shows the presence of many potential infective agents in hatcheries (including viruses that are newly discovered or otherwise not known to occur in salmon in BC), albeit mostly at low prevalence. All the agents recently detected in samples of farmed salmon in freshwater were also detected in marine samples and there is currently no evidence that these potential disease agents are associated with any disease in wild fish as a result of their movements with farmed salmon. Overall, there is considered to be a low-moderate risk of introducing a novel secondary species into new areas in BC, and the final score for Criterion 10X (a combination of Factors 10Xa and 10Xb) is a deduction of -3.2 out of -10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Justification of Rating

This criterion provides a measure of the escape risk (introduction to the wild) of secondary species (i.e., other than the principal farmed species) unintentionally transported during animal shipments.

According to the UN FAO (2012), the expanded and occasionally irresponsible global movements of live aquatic animals have been accompanied by the transboundary spread of a wide variety of pathogens. In some instances, these pathogens have caused serious damage to aquatic food productivity and resulted in pathogens becoming endemic in culture systems and the natural aquatic environment. The global salmon farming industry has suffered from the introduction of pathogens during the international movements of live animals, and transfers of live material is regarded as one of the most serious risk factors for spreading disease within the industry (Hjeltnes et al., 2016 – referring to the Norwegian industry). While the impacts to production are well documented, the ecological impacts beyond the farm are less apparent.

Factor 10Xa International or trans-waterbody live animal shipments

DFO published data on egg imports from 1985 to 2012 but has since ceased reporting on this topic. The BCSFA has confirmed no eggs have been imported since 2009 (BCSFA, pers. comm., 2021). Figure 32 shows the time series of previous imports.

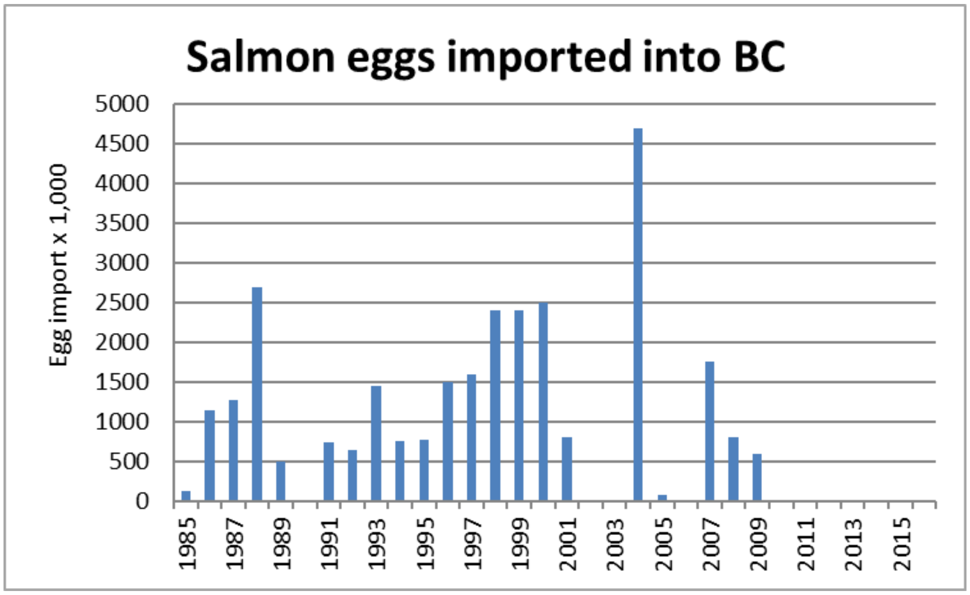

Figure 32: Salmon egg import data from 1985 to 2016. Source DFO and BCSFA.

The farming system involves the movement of live salmon smolts from freshwater hatcheries to seawater grow-out sites, and movement of fish from marine nursery sites to marine growout sites, and these transfers are managed in Salmonid Transfer Zones; Figure 33 shows the arrangement of zones. It can be seen that almost the entire industry in BC, including the freshwater hatcheries, operates in one transfer zone. As noted in Figure 18 in Criterion 7 –

Disease, the area within this transfer zone is divided into two fish health zones (zones 2 and 3) and nine subzones containing salmon farms (2.1 to 2.4, and 3.1 to 3.5).

1:3,500,000
Coordinate System: NAD 1983 BC Environment Albers

Produced by DFO Aquaculture Management Division
Last Updated: 17-10-2016; This map is for information only and is not to be used for navigational purposes. For more information, see http://www.pac.dfo-mpo.gc.ca/aquaculture/maps-cartes-eng.html

Figure 33: Salmonid Transfer Zones in BC Map copied from DFO[97]

DFO reports data on fish introductions and transfers in BC[98]. The data are somewhat dated (approximately one year old at the time of writing) but increased in detail from 2018 onwards. These movement data show that from 2018 to November 1, 2020, 24.1% of transfers occurred within the same fish health subzone, and 75.9% were across different subzones. Approximately

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[97] http://www.pac.dfo-mpo.gc.ca/aquaculture/maps-cartes-eng.html

[98] https://open.canada.ca/data/en/dataset/700fe290-7653-49e1-b961-741dc1ead924

76.2% of all movements were from freshwater hatcheries to marine grow-out sites, 21.0% were marine to marine movements, and 2.2% hatchery to hatchery.

With regard to the risks of introducing novel organisms during live animal movements (especially considering the potential for novel pathogens as indicated by recent research (see Criterion 7 – Disease)), movements across fish health subzones can be considered trans-waterbody movements. With 75.9% of movements occurring across fish health subzones, the score for Factor 10Xa is 2 out of 10.

Factor 10Xb Biosecurity of source/destination

The source of smolt movements are mostly freshwater hatcheries[99], typically land-based tank facilities operating as recirculating systems (Marine Harvest (Mowi), 2016). According to DFO[100], all movements of salmon for aquaculture purposes in BC require authorization under section 56 of the Fishery (General) Regulations, and an "Introduction and Transfer" license issued by the Introduction and Transfers Committee[101]. All transfer applications are accompanied by a signed veterinary attestation which details the health status of the fish to be transferred. Fish must be free of reportable diseases unless the Canadian Food Inspection Agency has provided a license to move fish with reportable diseases[102]. In addition, Atlantic salmon has been listed by the Introductions and Transfers Committee as a "Low Risk Species for Introduction and Transfer to Aquaculture Facilities" based on an assessment of disease risks (in addition to genetic and ecological risks)[103]; however, these aspects do not mean that hatchery fish are free of all diseases and that there is no transfer of pathogens or other secondary organisms.

Of all the movements from 2018 to November 1, 2020 (the latest data available as of August 23 2021), 6.9% of events involved fish with a designated fish health concern, but only 2.5% of all movements involved both a designated health concern and took place across different health subzones. These designated health concerns include poor gill health, mouth rot, BKD, winter ulcer, furunculosis, *Aeromonas salmonicida* and *Vibrio anguillarum*. In all cases, fish were graded, treated, or otherwise selected to reduce the concern, and transfer licenses were issued in all cases (on the condition that the fish are tested and cleared by a veterinarian of disease). It is important to note that there is no evidence that these movements of fish with a health concern were associated with any subsequent disease outbreak. Nevertheless, Bateman et al. (2021), using high-throughput qPCR methods to screen for 58 infective agents in freshwater

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[99] Approximately 21% of all movements are from marine to marine sites, where both the source and destination are open net pens.

[100] Managing transfers and fish health at British Columbia salmon farms. https://open.canada.ca/data/en/dataset/700fe290-7653-49e1-b961-741dc1ead924

[101] DFO British Columbia Introductions and Transfers. http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/intro-trans/licencereq-permisreq-eng.html

[102] CFIA Aquatic Animal Domestic Movements. http://www.inspection.gc.ca/animals/aquatic-animals/domestic-movements/eng/1450122972517/1450122973466

[103] DFO British Columbia Introductions and Transfers http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/intro-trans/species-especes-eng.html

and seawater farmed salmon cohorts, detected 20 agents in juvenile salmon in freshwater hatcheries (6 viruses, 9 bacteria, 1 Microsporidians, 4 Myxozoans, and 1 Protozoan) including 5 newly discovered viruses or otherwise not known to occur in salmon in BC. These agents typically had low prevalence in the freshwater sampling (maximum of 38% of samples testing positive), and again, it is important to note the discussion in Criterion 7 – Disease regarding the prevalence of microrganisms in aquatic environments and the implications of their detections in healthy, moribund and dead fish. There are currently no restrictions in transferring such fish from freshwater hatcheries to marine sites, but it is important to note that all the potential disease agents detected by Bateman et al. (2021) in freshwater hatchery sampling were also detected in farmed salmon in marine net pen sites.

The ultimate destination of the large majority of fish movements are marine net pen grow-out sites. The open nature of net pens is considered to result in inherently lower biosecurity (a score of 2 out of 10) than the source of (most) movements; the source, therefore, determines the score. Overall, land-based, often recirculating, hatcheries are the dominant source (nearly 80%) of salmon movements. While these systems are typically highly biosecure (a score of 8 out of 10), there is uncertainty in the robustness of in-practice biosecurity (a score of 6 out of 10) indicated by the presence of multiple microbial agents, albeit at typically low prevalence. In addition, some net-pen to net-pen movements across health zones justify some concern. Ultimately, the score for the biosecurity of the source of salmon movements, and the final score for Factor 10Xb, is 6 out of 10.

Conclusions and Final Score

Although there are no longer considered to be any salmon egg imports into BC, the industry is dependent on the movements of live salmon from hatcheries to marine grow-out sites, and to a lesser extent between marine grow-out sites. These movements mostly take place within one large Salmonid Transfer Zone under transfer licenses, but 76% of them cross Fish Health Zones. As systems open to the environment, the net pen sites that are the destination of most movements have inherently low biosecurity, so the source of salmon movements drives the overall risk. Tank-based freshwater hatcheries represent the dominant source of movements and have typically higher biosecurity, but while a small proportion of movements from hatcheries to marine sites in different fish health zones have designated fish health concerns, recent screening research shows the presence of many potential infective agents in hatcheries (including viruses that are newly discovered or otherwise not known to occur in salmon in BC), albeit mostly at low prevalence. The agents detected in farmed salmon in freshwater were all also detected in marine samples, and there is currently no evidence that these organisms are associated with any disease in the wild fish of primary concern as a result of their movements. Overall, there is considered to be a low-moderate risk of introducing a novel secondary species in new areas in BC, and the final score for Criterion 10X (a combination of Factors 10Xa and 10Xb) is a deduction of -3.2 out of -10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Acknowledgements

Scientific review does not constitute an endorsement of the Seafood Watch® program, or its seafood recommendations, on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

Seafood Watch would like to thank the consulting researcher and author of this report, Peter Bridson of Seagreen Research, as well as (in alphabetical order) Cormac O'Sullivan of SGS, Gary Marty of the Ministry of Agriculture, Food, and Fisheries, Kelly Roebuck of the Living Oceans Society, Krishna Thakur of the University of Prince Edward Island, Laura Braden of the Atlantic Veterinary College, Sean Godwin of Dalhousie University, Sonja Saksida of the Atlantic Veterinary College, Stephanie Peacock of the University of Calgary, and five other anonymous peer reviewers.

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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.

Criterion 1: Data	
Data Category	**Data Quality**
Production	7.5
Management	7.5
Effluent	7.5
Habitat	5.0
Chemical Use	7.5
Feed	7.5
Escapes	7.5
Disease	7.5
Source of stock	10.0
Wildlife mortalities	7.5
Escape of secondary species	7.5
C1 Data Final Score (0-10)	**7.50**
	Green

Criterion 2: Effluent	
Effluent Evidence-Based Assessment	**Data and Scores**
C2 Effluent Final Score (0-10)	**5**
Critical?	NO

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

Criterion 4: Chemical Use	
Single species assessment	**Data and Scores**
Chemical use initial score (0-10)	2.0
Trend adjustment	0.0

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

Criterion 5: Feed	
5.1 Wild Fish Use	
5.1a Forage Fish Efficiency Ratio (FFER)	**Data and Scores**
Fishmeal from whole fish, weighted inclusion level %	4.600
Fishmeal from byproducts, weighted inclusion %	0.600
Byproduct fishmeal inclusion (@ 5%)	0.030
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	8.900
Fish oil from byproducts, weighted inclusion %	1.600
Byproduct fish oil inclusion (@ 5%)	0.080
Fish oil yield value, weighted %	7.500
eFCR	1.300
FFER Fishmeal value	**0.268**
FFER Fish oil value	**1.557**
Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	6.000
Critical Source fisheries?	No
SFW "Red" Source fisheries?	No
FFER for red-rated fisheries	n/a
Critical (SFW Red and FFER >=1)?	No
Final Factor 5.1 Score	**4.670**

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

5.3 Feed Footprint	**Data and Scores**
CCI (kg CO2-eq kg-1 farmed seafood protein)	**23.542**
Contribution (%) from fishmeal from whole fish	1.767
Contribution (%) from fish oil from whole fish	0.231
Contribution (%) from fishmeal from byproducts	2.290
Contribution (%) from fish oil from byproducts	0.412

Contribution (%) from crop ingredients	82.041
Contribution (%) from land animal ingredients	13.259
Contribution (%) from other ingredients	0.000
Factor 5.3 score	**4**
C5 Final Feed Criterion Score	**4.1**
Critical?	**No**

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	4
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	4.000
F6.2 Invasiveness score	6
C6 Escape Final Score (0-10)	**5.0**
Critical?	No

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

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

Criterion 9X Wildlife Mortality parameters	**Data and Scores**
Single species wildlife mortality score	-2
System score if multiple species assessed together	n/a
C9X Wildlife Mortality Final Score	**-2**
Critical?	No

Criterion 10X: Introduction of Secondary Species	**Data and Scores**
Production reliant on transwaterbody movements (%)	75.9
Factor 10Xa score	2
Biosecurity of the source of movements (0-10)	6
Biosecurity of the farm destination of movements (0-10)	2

Species-specific score 10X score	-3.200
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**-3.200**
Critical?	n/a