

Monterey Bay Aquarium Seafood Watch®

Chinook salmon

Oncorhynchus tshawytscha



Image © Monterey Bay Aquarium

British Columbia, Canada

Marine Net Pens

June 3, 2019

Seafood Watch Consulting Researchers

Disclaimer

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

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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 originating from sources, whether fished¹ or farmed that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

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

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

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

Criterion	Score	Rank	Critical?
C1 Data	8.18	GREEN	
C2 Effluent	6.00	YELLOW	NO
C3 Habitat	6.27	YELLOW	NO
C4 Chemicals	9.00	GREEN	NO
C5 Feed	7.17	GREEN	NO
C6 Escapes	7.00	GREEN	NO
C7 Disease	4.00	YELLOW	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife mortalities	-2.00	GREEN	NO
C10X Introduced species escape	0.00	GREEN	
Total	45.61		
Final score (0-10)	6.52		

OVERALL RANKING

Final Score	6.52
Initial rank	YELLOW
Red criteria	0
Interim rank	YELLOW
Critical Criteria?	NO

FINAL RANK
YELLOW

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

- **Best Choice** = Final score > 6.66 and ≤10, **and** no Red criteria, **and** no Critical scores.
- **Good Alternative** = Final score > 3.33 and ≤6.66, **and/or** one Red criterion, **and** no Critical scores.
- **Avoid** = Final score ≥ 0 ≤ 3.33, **or** more than one Red criterion, **or** one or more Critical scores.

Summary

The final score for Chinook salmon farmed in net pens in British Columbia is 6.52 with no Red-ranked criteria. The final ranking is Yellow and a recommendation of Good Alternative.

Executive Summary

Salmon aquaculture in Canada's Pacific coast province of British Columbia (BC) began in the early 1970s with a small production of Chinook and coho salmon. Beginning in the mid-1980s, salmon farming grew rapidly as large corporations began farming Atlantic salmon, and Atlantic salmon production quickly overtook Pacific species. Currently, BC produces approximately 85,000 metric tons (MT) of farmed salmon per year. The vast majority of this production is Atlantic salmon, and Chinook salmon production accounts for just under 3% of the total production (around 2,500 MT per year). There are just three companies, at a combined eight farm sites, that account for all production. The majority of Chinook salmon farmed in BC (60%) is exported to the US.

This Seafood Watch assessment involves a number of different 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.² Although it is likely that some of the potential impacts are similar between Atlantic and Chinook salmon farms in BC, noting the differences between these species and the respective production practices employed are a key part of this assessment.

With historic and ongoing concern over net pen production systems and their environmental impacts, the considerable amount of scientific study means that data availability in BC is generally good compared to many aquaculture industries globally. However, disaggregating the impacts of the Chinook salmon aquaculture industry from the whole BC aquaculture industry, which is predominantly Atlantic salmon production, is not always possible. In addition, limited detail and gaps in public data availability still remain in some key areas, although two companies currently producing Chinook salmon in BC provided extensive data on their operations. Although government and company statistics are sometimes aggregated and rely on industry self-reporting (audited by regulators), the environmental impacts of salmon farming in BC have undergone substantial scientific study. Furthermore, the majority of Chinook farming in BC is produced by one company (Creative Salmon) that is certified to Canada's organic aquaculture standards. Nevertheless, there are limitations in the current scientific understanding of impacts associated with escapes and disease. Overall, data availability, quality, and confidence are largely considered to be moderate to high, and the final score for Criterion 1 – Data is 8.18 out of 10.

Globally, the salmon industry has increased its efficiency and made significant reductions in nutrient losses per ton of fish production. However, effluent in the form of soluble and particulate wastes still represents a substantial loss of the ecologically costly and globally sourced feed ingredients used to make salmon feed. Although the floating net pens themselves

² The full Seafood Watch aquaculture criteria are available at:
http://www.seafoodwatch.org/cr/cr_seafoodwatch/sfw_aboutsfw.aspx

have a minimal direct habitat impact, the operational impacts on the benthic habitats below and in the immediate vicinity of farms (i.e., within a regulatory allowable zone of effect) are potentially significant. For this Seafood Watch assessment, the impacts within the farm's immediate area (primarily on the seabed) are assessed in the Habitat Criterion, and the impacts beyond the immediate farm area on the seabed and in the water column are assessed in the Effluent Criterion.

Effluent discharges from net pen salmon farms have been extensively studied globally, and research specific to BC and Clayoquot Sound—where >80% of Chinook production takes place in BC—suggests that Chinook salmon farms do not cause impacts beyond the immediate vicinity of the farm. The regulatory system in BC falls under the Department of Fisheries and Oceans (DFO) and is intended to protect vulnerable habitats, and to require farms to demonstrate minimal impacts on the seabed beyond the immediate farm area at peak biomass. Monitoring of nutrients in the water column is not required due to the previous lack of detectable levels >30 m from the net pens, but seabed monitoring (which is typically conducted by third-party companies) at 30 m and 125 m beyond the pens is required, and subjected to enforcement audits by DFO at approximately 25% of active farms each year. The main regulatory mechanism in place addressing cumulative impacts are site separation provisions requiring farms to be >3 km apart, unless they are under a coordinated health management plan or owned by the same company; Creative Salmon operates six sites in Clayoquot Sound that are less than 3 km apart, and as such, these site separation provisions are not considered in effect. Overall, the results show that Chinook farms are largely compliant with regulations, with only one instance of a site at 125 m beyond the farm exceeding regulatory thresholds since 2011. Sites exceeding thresholds must be sampled again and shown to be compliant before restocking is permitted. However, given a lack of regulatory controls over cumulative impacts and the relatively clustered nature of the industry alongside Atlantic salmon farms in Clayoquot Sound, there is the potential for cumulative impacts at the waterbody scale. The final score for Criterion 2 – Effluent is 6 out of 10.

Floating net pens have a minimal direct physical habitat impact, but the operational benthic impacts in the immediate vicinity of farm sites can be significant. However, the chemical and biological effects of organic enrichment are relatively rapidly reversible by fallowing or relocating farms, and benthic monitoring beyond the immediate vicinity of the farm sites indicates minimal impacts. Some Chinook salmon farm sites in British Columbia occupy wild salmon habitats, but there is currently no evidence that habitat impacts directly affect the health or productivity of wild salmon populations. Although there are limited explicit regulations regarding the cumulative impacts of multiple sites, regulations are strong at the site level and the total area impacted is very small compared to the total coastal resource in BC. Data indicate that the potential for cumulative impacts are low, whether from adjacent sites or from the industry's total impact area. Therefore, the combination of relatively rapid reversibility of benthic impacts and moderately strong regulatory effectiveness results in a final score of 6.27 out of 10 for Criterion 3 - Habitat.

Chinook salmon production in BC is currently dominated by Creative Salmon, a producer certified to the Canadian Organic Aquaculture Standard, which does not permit the use of antibiotics in food production fish; it is understood that the other two current producers do not use antibiotics at any time in food production fish, and DFO staff confirmed that antibiotics are currently not used in Chinook food production fish. However, data from the DFO indicate that small amounts may be used occasionally in limited numbers of broodstock fish; data also indicate that Grieg Seafood, no longer farming Chinook, did use antibiotics in their previous Chinook food production fish, likely to control diseases such as BKD and furunculosis, and did so twice in one year at the same site several times.

Regarding pesticide usage, Chinook salmon are naturally more resistant to sea lice and amoebic gill disease infections (the leading causes of pesticide use in Atlantic salmon farming), and there is currently no pesticide use.

Overall, data show that chemical treatments have not been used in food production fish since 2014 (score of 10 out of 10); broodstock treatments, applied in the same net pen arrays as food production fish, are on average less than once per year (score of 8 out of 10); as such, the final score for Criterion 4 – Chemical Use is an intermediate 9 out of 10.

The industry's major feed supplier produces growout feed with a 40% protein content, and high fishmeal and fish oil inclusions (50% and 15%, respectively), though nearly all is sourced from byproducts. As a result of the use of byproducts and an economic feed conversion ratio of 1.72, the low FFER value shows that, on average, only 0.19 tons of wild fish are used to produce one ton of farmed Chinook salmon in BC. With the adjustment in the score due to the source fisheries (Mexican sardines and mixed Peruvian fisheries) for the remaining wild fishmeal, this results in a score of 9.33 out of 10 for Factor 5.1 – Wild Fish Use. The high use of byproducts results in a +24.21% net gain of edible protein, and the score for Factor 5.2 – Net Protein Gain/Loss is 10 out of 10. Due to the high inclusion rate of fishmeal and fish oil in the feed, it is estimated that 29.30 ha of land and ocean area are appropriated to feed one ton of harvested Chinook salmon; therefore, Factor 5.3 – Feed Footprint, is scored 0 out of 10. Combining Factors 5.1, 5.2, and 5.3 results in a numerical score of 7.17 out of 10 for Criterion 5 – Feed.

The risk of escape is balanced against the potential genetic and ecological impacts of escaped fish. Although net pen systems are inherently vulnerable to both large-scale escape events and chronic trickle losses, the documented track record of low reported Chinook escapes since 2011, in combination with the escape prevention measures utilized by farms demonstrates that the industry has effective management systems in place to mitigate the risk of escape. Data regarding escape records are considered robust, despite the risk of trickle losses occurring unaccounted for. This justifies a significantly lower level of concern than typical open systems using best management practices and the score for Factor 6.1 is 6 out of 10. Farmed Chinook salmon are at least six generations distinct from wild Chinook salmon, and although one producer uses triploid fish, escapes from the other two producers have the capability of spawning with their wild counterparts. Despite farmed Chinook salmon having better sperm performance than wild fish, the survival of their fry when crossed with wild females is low, and

therefore, the risk of farmed fish contributing to the gene pool of wild fish is low. Although there is a theoretical risk of ecological competition with wild salmon, the numbers of escaping salmon (two fish reported since 2011) are insignificant compared to the populations of wild salmon (despite concerns over wild population levels), including those nearly 40 million annually released by DFO for stock enhancement. These hatchery releases have resulted in widespread genetic dilution and mixing; historically, releases took place in different river catchments than parental origin, and hatchery fish tend to have higher rates of straying into different river catchments than wild-origin fish. Therefore, any competition, predation, disturbance, or other impacts to wild species, habitats, or ecosystems that may occur is low, and the score for Factor 6.2 is 8 out of 10. Overall, the final score for Criterion 6 – Escapes is a combination of the risk of escape (Factor 6.1) and the risk of competitive and genetic interactions (Factor 6.2), for a score of 7 out of 10.

The broad body of literature regarding disease transfer risk between salmon farms and wild salmon in British Columbia is largely focused on Atlantic salmon, and though there is often applicable information in these studies to this assessment of the risk posed by Chinook salmon farms, there is ultimately not enough data available to demonstrate the specific impact (or lack thereof) of Chinook salmon farms on the health of wild salmon in BC; therefore, the Risk-Based Assessment option in the Seafood Watch Aquaculture Standard is used (as opposed to the Evidence-Based option).

According to farm mortality rates, bacterial and viral pathogens cause approximately half, at most, of the 1% to 1.8% monthly mortality rates in BC Chinook aquaculture production (i.e., if all “fresh silvers” and “decomposed” fish died because of these pathogens). Although the actual number is likely to be less, the presence of pathogens on farms (including a chronic presence that may not cause high mortalities) represents a reservoir of potential infection to wild fish. To date, this connection and potential impact have not been fully understood, and the research of the Strategic Salmon Health Initiative (SSHI) and others are advancing this knowledge in BC. Although bacterial kidney disease (BKD) is the primary disease affecting Chinook salmon farms, piscine orthoreovirus (PRV) is of particular focus for the SSHI and in this report. The strain of PRV present in BC is believed to contribute to the development of the incompletely characterized jaundice or anemia syndrome seen in farmed Chinook salmon. At this stage, however, there is no evidence of bacterial or viral pathogens on Chinook salmon farms having an impact on wild salmonids in BC, but importantly, there is also no evidence that there is not an impact. There is therefore some level of concern, particularly in the context of the ecological importance of vulnerable wild salmonid populations in BC.

Chinook salmon are naturally more resistant to sea lice than Atlantic salmon, and Chinook salmon farms have never had sea lice levels exceed regulatory thresholds for reporting, nor levels that have required intervention or treatment; indeed, there is evidence that lice levels on wild Pacific salmon is commonly higher than that seen on farmed Chinook. Though Chinook salmon farms have the theoretical potential to act as point sources of sea lice infection for wild salmon, sea lice are naturally present in coastal waters throughout the year on non-salmonid

hosts. The low level of infection in farmed Chinook salmon and the relatively small size of the industry means that spillback of on-farm lice infection is of low concern.

Chinook farms in BC implement fish health management and biosecurity measures that result in low levels of disease-related mortality, as evidenced by the lack of reported disease events, no therapeutic treatments, and reported low mortality rates. Simultaneously, the majority of the Chinook industry is sited in Clayoquot Sound on the west coast of Vancouver Island (WCVI), where vulnerable wild Chinook stock levels are depressed and are under the lowest possible level of stock status classification by the DFO. Given the multitude and complexity of factors affecting wild fish productivity and survival, and the aforementioned low disease rates on Chinook salmon farms, an intermediate score is warranted, indicating that some disease-related mortality occurs on farms and the production system is open to the introduction and discharge of pathogens. As such, the final score for Criterion 7 – Disease is 4 out of 10.

The Chinook salmon farming industry in BC is entirely reliant on domesticated, hatchery-raised broodstock, eggs, and smolts. The final score for Criterion 8X – Source of Stock is –0 out of –10.

Data show that wildlife mortalities as a result of interactions with Chinook salmon aquaculture operations in BC are limited to exceptional cases; only three California sea lion and five harbor seal mortalities have been reported in the previous seven years, and none in the previous five. Though a number of native fish species are regularly caught as incidental catch, regulations require efforts be made for harmless release, and any mortalities that might result can be considered to be well below a level that could impact population status. Therefore, the final score for Criterion 9X – Wildlife and Predator Mortalities is –2 out of –10.

Chinook salmon are native to BC and broodstock are maintained in local hatcheries; thus, there is no risk of exotic pathogens being introduced by Chinook salmon farming. Furthermore, all transfers of fish occur within the government-mandated “salmonid transfer zones” whose boundaries constitute related watersheds. The final score for Criterion 10X – Escape of secondary species is –0 out of –10.

Overall, the final score for Chinook salmon farmed in net pens in British Columbia is 6.52 with no Red-ranked criteria. The final ranking is Yellow with a recommendation of Good Alternative.

Introduction

Scope of the analysis and ensuing recommendation

Species

Chinook salmon (*Oncorhynchus tshawytscha*)

Geographic coverage

British Columbia (BC), Canada

Production Method

Marine net pens

Species Overview

Chinook salmon (*Oncorhynchus tshawytscha*) is native to the North Pacific Ocean, and there are many genetically discrete populations throughout North America, Canada, Alaska, Russia, and Japan. They are anadromous, meaning they spawn in freshwater streams and rivers, and juveniles migrate to sea where they undergo extensive ocean-wide migrations in search of feeding grounds. Typically after three or four years, they return to the river or stream of their origin to spawn. Chinook salmon are semelparous, meaning all fish die after spawning.



Figure 1. Map showing the locations of marine net pen farms currently producing Chinook salmon in British Columbia. Red circles = farm locations. Image generated using Google Earth.

Production system

Farmed salmon fry are produced from broodstock in freshwater hatcheries utilizing land-based tank systems. After 7 to 12 months, the salmon smolts are stocked into marine net pens for growout, which is the longest phase of the production cycle (16 to 24 months) when the potential for most significant ecological impacts occur. Net pens are open to water exchange from the waterbodies in which they are sited and are constantly flushed by currents to bring clean, oxygenated water to the fish. However, this open water exchange also allows the free passage of effluents, disease, and chemotherapeutants between the net pen itself and the surrounding environment. Figure 1 shows the locations of farm sites currently producing Chinook salmon for commercial grow-out, although not all sites will be in production at the same time.

Production statistics

Globally, Chinook salmon are produced in New Zealand, Canada, and Chile; FAO statistics indicate that 14,890 MT were produced in 2017 (FAO, FishstatJ 2019), though this figure only includes New Zealand production. Communication with the Canadian Department of Fisheries and Oceans (DFO) indicated that Chinook production in British Columbia (BC) was 2,555 MT in 2016 (Figure 2); thus, the global total is over 17,000 MT.

Salmon farming in Canada began in the early 1970s with a small production of Chinook and Coho salmon (King et al., 2013). Beginning in the mid-1980s, salmon farming grew rapidly as large corporations began farming Atlantic salmon after permission was granted to farm them in BC Atlantic salmon production quickly overtook Pacific salmon production.

BC is Canada's largest salmon-producing region, accounting for over 60% of production.³ Canada's Department of Fisheries and Oceans (DFO) regulates aquaculture in BC and lists on their website 116 valid licenses with a potential peak biomass of 296,979 MT.⁴ At any given time, between 60 and 80 farms are actively farming salmon (K. Shaw, personal communication, DFO November 2018). However, aquaculture of Chinook salmon accounts for only about 3% of the total production of cultured salmon in BC with 2,520 MT in 2018 compared to 81,165 MT for Atlantic salmon in the same year (K. Shaw, personal communication, DFO 2019). Currently, Chinook salmon are produced in BC by only three companies: Creative Salmon Co. Ltd., Saltstream Engineering, and Yellow Island Aquaculture, at a combined eight farm sites. Other companies have farmed Chinook salmon in the past, but no longer do, such as Marine Harvest (last produced Chinook in 2008) and Grieg Seafood (last produced Chinook in 2015); many companies hold licenses authorizing the production of Chinook salmon at some sites, though they are not using them.

Creative Salmon was first salmon producer certified to the Canadian Organic Aquaculture Standard CAN/CGSB-32.312-2012 in 2013.⁵ This certification has been maintained with annual

³ <http://www.dfo-mpo.gc.ca/stats/aqua/aqua16-eng.htm>

⁴ <https://open.canada.ca/data/en/dataset/522d1b67-30d8-4a34-9b62-5da99b1035e6>

⁵ <http://www.creativesalmon.com/organic-farming.php>

audits performed by SAI Global and is still currently valid in 2018 (CANORG certificates, supplied by Tim Rundle, Creative Salmon, 2018). Yellow Island Aquaculture maintains its own internal set of principles that were published by the BC Association for Regenerative Aquaculture in 1999. Yellow Island has not supplied publicly available reports of adherence to its principles, though they are detailed extensively on the company website.⁶

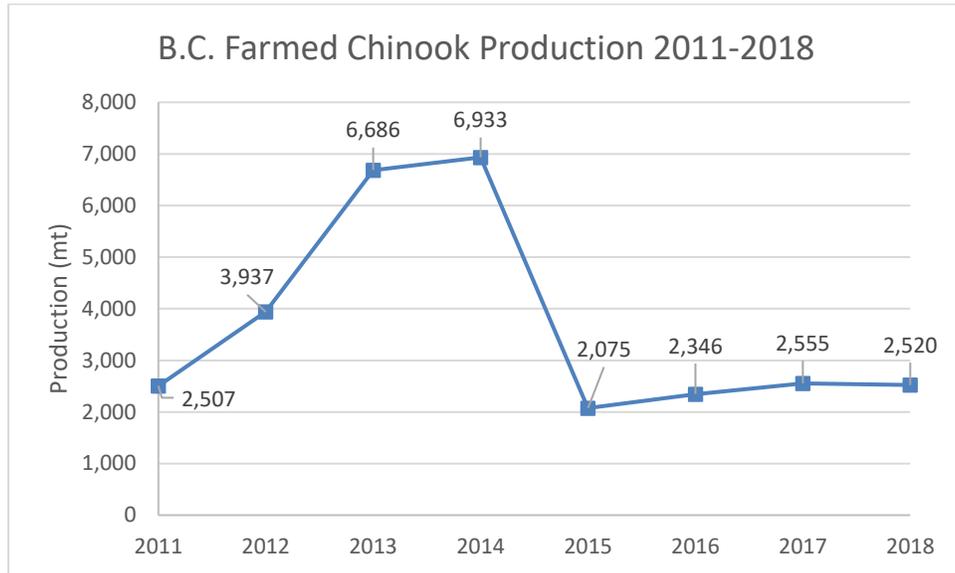


Figure 2. Approximate annual production of farmed Chinook salmon in BC. Data provided by the DFO.

Import and export sources and statistics

In 2018,⁷ 1,131 MT of fresh farmed Chinook salmon were exported from BC to the US; approximately 339 MT of frozen Chinook salmon were imported over the same time period, though the proportion of this figure that is sourced from farms is unknown. In 2017, 1,105 MT were imported, which is roughly 43% of the total production from BC for that year. Chinook salmon are exported to the US, Japan, France, UAE, Switzerland, and Taiwan.

Common and market names

Scientific Names	<i>Oncorhynchus tshawytscha</i>
Common Names	Chinook salmon
United States	King or spring salmon
Spanish	Salmón real
French	Saumon royal
Japanese	チヌック鮭 (Chinukku sake)

⁶ <http://yellowislandaquaculture.ca/organics/>

⁷

https://www.st.nmfs.noaa.gov/pls/webpls/trade_prdct_cntry_ind.results?qttype=IMP&qyearfrom=2013&qyearto=2018&qprod_name=SALMON+CHINOOK&qcountry=1220&qsort=COUNTRY&qoutput=TABLE

Product forms

Chinook salmon are sold fresh or frozen whole, dressed, headed and gutted, steaks and fillets (bone-in or boneless), 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: having robust and up-to-date information on production practices and their impacts available for analysis.

Criterion 1 Summary

Data Category	Data Quality	Score (0-10)
Industry or production statistics	10	10
Management	10	10
Effluent	7.5	7.5
Habitat	7.5	7.5
Chemical use	7.5	7.5
Feed	7.5	7.5
Escapes	7.5	7.5
Disease	5	5
Source of stock	10	10
Predators and wildlife	7.5	7.5
Introduced species	10	10
Other – (e.g. GHG emissions)	Not Applicable	n/a
Total		90

C1 Data Final Score (0-10)	8.18	GREEN
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Brief Summary

With historic and ongoing concern over net pen production systems and their environmental impacts, the considerable amount of scientific study means that data availability in BC is generally good compared to many aquaculture industries globally. However, disaggregating the impacts of the Chinook salmon aquaculture industry from the whole BC aquaculture industry, which is predominantly Atlantic salmon production, is not always possible. In addition, limited detail and gaps in public data availability still remain in some key areas, although two companies currently producing Chinook salmon in BC provided extensive data on their operations. Although government and company statistics are sometimes aggregated and rely on industry self-reporting (audited by regulators), the environmental impacts of salmon farming in BC have undergone substantial scientific study. Furthermore, the majority of Chinook farming in BC is produced by one company that is certified to Canada’s organic aquaculture standards. Nevertheless, there are limitations in the current scientific understanding of impacts associated

with escapes and disease. Overall, data availability, quality, and confidence are largely considered to be moderate to high, and the final score for Criterion 1 – Data is 8.18 out of 10.

Justification of Ranking

Industry or Production Statistics

Industry and production statistics are readily available from DFO, the BC Ministry of Agriculture, the BC Salmon Farmers Association (BCSFA), and FAO's FishstatJ software. Site names, companies, and maximum biomass available from DFO (note that maximum biomass is not the same as production, for which site-specific data are not publicly available).⁸ Although these data are generally good, data specific to Chinook salmon production had to be requested from the DFO, as they are otherwise aggregated with other Pacific salmon production; currently, Chinook are the only Pacific salmon being farmed. Discrepancies in production numbers were found in several official publications from DFO and the BC Ministry of Agriculture, likely due to units of production being considered (round weight vs. processed, for example). Requested data from DFO are considered to be accurate, and as such, the Data score for Industry or production statistics is 10 out of 10.

Management and Regulations

A large amount of information on aquaculture regulation in Canada and specifically in BC is available from DFO and the Pacific region⁹ websites, with evidence of enforcement in the form of monitoring and/or audit data.¹⁰ The BCSFA website has further information about farm-level management practices. Overall, general production and management are well understood, and complete information on the regulatory system is available. The data score for management and regulations is 10 out of 10.

Effluent and Habitat

There is no regulatory requirement for monitoring soluble effluent in BC (historical evidence behind that decision is available, e.g., (Brooks and Mahnken 2003). DFO's website has industry-reported benthic monitoring results (typically conducted by third-party companies¹¹) and the results of DFO's auditing. DFO has information on the regulatory management of effluent, including site separation requirements, 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., Husa et al. 2014 from Norway) can be carefully used to make comparisons to BC's scale of production. In BC, references such as Backman et al. (2009) provide context, and recent papers such as 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. The data scores for the Effluent and Habitat criteria are both 7.5 out of 10.

⁸ <http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/mar-eng.html>

⁹ <http://laws-lois.justice.gc.ca/eng/regulations/SOR-2010-270/>

¹⁰ <http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/index-eng.html>

¹¹ <http://www.pac.dfo-mpo.gc.ca/aquaculture/index-eng.html>

Chemical Use

Data on antibiotic usage by Chinook farms specifically dating from 2008 to 2017 were obtained from DFO veterinarians, though two years could not be publicly shared due to only two producers harvesting in those years. Some information regarding treatment frequency was obtained through DFO fish health audits. Pesticide usage is understood to be low given the lack of sea lice infestations, though data regarding treatments are limited; data from the DFO indicate that emamectin benzoate is not used, though data prior to 2016 regarding use of other treatments such as hydrogen peroxide are limited to personal communications. Overall, though some data are aggregated and incomplete, total chemical use can be reasonably and accurately determined through 2016, and the overall confidence in understanding the nature of chemical use on Chinook salmon farms in BC is high. The data score for Chemical Use is 7.5 out of 10.

Feed

Taplow Feeds¹² is the primary feed supplier of the two primary companies farming Chinook salmon in BC, though no information regarding feed used by the third producer was obtained. The feed company provided much of the relevant information required for the calculations in this assessment, including the primary sources of wild fish in their feeds. Specific information regarding the sustainability of these sources was limited for some sources, though for others it was robust. The data score for Feed is 7.5 out of 10.

Escapes

DFO publishes farm-level escape data based on farm reports,¹³ although only recent data after 2010 are available due to the transition of regulatory control of aquaculture to DFO. However, the risk of some unreported “trickle” losses limits full confidence in these data, though these data are still considered robust. There is a lack of specific data for Chinook salmon regarding the fate of escaped fish (due to the lack of escaped fish), although the potential competitive and genetic risks of an escaped farmed Chinook salmon in BC has been studied and is available in the academic literature. Personal communications with DFO staff in the Molecular Genetics office shed light on the risk that escaped Chinook may pose to wild populations relative to hatchery fish. The Annual “State of the Pacific Ocean” science advisory reports produced by DFO and the Canadian Scientific Advisory Secretariat, as well as DFO’s Annual Salmon Outlook,¹⁴ contain volumes of data on wild fish stocks for the Strait of Georgia, the greater Georgia Basin, the ocean west of Vancouver Island and the larger NE Pacific region.¹⁵ The data score for Escapes is 7.5 out of 10.

Disease

Fish health management information including fish health audits, industry reported health inspections and therapeutant use (antibiotic and sea lice pesticide) by facility is available from

¹² <http://www.taplow.com>

¹³ <http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/escape-evasion-eng.html>

¹⁴ <http://www.pac.dfo-mpo.gc.ca/fm-gp/species-especies/salmon-saumon/outlook-perspective/2018-somm-somm-eng.html>

¹⁵ <http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.html>

DFO. Data from the DFO as well as communications with Chinook producers indicated that they have never had sea lice levels exceed regulatory thresholds for reporting, nor levels that have required intervention or treatment; in conjunction with literature, it is understood that sea lice infestations are not high concerns for Chinook salmon farms. Although disease incidence data are generally robust for on-farm fish health and there is a large body of literature regarding the disease transmission dynamics between Atlantic salmon farms and wild fish, there is a lack of information regarding this as it relates specifically to Chinook salmon farming. As such, the data score for Disease is 5 out of 10.

Source of stock

As is the case for salmon production globally, farmed Chinook salmon eggs and smolts are produced by domesticated broodstocks and are therefore independent of wild salmon populations. There is also literature specific to the Canadian industry available detailing selective breeding strategies and programs. The data score for Source of Stock is 10 out of 10.

Predator and wildlife mortalities

DFO¹⁶ provides data on deliberate and accidental mortalities of marine mammals, including harbor seals, California sea lions, Steller sea lions, and cetaceans. The data are updated quarterly with a time lag of approximately one year. Additional information on licensing and management policies are also available from the same website. More recent events, prior to publication by DFO, can also be identified through media news reports from the region (for example, whale entanglements in BC in 2016—attributed to the Atlantic salmon industry—were reported in the news prior to updates to the DFO website). Information on population numbers and potential population impacts are available from a variety of sources, such as the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Although it is possible that some mortalities are unreported, the data score for Wildlife and Predator Mortalities is 7.5 out of 10.

Escape of secondary species

Locations of active Chinook salmon farm growout sites and hatcheries are known from DFO license data, and indicate that no transfers occurred across Salmonid Transfer Zones. In addition, DFO's classification of Chinook salmon as a "low risk" species for unintentionally spreading diseases or pests (among other considerations) is available.¹⁷ The data score is 10 out of 10.

Conclusions and Final Score

The availability and quality of data regarding Chinook salmon farming in BC is largely good, though some aggregation and gaps exist. There is moderate to high confidence in the available data to give a reliable representation of the operations and their impacts, though there are uncertainties and limitations in the current scientific understanding of impacts of escapes and disease. Much of the available information is industry self-reported and audited by regulators,

¹⁶ http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/mar_mamm-eng.htm

¹⁷ <http://www.dfo-mpo.gc.ca/aquaculture/management-gestion/intro-eng.htm>

yet in combination with independently collected government data and available scientific research, this results in the moderate to high final score for Criterion 1 – Data of 8.18 out of 10.

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: not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level.

Criterion 2 Summary

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0-10)	6	YELLOW
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Brief Summary

Effluent discharges from net pen salmon farms have been extensively studied globally, and research specific to BC and Clayoquot Sound—where >80% of Chinook production takes place in BC—suggests that Chinook salmon farms do not cause impacts beyond the immediate vicinity of the farm.

The regulatory system in BC falls under the Department of Fisheries and Oceans (DFO) and is intended to protect vulnerable habitats, and to require farms to demonstrate minimal impacts on the seabed beyond the immediate farm area at peak biomass. Monitoring of nutrients in the water column is not required due to the previous lack of detectable levels >30 m from the net pens, but seabed monitoring (which is typically conducted by third-party companies) at 30 m and 125 m beyond the pens is required, and subjected to enforcement audits by DFO at approximately 25% of active farms each year. The main regulatory mechanism addressing cumulative impacts are site separation provisions in place requiring farms to be >3 km apart, unless they are under a coordinated health management plan or owned by the same company; Creative Salmon operates six sites in Clayoquot Sound that are less than 3 km apart, and as such, these site separation provisions are not considered applicable.

Overall, the results show that Chinook farms are largely compliant with regulations, with only one instance of a site at 125 m beyond the farm exceeding regulatory thresholds since 2011. Sites exceeding thresholds must be sampled again and shown to be compliant before restocking is permitted.

However, given a lack of regulatory controls over cumulative impacts and the relatively clustered nature of the industry alongside Atlantic salmon farms in Clayoquot Sound, there is

the potential for cumulative impacts at the waterbody scale. The final score for Criterion 2 – Effluent is 6 out of 10.

Justification of Ranking

The Effluent Criterion considers impacts of farm wastes beyond the immediate farm area or outside a regulatory allowable zone of effect (AZE), and the subsequent Habitat Criterion considers impacts within the immediate farm area. According to the Seafood Watch Aquaculture Standard, the AZE for net pen farms is 30 m distance from the edge of the pens. Although the two criteria cover different impact locations, some overlap is inevitable between them in terms of monitoring data and scientific studies on soluble and particulate wastes. The majority of this information will be presented in this Effluent Criterion, with the intent of minimizing (but not entirely avoiding) replication in the Habitat Criterion. Due to the large volume of available data and literature regarding potential effluent impacts from net pen salmon farms, including those with a particular focus on Clayoquot Sound, the Evidence-Based assessment option is used. See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations.

There is a substantial body of literature on the fate and impact of nutrient wastes from net pen fish farms, including salmon farms, and key recent reviews such as Price et al. (2015) provide a useful summary. Price et al. (2015) conclude that 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 from 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 near shore, 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. Price et al. caution that, regardless of location, other environmental risks may still face this industry; for example, significant questions remain about the additive (i.e., cumulative) impacts of discharge from proximal farms, potentially leading to increased primary production and eutrophication.

In BC, Backman et al. (2009) note that introduced soluble wastes 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) showed that “in no case was dissolved inorganic nitrogen significantly increased at >30 m downcurrent when compared to upcurrent reference,” and concluded that outside of shallow, poorly flushed environments (which are poor locations for growing fish and therefore no longer used by BC farmers), the potential for net pen enhancement of phytoplankton populations is remote or nonexistent. Brooks (2007) calculated that 15.8 t/day of dissolved inorganic nutrients are released from salmon farms in BC, which was considered 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.”

Specific to Clayoquot Sound, where over 85% of Chinook salmon production occurs, Cross and Byrne (2017) provide a review of previous nutrient studies and the potential impact salmon farms may have. Hahn (2004) conducted a study examining the effects of discharged salmon farm wastes on surrounding intertidal communities. Hahn examined the community structure and biomass of intertidal mussels, macroalgae (*Fucus* spp.) and eelgrass, and phytoplankton, as well as using ¹⁵N as an isotopic tracer of farm-derived nitrogen assimilated within these organisms. There were approximately 20 active salmon farming sites over the time period that this study was conducted (2001 to 2003), inclusive of both Chinook and Atlantic salmon production, and salmon farms had been operating in Clayoquot Sound for nearly twenty years at that time. The conclusions reached by the study are as follows:

“There is no evidence from this study to suggest that open net-pen salmon farms provide a resource subsidy to adjacent intertidal communities in Clayoquot sound. Biomass of primary producers and mussels, their stable isotope content and invertebrate community structure at farms was not different from reference locations. The stable isotope ¹⁵N was not an informative tracer of farm-derived nitrogen. The lack of support for the predictions of this study are likely because farms are anchored too far from the shore, dilution of wastes by currents and pulsed feeding, and natural variation on multiple spatial scales” (Hahn 2004).

Although this study was conducted nearly fifteen years ago, operating conditions then were similar to those today, with 21 licensed sites and an average of 14 active sites annually.¹⁸ As is the case today, the overwhelming majority of production in Clayoquot Sound (and BC more generally) is Atlantic salmon; the majority of the Chinook salmon industry today not only farms fewer fish, but also operates at significantly lower densities (a maximum of 10 kg/m³ relative to average 15 kg/m³ for Atlantic salmon farms¹⁹; Canadian Organic Aquaculture Standards, 2018), further reducing the risk of effluent impact.

Cross & Byrne (2017) also reveal data from a currently ongoing study assessing the potential for integrated multi-trophic aquaculture (IMTA) using kelp to absorb discharged nutrients downstream of Clayoquot Sound salmon farms; the presence of a near-field dissolved nutrient plume is evident, but data show “no discernable elevations in bioavailable concentrations [of nutrients] beyond 100 m.” Colombo et al. (2016) show a similar, expected pattern of decreasing effects with increasing distance from farms using novel methods to detect changes in the fatty acid composition of resident (wild) marine organisms consuming aquaculture feed waste and fecal particles, with a limit of detection at a maximum of approximately 750 m.

¹⁸ <https://open.canada.ca/data/en/dataset/522d1b67-30d8-4a34-9b62-5da99b1035e6>

¹⁹ http://bcsalmonfarmers.ca/wp-content/uploads/2015/04/Feasibility_Study_ClosedContainment_BC.pdf

A primary cumulative impact of concern resulting from effluent discharges from multiple salmon farms is an algae bloom. Although no algae blooms have occurred at Chinook salmon farms (algae blooms have occurred in Clayoquot Sound where Atlantic salmon farms are sited, as recently as 2016²⁰), their nutrient discharge can cumulatively contribute to conditions that may precipitate an algae bloom. Algae blooms are natural events and a combination of factors, some related to climate change (water temperature, circulation, rainfall and runoff, sunlight, etc.), are important contributors or causes to the blooms (Chittenden et al. 2018) (McCabe et al. 2016) (Chandler et al. 2016); to date, there is no evidence to indicate that the algae blooms were directly caused by salmon farm effluent.

From a regulatory perspective, the Department of Fisheries and Oceans Canada (DFO) is responsible for regulating and managing the aquaculture industry in BC. These responsibilities include the licensing of aquaculture sites and the conditions of licensure. In addition to the conditions set out in subsection 22(1) of the Fishery (General) Regulations, the Minister may specify additional conditions in an aquaculture license, including the waters in which aquaculture is permitted (siting), and measures that must be taken to minimize the impact of the operations on fish and fish habitat (Foreman et al. 2015).

For DFO, the Fishery (General) Regulations (FGR), Pacific Aquaculture Regulations (PAR), and Aquaculture Activities Regulations (AAR) are the principal Fisheries Act regulations governing the activity of marine finfish aquaculture in British Columbia. In addition to the requirements of the Species at Risk Act (SARA) and the principles of the Oceans Act, these regulations frame the management and regulation of aquaculture activities on the Pacific coast of Canada. Although more specific hydrodynamic modeling systems are under development for key Atlantic salmon farming regions in BC (Kyuquot Sound, Broughton Archipelago, and Discovery Islands regions), the current siting criteria are a set of generic considerations that are applied on a coast-wide basis (Foreman et al. 2015).

For new sites, recent revisions to the siting guidelines²¹ (June 2015) now include broad provisions for impact minimization, including:

- Require the proponent of each application to conduct surveys, undertake analyses, and submit a set of comprehensive reports detailing the physical and biological characteristics of the ecosystem beneath and around the proposed site location.
- Aquaculture facilities should be capable of meeting performance measures for benthic conditions, as identified in the Aquaculture Activities Regulations, to mitigate impact to the ecosystem below the facility.
- The predicted footprint of increased deposition should be located in water depth of greater than 30 m to mitigate potential impacts to shallow water habitats.

²⁰ <https://www.cbc.ca/news/canada/british-columbia/2-clayoquot-sound-salmon-farms-hit-by-toxic-algae-1.3633722>

²¹ DFO Siting Guidelines for Marine Finfish Aquaculture in British Columbia: <http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/site-guide-direct-eng.html>

- Placement and operation of the proposed aquaculture facility should not impact Species at Risk Act (SARA) listed species.
- Aquaculture facilities should be located at least 3 km from an existing marine finfish facility or operate under coordinated health management plans.

Regarding the last of those guidelines, the separation of sites can be less than 3 km in some cases where there are coordinated Health Management Plans, and the previous guidelines permitted a minimum separation of 1 km between sites if they were owned by the same company. Provincial guidelines still specify the 3-km separation, but in practical terms, a 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 examples where farm sites were less than 3 km apart. Creative Salmon owns six sites in Clayoquot Sound located less than 3 km from each other; as such, the site separation provisions are not considered applicable for the Chinook salmon industry. However, only four of these sites operate at any time, leaving two sites fallow, and only two sites receive fish in any year, with the remaining two being harvested (T. Rundle, personal communication, Creative Salmon 2016). Sites with lower currents follow a longer-term fallowing regime, where they are used for four years and then left fallow for four years.

For existing operational sites in BC, there are no requirements for the monitoring of dissolved nutrients in the water column or their impacts (Day et al. 2015). After studies in BC and Washington State (e.g., Brooks and Mahnken 2003) did not detect significant nutrient levels more than 30 m downstream of the net pens, the requirements for water column monitoring were dropped from the regulations.

Benthic monitoring, on the other hand, is required. Previously listed in the License Conditions, these requirements are now detailed in the “Program Protocols for Marine Finfish Environmental Monitoring in British Columbia,” available in DFO’s Aquaculture Activities Regulations (AAR) guidance document.²² Sampling is required once every production cycle within 30 days of peak biomass. Specific sampling details apply to both direct sediment sampling on soft substrates and visual (video) surveys of harder erosional substrates; sampling transects and distances from the net pens are specified in detail. In brief, the direct sampling is based primarily on the measurement of free sulfides with regulatory thresholds at 30 m and 125 m, designed so that benthic recovery can occur when fish are removed and the site fallowed. Visual surveys operate on at least two transects extending from the edge of the net pens, and focus on the presence of *Beggiatoa* bacterial mats and marine worms (opportunistic polychaete complexes, OPC), both of which are indicative of organic enrichment, in a compliance zone between 100 and 124 m. If any single sample exceeds the threshold levels, the site is required to undertake an additional survey prior to restocking the site in the subsequent production cycle. In regard to potential impacts beyond the immediate farm area considered in the Effluent Criterion, the results at 30 m and at 125 m provide useful information on the likely impacts.

²² <http://www.dfo-mpo.gc.ca/aquaculture/management-gestion/aar-raa-gd-eng.htm#annex8.2>

Creative Salmon has long-conducted its own benthic monitoring program (T. Rundle, personal communication, Creative Salmon 2016), and in 1998, the BC Ministry of the Environment (MoE) began monitoring sediment chemistry and biology in the vicinity of fish farms, which is now currently under the purview of DFO, since a transfer of authority in 2010. The aquaculture industry, using third-party contractors, self-conducts and self-reports monitoring data, of which at least 25% of Chinook farm reports are audited by DFO annually (though there were no audits of Chinook farms in 2014) and assessed for compliance against individual site license conditions and regulations. “Aquaculture Regulation and Compliance” are described on DFO’s website²³ with annual enforcement activities including benthic monitoring. The most recent publicly available data for 2011 to 2017²⁴ show that DFO audited a Creative Salmon site every year except 2014 (most recently, July 2017); Yellow Island was audited once in 2015 via video assessment. No such auditing data are found for Saltstream Engineering, a third company currently operating a single site, though publicly available self-reported results indicate compliance with regulations as well. Though no longer operating any sites with Chinook salmon, Grieg Seafood had three of its four Chinook sites audited four times between 2013 and 2014.

These industry-reported monitoring results (typically conducted by contracted third-party specialists) are posted quarterly from DFO,²⁵ though the data currently available online are less detailed than previously; fortunately, the detailed data, last updated May 2017, are still accessible through the Internet Archive and range from 2011 to 2015.²⁶

All of Creative Salmon’s six sites are soft-bottomed sites, and they have sampled 2–3 sites per year with all sites being sampled at least once since 2011. On all occasions in the detailed dataset (n=12), self-reported monitoring data showed mean free sulfides were within the regulatory limits of 1,300 µM at a distance of 30 m from the cage array (under the scope of Criterion 3 – Habitat, since 30 m is the boundary of the allowable zone of effect [AZE]) and 700 µM at 125 m from the cage array, although these results were contradicted by DFO audits, which revealed that these thresholds were exceeded on three occasions: twice at the 30 m sampling sites (once in 2011, once in 2012) and once at the 125 m sampling site (in 2011). These resulted in further surveying required prior to fish restocking to ensure the benthos recovered. More recent data, though less detailed, indicate that since 2015, Creative Salmon sampled four sites six times (two individual sites were sampled in both 2016 and 2017), with no sites exceeding regulatory thresholds, confirmed by DFO audits. The Yellow Island Aquaculture site is hard-bottomed, and has been sampled three times since 2011—in 2013, 2015, and 2017. On all occasions, the results of benthic monitoring were considered to be within regulatory limits, and a DFO audit in 2015 confirmed the self-reported result that year. Saltstream Engineering is a soft bottomed site and has submitted samples twice—in 2013 and 2016—both

²³ <http://www.pac.dfo-mpo.gc.ca/aquaculture/regs-eng.html>

²⁴ <https://open.canada.ca/data/en/dataset/c1a54a0c-4eb0-4b50-be1f-01aee632527e>

²⁵ <https://open.canada.ca/data/en/dataset/7e76fdc8-c36a-491a-9afb-4f9280c929e8>

²⁶ <https://web.archive.org/web/20170506005847/http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/benth-eng.html>

times have been below regulatory impact thresholds; despite no DFO audits, DFO staff observe very low impacts at this site (K. Shaw, personal communication, DFO November 2018). Grieg Seafood sites with Chinook salmon were sampled 14 times from 2011 to 2014, with one site exceeding regulatory thresholds at 30 m in 2012; this resulted in further surveying required prior to fish restocking to ensure the benthos recovered. Grieg Seafood was audited four times by DFO over the same time period, and there was agreement with the industry results each time.

In total, 37 samples have been submitted by the Chinook industry from 2011 to 2017 and were found to have exceeded regulatory thresholds beyond the AZE (>30 m), either by self-assessment or DFO audit, once (2.7%). All sites have had indicators return to below thresholds prior to restocking. There have been no samples that exceeded thresholds since 2012, more than six years ago.

Although some studies such as Husa et al. (2014), in much more densely farmed regions relative to British Columbia, also show few direct impacts (for example, the Hardangerfjord in Norway, where a single fjord produces a volume of salmon (70,000 to 80,000 mt) approximately equivalent to the entirety of BC—approximately 90,000 MT), others emphasize the importance of less well-studied impacts of salmon farm effluent, including changes to the natural nutrient ratios and the effects on microbial communities and food webs, e.g., in Chile (Elizondo-Patrone et al. 2015) (Niklitschek et al. 2013) (Mayr et al. 2014). Emphasizing the importance of this, a recent study in Atlantic Canada found that a rainbow trout site (8 net pens, ~400,000 fish) could increase anthropogenic total dissolved nitrogen loading to the bay it is sited in by 14.4%, based on a computer model (McIver et al. 2018). Though noteworthy, this study does not examine nor indicate any impacts that have occurred due to this farm site, nor does it indicate the natural levels of dissolved nitrogen in the bay; the authors do, however, posit a variety of potential impacts from increasing anthropogenic dissolved nitrogen loading and suggest that there may be impacts we are still yet unaware of. Indeed, McIver et al. (2018) conclude by stating, “our study [highlights] the need for more effective monitoring and assessment methods to improve the detection of aquaculture effects at far-field scales and to assess those effects in relation to other natural and anthropogenic factors impacting coastal habitats.”

When considering all the currently available evidence, the data is considered sufficient to determine that effluent discharges from BC Chinook salmon farms do not cause impacts beyond the immediate vicinity of the farm. However, given a lack of regulatory controls over cumulative impacts and the relatively clustered nature of the industry alongside Atlantic salmon farms in a single sound (Clayoquot Sound, where >80% of production occurs), there is the potential for cumulative impacts at the waterbody scale. The final score for Criterion 2 – Effluent is 6 out of 10.

Conclusions and Final Score

Effluent discharges from net pen salmon farms have been extensively studied globally, and research specific to BC and Clayoquot Sound—where >80% of Chinook production takes place

in BC—suggests that Chinook salmon farms do not cause impacts beyond the immediate vicinity of the farm.

The regulatory system in BC falls under the Department of Fisheries and Oceans (DFO) and is intended to protect vulnerable habitats, and to require farms to demonstrate minimal impacts on the seabed beyond the immediate farm area at peak biomass. Monitoring of nutrients in the water column is not required due to the previous lack of detectable levels >30 m from the net pens, but seabed monitoring (which is typically conducted by third-party companies) at 30 m and 125 m beyond the pens is required, and subjected to enforcement audits by DFO at approximately 25% of active farms each year. The main regulatory mechanism addressing cumulative impacts are site separation provisions in place requiring farms to be >3 km apart, unless they are under a coordinated health management plan or owned by the same company; Creative Salmon operates six sites in Clayoquot Sound that are less than 3 km apart, and as such, these site separation provisions are not considered applicable.

Overall, the results show that Chinook farms are largely compliant with regulations, with only one instance of a site at 125 m beyond the farm exceeding regulatory thresholds since 2011. Sites exceeding thresholds must be sampled again and shown to be compliant before restocking is permitted.

However, given a lack of regulatory controls over cumulative impacts and the relatively clustered nature of the industry alongside Atlantic salmon farms in Clayoquot Sound, there is the potential for cumulative impacts at the waterbody scale. The final score for Criterion 2 – Effluent is 6 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: being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats.

Criterion 3 Summary

Habitat parameters	Value	Score
F3.1 Habitat conversion and function		7
F3.2a Content of habitat regulations	3	
F3.2b Enforcement of habitat regulations	4	
F3.2 Regulatory or management effectiveness score		4.8
C3 Habitat Final Score (0-10)		6.27
Critical?	NO	YELLOW

Brief Summary

Floating net pens have a minimal direct physical habitat impact, but the operational benthic impacts in the immediate vicinity of farm sites can be significant. However, the chemical and biological effects of organic enrichment are relatively rapidly reversible by fallowing or relocating farms, and benthic monitoring beyond the immediate vicinity of the farm sites indicates minimal impacts. Some Chinook salmon farm sites in British Columbia occupy wild salmon habitats, but there is currently no evidence that habitat impacts directly affect the health or productivity of wild salmon populations. Although there are limited explicit regulations regarding the cumulative impacts of multiple sites, regulations are strong at the site level and the total area impacted is very small compared to the total coastal resource in BC. Data indicate that the potential for cumulative impacts are low, whether from adjacent sites or from the industry’s total impact area. Therefore, the combination of the relatively rapid reversibility of benthic impacts and moderately strong regulatory effectiveness results in a final score of 6.27 out of 10 for Criterion 3 – Habitat.

Justification of Ranking

The floating net pens used in salmon farming have relatively few direct habitat impacts, but the operational impacts on the benthic habitats below the farm and within an allowable zone of effect (AZE) can be significant.

As discussed in the Effluent Criterion, there is inevitably some overlap with the Habitat Criterion as the source of the impacts for both is the same (i.e., uneaten feed and fish waste). The Seafood Watch criteria assess the environmental impacts of these wastes as follows:

- The previous Effluent Criterion (C2) assesses impacts of both particulate and soluble wastes *beyond* the immediate farm area or a regulatory AZE.
- This Habitat Criterion (C3) assesses the impacts of primarily particulate wastes directly under the farm and *within* a regulatory AZE.

Factor 3.1 Habitat conversion and function

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), and can strongly influence the abundance and diversity of infaunal communities. In the area under the net pens or within the regulatory AZE, the impacts may be profound, but are now relatively well understood (Black et al. 2008) (Backman et al. 2009) (Keeley et al. 2013) (Keeley et al. 2015). Primarily, changes can be anticipated in total volatile solids, redox potential, and sulfur chemistry in the sediments in the immediate vicinity of operational net pens, along with changes to the species composition, total taxa, abundance, and total biomass (Keeley et al. 2013). Significant decreases in both the abundance and diversity of macrofauna are sometimes seen under farms located in depositional areas, characterized by slow currents and fine-grained sediments, although net pens located in erosional environments with fast currents and sediments dominated by rock, cobble, gravel, and shell hash can dramatically increase macrobenthic production (Keeley et al. 2013).

According to the industry-reported benthic monitoring reports, all sites owned by Creative Salmon are classified by DFO as consisting of soft sediments, suggestive of depositional environments, and the Yellow Island Aquaculture site is classified by DFO as hard substrate; no such classification could be found for Saltstream Engineering, though DFO staff indicated this is a soft bottomed site with extremely low observed impacts (K. Shaw, personal communication, DFO November 2018). As described in Criterion 2 – Effluent, industry-reported benthic monitoring has shown compliance with regulatory thresholds for benthic impacts, where only two samples from all sites over the past eight years (21 samples) indicated pollution sufficient to decrease species diversity at a distance of 30 m, or indicated non-normal conditions at 125 m from the net pens' edges; over the same time period, taking DFO audits (n=11) into account, data indicate that a total of three 30 m sites exceeded regulatory thresholds, in contrast with the industry-reported results.

It is now a globally common practice for 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 guidance document²⁷ does not mandate a fallow period in BC; instead, all sites must be shown to be under the thresholds before restocking. According to Brooks and Mahnken (2003), chemical and biological remediation in BC has been shown to

²⁷ <http://www.dfo-mpo.gc.ca/aquaculture/management-gestion/aar-raa-gd-eng.htm#monitoring>

occur naturally during fallow periods at every salmon farm studied, but Keeley et al. (2015) showed that, although significant recovery was evident at the fallowed site 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 is then reestablished (at restocking). For full recovery, Keeley et al. (2015) and references show that estimates vary between six months and five years or more, and are highly specific to the environment and the situation. Creative Salmon always fallows two of their six sites at any one time, and only two sites receive fish in any year, with the remaining two being harvested; sites with lower currents are fallowed for four years after being in production for four years (T. Rundle, personal communication, Creative Salmon 2016). Whether fallow periods are used or not, the regulatory system in BC is still intended to prevent unacceptable impacts to benthic habitats over long periods (multiple production cycles) by ensuring that all sites either meet the thresholds at peak biomass or before restocking, if necessary. Though this may maintain an ongoing impact, Keeley et al. (2015) show these impacts are relatively quickly reversible by reducing the load, fallowing, and/or removing the farm.

Although some Chinook salmon aquaculture sites in BC are located in habitats important for wild salmon, it is unlikely that habitat impacts at the sites (i.e., nutrient enrichment of the directly-underlying seabed and immediate water column) affect wild salmon; for example, according to Noakes (2011), who assessed the impact of (all) salmon farms on Fraser River sockeye salmon, “there is no obvious plausible link or evidence to support a link between the deposit of waste on the sea bed or into the water column and sockeye salmon survival. The impact of waste appears to be limited to the immediate vicinity of the farms (within 30 m).” Indeed, in the years since this publication (Noakes 2011), there remains a lack of evidence that the deposition of farm wastes on the benthos results in a loss of functionality of the ecosystems in which farms are sited.

It has been noted that heavy metals, such as copper (used in antifouling paints and net treatments) and zinc (used as a mineral supplement in feeds) can have an impact on organisms beyond the farm site (Burrige et al., 2010). Due to the requirements of the Canadian Organic Aquaculture Standards, however, Creative Salmon (as a certified organic producer) does not use any copper-based antifoulants on net pens; Yellow Island Aquaculture also reports that copper-based antifoulants are not used at their site (J. Heath, personal communication, Yellow Island Aquaculture 2018). Mineral supplements are permitted in organic feed (Canadian Organic Aquaculture Standards 2018), but due to several factors (e.g., low stocking density at BC Chinook farms, typically-low feed wastage in current feeding practices, etc.), zinc accumulation in the benthos is unlikely. 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 (Burrige et al. 2011) rather than confounding factors. Regulatory monitoring of metal residues in the benthos is no longer required in BC, and due to the lack of antifoulant use in Chinook farming, the potential deposition of copper is not considered a concern in this assessment.

Ultimately, the functionality of benthic habitats within the AZEs of Chinook salmon farm sites are considered to be maintained but moderately impacted. Although localized impacts under net pens may be substantial, the provision of ecosystem services at any one farm site may be relatively rapidly restored. The score for Factor 3.1 – Habitat Conversion and Function is 7 out of 10.

Factor 3.2 Farm siting regulation and management

Factor 3.2 assesses the effectiveness of the regulatory and farm management practices in addressing the potential cumulative impacts from multiple farming sites. As articulated in the Effluent Criterion above (Criterion 2), the BC government regulates all salmonid aquaculture under the same regime; therefore, the regulations that govern habitat impacts apply to both Chinook and Atlantic salmon production. The following section is again largely duplicated from the most recent Seafood Watch assessment of BC farmed Atlantic salmon (Seafood Watch 2017).

Factor 3.2a: Content of habitat management measures

As discussed in Criterion 2 – Effluent, DFO is responsible for siting licenses and the subsequent monitoring of benthic habitat impacts to minimize the effects of fish farms on the environment within the Aquaculture Activities Regulations (AAR). Full details of the siting and monitoring requirements can be found in DFO’s Siting Guidelines for Marine Finfish Aquaculture in British Columbia,²⁸ and the “Program Protocols for Marine Finfish Environmental Monitoring in British Columbia.”²⁹ Previously, as part of the license conditions, thresholds were set for free sulfides (soft-bottomed sites) and *Beggiotoa*-like species and/or opportunistic polychaete complexes (hard-bottomed sites), and fallowing and further monitoring were required if these thresholds were breached. As of 2016, however, the licenses no longer require monitoring or reporting for these factors but they are monitored for the AARs (see Criterion 2 for more details).

In terms of regulatory control of cumulative impacts, as noted in the Effluent Criterion, sites in BC are typically a minimum of 3 km apart; however, there are some exceptions, including for the Chinook industry, as described in Criterion 2 – Effluent. The range of benthic impacts described above indicate that direct cumulative overlap between sites is unlikely. Husa et al. (2014) noted that the cumulative effect of numerous impacted areas of an industry’s multiple farms must be taken into consideration when further evaluating the total impact from fish farming on ecosystem functioning. However, it is important to note that this study was based on one large fjord in Norway, the Hardangerfjord, which contains salmon farm production nearly equivalent to the entire BC salmon industry, inclusive of Chinook farming (70,000 to 80,000 mt in Hardangerfjord compared to nearly 90,000 mt total in BC with Chinook accounting for <2,500 mt).

The small total area of the impact of salmon farm sites in BC (specifically, or in comparison to the total inshore area) indicate that the potential for cumulative direct habitat impacts from

²⁸ <http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/site-guide-direct-eng.html>

²⁹ Annex 8 in <http://www.dfo-mpo.gc.ca/aquaculture/management-gestion/aar-raa-gd-eng.htm#annex8.2>

the industry as a whole are currently limited. However, as described in Criterion 2 – Effluent, the majority of Chinook salmon industry operates in Clayoquot Sound with sites <3 km apart, and site separation provisions are not considered to be in effect for the industry.

Overall, the regulatory systems require specific monitoring of the primary benthic habitat impacts at and near net pen salmon sites, and though cumulative impacts appear unlikely, the management of cumulative risk with site separation distances does not apply in the Chinook salmon industry. The score for Factor 3.2a is 3 out of 5.

Factor 3.2b: Enforcement of habitat management measures

“Aquaculture Regulation and Compliance” are described on DFO’s website³⁰ with annual enforcement activities including benthic monitoring. The most recent publicly available data for 2011 to 2017³¹ show that DFO audited a Creative Salmon site every year except 2014 (most recently, July 2017); Yellow Island was audited once in 2015 via video assessment. No such auditing data are found for Saltstream Engineering, a third company currently operating a single site, though publicly available self-reported results indicate compliance with regulations as well. Though no longer operating any sites with Chinook salmon, Grieg Seafood had three of its four Chinook sites audited four times between 2013 and 2014.

These industry-reported monitoring results (typically conducted by contracted third-party specialists) are posted quarterly from DFO,³² though the data currently available online are less detailed than previously; fortunately, the detailed data, last updated May 2017, are still accessible through the Internet Archive and range from 2011 to 2015.³³

As described in Criterion 2 – Effluent, all of Creative Salmon’s six sites are soft-bottomed sites, and they have sampled 2 to 3 sites per year with all sites being sampled at least once since 2011. On all occasions in the detailed dataset (n=12), self-reported monitoring data showed mean free sulfides were within the regulatory limits of 1,300 µM at a distance of 30 m from the cage array and 700 µM at 125 m from the cage array, although these results were contradicted by DFO audits, which revealed that these thresholds were exceeded on three occasions: twice at the 30 m sampling sites (once in 2011, once in 2012) and once at the 125 m sampling site (in 2011). These resulted in further surveying required prior to fish restocking to ensure the benthos recovered. More recent data, though less detailed, indicate that since 2015, Creative Salmon sampled four sites six times (two individual sites were sampled in both 2016 and 2017), with no sites exceeding regulatory thresholds, confirmed by a DFO audits. The Yellow Island Aquaculture site is hard-bottomed, and has been sampled three times since 2011: in 2013, 2015, and 2017. On all occasions, the results of benthic monitoring were considered to be within regulatory limits, and a DFO audit in 2015 confirmed the self-reported result that year. Saltstream Engineering is a soft-bottomed site and has submitted samples twice—in 2013 and

³⁰ <http://www.pac.dfo-mpo.gc.ca/aquaculture/regs-eng.html>

³¹ <https://open.canada.ca/data/en/dataset/c1a54a0c-4eb0-4b50-be1f-01aee632527e>

³² <https://open.canada.ca/data/en/dataset/7e76fdc8-c36a-491a-9afb-4f9280c929e8>

³³ <https://web.archive.org/web/20170506005847/http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/benth-eng.html>

2016—and both times have been below regulatory impact thresholds; despite no DFO audits, as mentioned previously, DFO staff observe very low impacts at this site. Grieg Seafood sites with Chinook salmon were sampled 14 times from 2011 to 2014, with one site exceeding regulatory thresholds at 30 m in 2012; this resulted in further surveying required prior to fish restocking to ensure the benthos recovered. Grieg Seafood was audited four times by DFO over the same time period, and there was agreement with the industry results each time.

In total, 37 samples have been submitted by the Chinook industry from 2011 to 2017 and were found to have exceeded regulatory thresholds within the AZE (≤ 30 m), either by self-assessment or DFO audit, three times (8.1%). All sites have had indicators return to below thresholds prior to restocking. There have been no samples that exceeded thresholds since 2012, more than six years ago.

Overall, the enforcement agencies of the industry are identifiable, contactable, and their resources are seemingly appropriate to the scale of the industry. The publicly-available results show active enforcement at the site level with effective control of benthic impacts at peak production and prior to restocking. With area-based regulation limited to site separation distances, enforcement does not appear to be fully active at an area of regional cumulative impact level at present. The score for Factor 2.2b is 4 out of 5.

Factor 3.2 Conclusion

The final score for Factor 3.2 combines the scores for the regulatory content (Factor 3.2a, 3 out of 5) with the effectiveness of the enforcement (Factor 3.2b, 4 out of 5), and the score Factor 3.2 is 4.8 out of 10.

Conclusions and Final Score

The final score for the Habitat Criterion is a combination of the habitat conversion score (Factor 3.1) and the content and effectiveness of the regulatory system in managing potential cumulative impacts (Factor 3.2). As the direct habitat impacts of the fish farms are relatively rapidly reversible and regulatory effectiveness is moderately good, the scores for Factors 3.1 (7 out of 10) and 3.2 (4.8 out of 10) combine to result in a final numerical score of 6.27 out of 10 for Criterion 3 – Habitat.

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: limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms.

Criterion 4 Summary

Chemical Use parameters	Score	
C4 Chemical Use Score (0-10)	9	
Critical?	NO	GREEN

Brief Summary

Chinook salmon production in BC is currently dominated by Creative Salmon, a producer certified to the Canadian Organic Aquaculture Standard which does not permit the use of antibiotics in food production fish; it is understood that the other two current producers do not use antibiotics at any time in food production fish, and DFO staff confirmed that antibiotics are currently not used in Chinook food production fish. However, data from the DFO indicate that small amounts may be used occasionally in limited numbers of broodstock fish; data also indicate that a Grieg Seafood, no longer farming Chinook, did use antibiotics in their previous Chinook food production fish, likely to control diseases such as BKD and furunculosis, and did so twice in one year at the same site several times.

Regarding pesticide usage, Chinook salmon are naturally more resistant to sea lice and amoebic gill disease infections (the leading causes of pesticide use in Atlantic salmon farming), and there is currently no pesticide use.

Overall, data show that chemical treatments have not been used in food production fish since 2014 (score of 10 out of 10); broodstock treatments, applied in the same net pen arrays as food production fish, are on average less than once per year (score of 8 out of 10); as such, the final score for Criterion 4 – Chemical Use is an intermediate 9 out of 10.

Justification of Ranking

The expansion of commercial aquaculture has necessitated the routine use of veterinary medicines to prevent and treat disease outbreaks, assure healthy stocks, and maximize production (FAO 2012); however, the characteristics of chemical use are highly variable according to the species produced and the management characteristics. This Seafood Watch assessment focuses on antibiotics and sea lice pesticides as the dominant veterinary chemicals

applied to salmon farming. Although other types of chemicals may be used in salmon aquaculture (e.g., antifoulants, anesthetics), the risk of impact to the ecosystems that receive them is widely acknowledged to be less than that for antibiotics and pesticides. See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations.

Antibiotics

Where antibiotics are used in aquaculture, they can pass into the environment through uneaten feed and/or incomplete absorption during digestion, which can have negative effects on marine biodiversity and terrestrial animal and human health (Buschmann et al. 2012), including a contribution to the development of resistant bacteria and/or resistance genes (Cabello et al., 2013); importantly, the excessive use of antibiotics can have a negative impact on ecosystem functionality (Buschmann et al. 2012) (Cabello et al. 2013). In salmon farming in British Columbia, antibiotic use has decreased significantly in recent years as a result of effective vaccines, despite significant increases in production³⁴ (Morrison and Saksida 2013).

The BC regulations regarding the use of antibiotics in aquaculture state that: 1) all treatments are by veterinarian prescription only; 2) treatments are utilized for clinical diseases only and not for prophylaxis; 3) treatments are reported to and monitored by DFO; and 4) treatments are delivered to animals via medicated feed (Morrison and Saksida 2013). In addition, there are only four licensed antibiotics for use in BC salmon aquaculture: Aquaflor® (florfenicol), Romet-30® (sulfadimethoxine/ormetoprim), Tribrisen-40 powder® (sulfadiazine/trimethoprim), and Terramycin Aqua® (oxytetracycline). Of these compounds, sulfadimethoxine, sulfadiazine, trimethoprim, oxytetracycline, and florfenicol are considered highly important for human medicine by the World Health Organization, though the use of florfenicol is solely veterinary (WHO 2016).

Detailed data on antibiotic use are available from DFO for 2016 and 2017.³⁵ For antibiotic use prior to 2016, the BC Ministry of Agriculture provided data displaying the amount of antibiotic incorporated in farmed Chinook salmon feed by BC feed mills from 2008 to 2017, which are aligned with the more recent data provided by DFO (Table 1; G. Marty, personal communication, DFO 2018). These data do not indicate the proportion of this feed that was actually fed nor the proportion of antibiotic treatments applied to broodstock, which generally falls outside of the scope of this assessment; however, the assessment scope includes treatments to broodstock held and treated in the same net pen arrays as food production fish. These data also do not include antibiotic treatments at DFO Salmonid Enhancement Project hatcheries, some of which do apply antibiotic treatments to their Chinook salmon (G. Marty, personal communication, DFO 2018). When there are two or fewer active producers of Chinook salmon that harvest in a given year, BC Ministry of Agriculture is unable to release antibiotic use data; as such, the amount of active ingredient sold in 2011 is unknown, and data from DFO is used for 2016.

³⁴ <http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/therapeut/index-eng.html>

³⁵ <https://open.canada.ca/data/en/dataset/288b6dc4-16dc-43cc-80a4-2a45b1f93383>

Table 1. Antimicrobial use in BC Chinook salmon farms. Data from BC MoA.

Year	Antimicrobial	Active ingredient used (kg)
2008	Florfenicol	0.02
	Oxytetracycline hydrochloride	1,203.26
2009	Oxytetracycline hydrochloride	1,309.89
2010	Oxytetracycline hydrochloride	81.31
2011	Oxytetracycline hydrochloride	only two producers
2012	Florfenicol	17.53
	Oxytetracycline hydrochloride	522.78
2013	Oxytetracycline hydrochloride	956.37
2014	Oxytetracycline hydrochloride	191.85
2015	Oxytetracycline hydrochloride	0.00
2016	Florfenicol	only two producers; 4.30 (DFO data)
2017	Oxytetracycline hydrochloride	only two producers; 48.50 (DFO data)
	Oxytetracycline hydrochloride	41.45

As can be seen in Table 1, oxytetracycline hydrochloride (OTC) is the primary antibiotic used in Chinook salmon farming. When this information is cross-referenced with the DFO fish health audit database,³⁶ it can be seen that Grieg Seafood applied two antibiotic treatments in 2011 at one site, four treatments in 2012 at two sites, one treatment in 2013 at one site, and three treatments in 2014 at three sites (the same two as 2012 and one additional). This likely accounts for the majority of the antibiotic usage in Table 1, and was likely used to treat bacterial kidney disease (BKD) or furunculosis, given the disease diagnoses in the DFO health audit; this audit database also reveals Grieg Seafood as the only producer to have reported antibiotic treatment events to the DFO from 2011 to 2016. Grieg Seafood began to decrease Pacific salmon production in 2014, and the last of their stock were harvested in Q3 2015.³⁷ It is unclear why antimicrobial usage spiked in 2013, since there were no notable disease outbreaks in Chinook farms reported in the DFO fish health audits and only one antibiotic treatment was reported by Grieg Seafood.

The two primary producers currently operating (Creative Salmon and Yellow Island) both report that they do not use antibiotics in food production fish; Creative Salmon has not used antibiotics in food production fish since 2001³⁸ (the company has maintained continued certification to the Canadian Organic Standard, which prohibits the administration of antibiotics to aquaculture animals destined for human consumption). The more recent, detailed data from the DFO³⁹ (2016 onwards) indicate the application of two antibiotic treatments at two sites (one at each) in 2016 totaling 48.5 kg, and three total treatments at two sites totaling 41.34 kg

³⁶ <https://open.canada.ca/data/en/dataset/6c891715-317c-4d4d-9fe8-ea425e01d9d2>

³⁷ <https://www.griegseafood.no/wp-content/uploads/2016/04/GSF-2015-Annual-Report-ENG3.pdf>

³⁸ <http://www.creativesalmon.com/organic-farming.php>

³⁹ <https://open.canada.ca/data/en/dataset/288b6dc4-16dc-43cc-80a4-2a45b1f93383>

in 2017; DFO and Creative Salmon staff confirmed these treatments were for broodstock (K. Shaw, personal communication, DFO November 2018) (T. Rundle, personal communication, Creative Salmon October 2018). With four sites active in each year, treatments were used on average less than once per production cycle (0.50 and 0.75 treatments per year per site). Yellow Island Aquaculture states they have never used antibiotics or any other type of chemical therapeutant (J. Heath, personal communication, Yellow Island Aquaculture 2018), and this is confirmed by the absence of any treatments in the DFO data. A third producer, Saltstream Engineering, only occupies one site, and though not much information could be found about their operation, data from the DFO do indicate that two treatments of florfenicol totaling 4.3 kg were applied in 2016; again, DFO staff confirmed that these treatments were for broodstock (K. Shaw, personal communication, DFO November 2018).

Data from the DFO fish health audit database indicate that, at most,⁴⁰ ten antibiotic treatment events occurred at four food production sites in the BC Chinook salmon farming industry between 2011 and 2014, while the dataset covers 2011 to 2016 (Table 2).

Table 2. Industry reported antibiotic treatment events per year at food production sites, 2011 to 2016. Data from DFO Fish Health Audit Database.

Year	Active sites	Sites treated	Treatments applied	Average treatments per site
2011	9	1	2	0.22
2012	13	2	4	0.31
2013	10	1	1	0.10
2014	10	3	3	0.30
2015	6	0	0	0.00
2016	7	0	0	0.00

While some sites received multiple treatments per year in 2011, 2012, 2016, and 2017 (2016–2017 broodstock only), the annual average treatment per site was below 1 every year between 2011 and 2017. As mentioned previously, the majority of these treatments are known to have occurred at Grieg Seafood sites, and this company is no longer farming Chinook salmon.

Antibiotic Resistance

The use of appropriate antimicrobial treatments is one of the most effective management responses to emergencies associated with infectious disease epizootics; however, their inappropriate use can lead to increased frequency of bacterial resistance and the potential transfer of resistance genes in bacteria from the aquatic environment to other bacteria (FAO 2012).

Given the general lack of antibiotic treatments in the BC Chinook farming industry, the risk of development of resistance as a result of Chinook salmon farm antibiotic use is, at most, low. A

⁴⁰ Five treatments were applied to “Chinook salmon / Coho salmon” over this time period, and the proportion allocated to Chinook salmon is unclear.

comprehensive summary of the risk of antibiotic resistance as a result of antibiotic usage in the Atlantic salmon industry can be found in the Seafood Watch British Columbia Farmed Atlantic salmon report (2017).

Pesticides

The primary use for pesticide compounds in salmon farming (of all salmon species) is the treatment of parasitic sea lice, with a lesser use to treat amoebic gill disease (AGD) (Aaen et al. 2015).

Chinook salmon are naturally more resistant to sea lice infection than are Atlantic salmon (Beamish et al. 2005); see Criterion 7 – Disease for more details. Similarly, although AGD has been recorded in Chinook salmon, Pacific salmon in general appear to have inherent resistance and infection rarely warrants treatment (Mitchell and Rodger, 2011). Consequently, pesticides are not used in Chinook salmon farms in BC (N. de With, personal communication, DFO 2017) (J. Heath, personal communication, Yellow Island Aquaculture, 2018) (T. Rundle, personal communication, Creative Salmon 2018).

Furthermore, the Canadian Organic Aquaculture Standard—to which Creative Salmon is certified—states that, only one treatment (of any permitted product) is permitted for fish under one year old and a maximum of two treatments for older fish (Canadian Organic Aquaculture Standard 2018). If treatments exceed the thresholds outlined in the Canadian Organic Aquaculture Standard, any treated stock must be withdrawn from organic production. Regardless, Creative Salmon has never treated for sea lice (T. Rundle, personal communication, Creative Salmon 2018).

As Chinook salmon have relatively high resistance to sea lice infections, which reduces the need for sea lice parasiticides, and any chemical treatments that would be used to treat them are severely restricted for organic production, the potential for impact to non-target pelagic or demersal organisms or the long-term accumulation of chemicals in the sediments in the vicinity of Chinook salmon farms is low.

Antifoulants

Copper-based antifoulant treatments used on nets may have toxic effects on non-target marine life both in the water column and in the sediments below the net pens (Burridge et al. 2010); however, they are not used by Creative Salmon (who clean their nets by power washing with seawater or air drying⁴¹) or Yellow Island (who clean their nets with freshwater on land if excessive fouling occurs (J. Heath, personal communication, Yellow Island Aquaculture 2018).

Conclusion and Final Score

Chinook salmon production in BC is currently dominated by Creative Salmon, a producer certified to the Canadian Organic Aquaculture Standard, which does not permit the use of antibiotics in food production fish; it is understood that the other two current producers do not

⁴¹ <http://www.creativesalmon.com/our-practices.php>

use antibiotics at any time in food production fish, and DFO staff confirmed that antibiotics are currently not used in Chinook food production fish. However, data from the DFO indicate that small amounts may be used occasionally in limited numbers of broodstock fish; data also indicate that Grieg Seafood, no longer farming Chinook, did use antibiotics in their previous Chinook food production fish, likely to control diseases such as BKD and furunculosis, and did so twice in one year at the same site several times.

In regards to pesticide usage, Chinook salmon are naturally more resistant to sea lice and amoebic gill disease infections (the leading causes of pesticide use in Atlantic salmon farming), and there is currently no pesticide use.

Overall, data show that chemical treatments have not been used in food production fish since 2014 (score of 10 out of 10); broodstock treatments, applied in the same net pen arrays as food production fish, are on average less than once per year (score of 8 out of 10); as such, the final score for Criterion 4 – Chemical Use is an intermediate 9 out of 10.

Criterion 5: Feed

Impact, unit of sustainability and principle

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

Criterion 5 Summary

Feed parameters	Value	Score
F5.1a Feed Fish Efficiency Ratio (FFER)	0.19	9.52
F5.1b Source fishery sustainability score	-5.00	
F5.1: Wild fish use score		9.33
F5.2a Protein IN (kg/100kg fish harvested)	18.45	
F5.2b Protein OUT (kg/100kg fish harvested)	22.92	
F5.2: Net Protein Gain or Loss (%)	24.21	10
F5.3: Feed Footprint (hectares)	29.30	0
C5 Feed Final Score (0-10)		7.17
Critical?	NO	GREEN

Brief Summary

The industry's major feed supplier produces growout feed with a 40% protein content, and high fishmeal and fish oil inclusions (50% and 15%, respectively), though nearly all is sourced from byproducts. As a result of the use of byproducts and an economic feed conversion ratio of 1.72, the low FFER value shows that, on average, only 0.19 tons of wild fish are used to produce one ton of farmed Chinook salmon in BC. With the adjustment in the score due to the whole fish source fisheries (Mexican sardines and mixed Peruvian fisheries) for the remaining wild fishmeal, this results in a score of 9.33 out of 10 for Factor 5.1 – Wild Fish Use. The high use of byproducts results in a +24.21% net gain of edible protein, and the score for Factor 5.2 – Net Protein Gain/Loss is 10 out of 10. Due to the high inclusion rate of fishmeal and fish oil in the feed, it is estimated that 29.30 ha of land and ocean area are appropriated to feed one ton of harvested Chinook salmon, and therefore, Factor 5.3 – Feed Footprint, is scored 0 out of 10. Combining Factors 5.1, 5.2, and 5.3 results in a numerical score of 7.17 out of 10 for Criterion 5 – Feed.

Justification of Ranking

According to DFO (2012), the Canadian aquafeed sector is a global leader in the replacement of fishmeal and fish oil with alternative sources, and the sector is researching the continued development of alternative feeds derived from animal, vegetable, microbial, and algal sources. Sarker et al. (2013) provide a review of the development of formulated feeds in Canada and sustainability issues related to feeding salmonids, and conclude that the production efficiency of farmed salmonids has significantly improved over time due to continued innovations in feed formulations.

The two primary companies (Creative Salmon and Yellow Island) producing Chinook salmon in marine net pens in BC primarily use organic feed produced by Taplow Feeds, who provided much of the relevant data required for this assessment; no information was available for a third company, Saltstream Engineering, though they represent a minor fraction of the industry. As such, the data provided by the primary companies are considered representative of the BC Chinook industry. The economic feed conversion ratio (eFCR) utilized for this report was averaged from production data provided by Creative Salmon, as well as Chinook production data from similar systems in New Zealand (Seafood Watch 2014).

For a full explanation of the calculations, see the Seafood Watch Aquaculture Standard.⁴²

Factor 5.1 Wild Fish Use

Factor 5.1 combines an estimate of the amount of wild fish used to produce farmed Chinook salmon with a measure of the sustainability of the source fisheries. Table 3 shows the data used and the calculated Fish Feed Equivalency ratio (FFER) for fishmeal and fish oil.

Factor 5.1a Feed Fish Efficiency Ratio (FFER)

As Table 3 shows, the BC Chinook salmon industry utilizes very high inclusions of fishmeal and fish oil as compared to other salmon industries, with 50% fishmeal inclusion and 15% fish oil inclusion. However, nearly all marine ingredients are byproduct sources; 95% of fishmeal and 100% of fish oil are derived from byproducts. This leads to whole-fish (i.e., directly from reduction fisheries) inclusions of 2.5% and 0% for fishmeal and fish oil respectively. The industry-wide eFCR is estimated to be 1.72. These values are used to calculate the FFER.

Although there are several different methods of calculating FFER (see Sarker et al. 2013) for a review), the calculation used by Seafood Watch is the “academic” calculation, as used in such literature as Tacon and Metian (2008) and in the multi-stakeholder Salmon Aquaculture Dialogue.

⁴²http://www.seafoodwatch.org/-/m/sfw/pdf/criteria/aquaculture/mba_seafood%20watch_aquaculture%20standard_version%20a3.2.pdf?la=en

Table 3: The parameters used and their calculated values to determine the use of wild fish in feeding farmed BC Chinook salmon production.

Parameter	Data
Fishmeal inclusion level	50%
Percentage of fishmeal from by-products	95%
Fishmeal yield (from wild fish)	22.5% ⁴³
Fish oil inclusion level	15%
Percentage of fish oil from by-products	100%
Fish oil yield	5.0% ⁴⁴
Economic Feed Conversion Ratio (eFCR)	1.72
Calculated Values	
Feed Fish Efficiency Ratio (FFER) (fishmeal)	0.19
Feed Fish Efficiency Ratio (FFER) (fish oil)	0.00
Seafood Watch FFER Score (0–10)	9.52

The SFW Feed Criterion considers the FFER from both fishmeal and fish oil and uses the higher of the two to determine the score. As 100% of the fish oil used is from byproducts (B. Hicks, personal communication, Taplow Feeds 2017), the fishmeal inclusion level drives the FFER for farmed Chinook salmon. Since 95% of the fishmeal used is from byproducts, based on first principles, 0.19 tons of wild fish are required to provide sufficient fishmeal to produce one ton of farmed Chinook salmon, and results in a 5.1a – Feed Fish Efficiency Ratio (FFER) score of 9.52 out of 10.

Factor 5.1b Sustainability of the Source of Wild Fish

The basic wild fish use score (Factor 5.1a) is adjusted based on the sustainability of the source fisheries for the production of fishmeal and fish oil. Fishmeal and fish oil originate from a possibility of several sources: Pacific herring and North Pacific hake from BC, sardines from Mexico, and a mix of species from Peru. The majority of fishmeal and fish oil (95% of FM, 100% of FO) is sourced from processing byproducts of the BC herring and hake fisheries, with small amounts (5% of FM) of whole fish wild Mexican sardine and mixed Peruvian species as needed (B. Hicks, personal communication, Taplow Feeds 2018). Although FishSource scores are known for North Pacific hake⁴⁵ (all 10 except for future health, which scored 7.9) and the fishery is Marine Stewardship Council (MSC) certified, Pacific herring is unassessed by FishSource,⁴⁶ though it is SFW yellow-rated. FishSource scores are known for Mexican sardines⁴⁷ (all ≥6) and some of the fishery is MSC certified. No additional information was provided regarding species

⁴³ 22.5% is a fixed value from the Seafood Watch Aquaculture Standard based on global values of the yield of fishmeal from typical forage fisheries. Yield estimated by Tacon and Metian (2008).

⁴⁴ 5% is a fixed value from the Seafood Watch Aquaculture Standard based on global values of the yield of fish oil from typical forage fisheries. Yield estimated by Tacon and Metian (2008).

⁴⁵ https://www.fishsource.org/stock_page/1942

⁴⁶ https://www.fishsource.org/stock_page/1357

⁴⁷ https://www.fishsource.org/stock_page/2051

composition of the mixed Peruvian species, so the sustainability of this source is unknown. Marine Stewardship Council (MSC) and IFFO-certified “Responsible” fisheries are the preferred sources for raw ingredients from any of the sourced fisheries, though not required (B. Hicks, personal communication, Taplow Feeds 2018). Considering the range of possible sources and possible levels of confirmed sustainability, Factor 5.1b – Sustainability of the Source of Wild Fish (SSWF) scores –5 out of –10, and an adjustment of –0.19 to the 5.1a score. When combined, the Factor 5.1a and Factor 5.1b scores result in a final Factor 5.1 score of 9.33 out of 10.

Factor 5.2 Net Protein Gain or Loss

Factor 5.2 uses the protein inputs in feed (from marine, crop, and land animal sources) and the protein output (of harvested, edible farmed fish) to calculate a protein budget. Table 4 shows the data used for this calculation.

Table 4: The parameters used and their calculated values to determine the protein gain or loss in the production of farmed BC Chinook salmon.

Parameter	Feed data
Protein content of feed	40.0%
Percentage of total protein from non-edible sources (by-products, etc.)	73.18%
Percentage of protein from edible sources	26.82%
Percentage of protein from crop sources	24.78%
Feed conversion ratio	1.72
Protein INPUT per ton of farmed salmon	184.5 kg
Protein content of whole harvested salmon	18.5%
Percentage of farmed salmon by-products utilized	100%
Utilized protein OUTPUT per ton of farmed salmon	229.2 kg
Net protein gain or loss	+24.21%
Seafood Watch score (0–10)	10

The crude protein content of growout feed is 40%. The percentage of feed protein from non-edible sources is 73.18%, and aside from that provided by fishmeal (whose inclusion is dominated by non-edible byproduct ingredients), only protein from organic wheat (considered an edible crop source) is used (B. Hicks, personal communication, Taplow Feeds 2017). Based on an inclusion level of 35%, and a protein content of ~28%, the percent of the total feed protein that organic wheat represents is calculated to be 24.78%. The eFCR of 1.72 from the average of previous and recent cycles at Creative Salmon (T. Rundle, personal communication, Creative Salmon 2018). Both primary producers, Creative Salmon and Yellow Island, have communicated that all of the protein in the harvest farmed salmon is either used for direct human consumption or the byproducts are processed and returned to the food chain in one form or another, such as fertilizer and animal feeds (T. Rundle, personal communication, Creative Salmon 2018) (J. Heath, personal communication, Yellow Island Aquaculture 2018); as such, it is considered that 100% of harvesting byproducts are used for further food protein production.

Given these figures, Chinook salmon farming in BC results in a +24.21% net gain of edible protein and scores 10 out of 10 for Factor 5.2.

Factor 5.3 Feed Footprint

By considering the grouped inclusion levels of marine, terrestrial crop, and terrestrial land animal feed ingredients, Factor 5.3 approximates the ocean and land area appropriated per ton of farmed salmon production.

Table 5: The parameters used and their calculated values to determine the ocean and land area appropriated in the production of farmed BC Chinook salmon.

Parameter	Feed data
Marine ingredients inclusion	65%
Crop ingredients inclusion	35%
Land animal ingredients inclusion	0%
Ocean area (hectares) used per ton of farmed salmon	29.08 ha
Land area (hectares) used per ton of farmed salmon	0.23 ha
Total area (hectares)	29.31 ha
Seafood Watch Score (0–10)	0

Due to the high inclusion rate of fishmeal and fish oil in the diet, the ocean area required to produce the wild fish sources is 29.08 ha; additionally, 0.23 ha of land area is required to produce the crop ingredients in the feed. Therefore, the total feed footprint of BC Chinook feeds is 29.31 ha per ton of farmed salmon, and scores 0 out of 10.

Conclusions and Final Score

The final score is a combination of the three factors with a double weighting for the Wild Fish Use factor. The predominant use of fish byproducts results in a very low FFER value, showing that on average only 0.19 tons of wild fish are used to produce one ton of farmed Chinook salmon in BC. With the adjustment in the score accounting for the sustainability of the source fisheries, a score of 9.33 out of 10 is given for Factor 5.1 – Wild Fish Use. The high use of fish and crop byproducts results in a +24.21% net gain of edible protein, and the score for Factor 5.2 – Net Protein Gain/Loss is 10 out of 10. For Factor 5.3 – Feed Footprint, it is estimated that 29.31 ha of ocean and land area are appropriated to feed one ton of harvested Chinook salmon, and therefore, it scores 0 out of 10. Combining Factors 5.1, 5.2, and 5.3 results in a numerical score of 7.17 out of 10 for Criterion 5 – Feed.

Criterion 6: Escapes

Impact, unit of sustainability and principle

- Impact: competition, genetic loss, predation, habitat damage , spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations
- Sustainability unit: affected ecosystems and/or associated wild populations.
- Principle: preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes.

Criterion 6 Summary

Escape parameters	Value	Score
F6.1 System escape risk	6	
F6.1 Recapture adjustment	0	
F6.1 Final escape risk score		6
F6.2 Invasiveness		8
C6 Escape Final Score (0-10)		7
Critical?	NO	GREEN

Brief Summary

For this criterion, the risk of escape is balanced against the potential genetic and ecological impacts of escaped fish. Although net pen systems are inherently vulnerable to both large-scale escape events and chronic trickle losses, the documented track record of low reported Chinook escapes since 2011, in combination with the escape prevention measures used by farms demonstrates that the industry has effective management systems in place to mitigate the risk of escape. Data regarding escape records are considered robust, despite the risk of trickle losses occurring unaccounted for. This justifies a significantly lower level of concern than typical open systems using best management practices; therefore, the score for Factor 6.1 is 6 out of 10.

Farmed Chinook salmon are at least six generations distinct from wild Chinook salmon, and although one producer uses triploid fish, escapes from the other two producers have the capability of spawning with their wild counterparts. Despite farmed Chinook salmon having better sperm performance than wild fish, the survival of their fry when crossed with wild females is low; therefore, the risk of farmed fish contributing to the gene pool of wild fish is low. Though there is a theoretical risk of ecological competition with wild salmon, the numbers of escaping salmon (two fish reported since 2011) are insignificant compared to the populations of wild salmon (despite concerns over wild population levels), including the nearly 40 million annually released by DFO for stock enhancement. These hatchery releases have resulted in widespread genetic dilution and mixing; historically, releases took place in different river catchments than parental origin, and hatchery fish tend to have higher rates of straying into different river catchments than wild-origin fish. Therefore, any competition, predation,

disturbance, or other impacts to wild species, habitats, or ecosystems that may occur is low, and the score for Factor 6.2 is 8 out of 10.

Overall, the final score for Criterion 6 – Escapes is a combination of the risk of escape (Factor 6.1) and the risk of competitive and genetic interactions (Factor 6.2), and is 7 out of 10.

Justification of Ranking

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

Factor 6.1 Escape risk

Globally, hundreds of thousands of farmed salmon escape into the wild each year (Glover et al., 2017). In BC, the Pacific Aquaculture Regulations require license holders to report suspected and confirmed escapes within 24 hours. DFO has published these industry-reported escape data since 2011 (after assuming authority from the Ministry of Agriculture in 2009), which show recent escape numbers of Chinook salmon from net pens have been low.⁴⁸ Although a Chinook escape event in 2012 resulted in the escapement of 2,745 fish, these fish were being held in a novel floating tank system, which was damaged by a storm, and not from net pens. This escape event occurred at a research facility owned by AgriMarine Industries, which does not currently operate Chinook farms.⁴⁹ Only two net pen-raised fish have been reported to escape since 2011; one in 2012 (one of the 2,746 reported total) and one in 2015. Creative Salmon report 72 escaped Chinook salmon from their sites over the last 15 years, with the large majority occurring prior to 2009 (T. Rundle, personal communication, Creative Salmon 2016).

Table 6. Number of reported Chinook salmon escapes in BC since 2011. All but one in 2012 were from a novel production system not under assessment in this report. * Dataset last updated October 20, 2018.

Year	Total reported escapes
2011	0
2012	2,746
2013	0
2014	0
2015	1
2016	0
2017	0
2018 *	0

As explained in the Seafood Watch BC Farmed Atlantic Salmon assessment (2017), it is possible that reported escape numbers may be less than actual escapes for various reasons, including

⁴⁸ <https://open.canada.ca/data/en/dataset/691dd994-4911-433d-b3b6-00349ba9f24e>

⁴⁹ <http://agrimarine.com/>

the difficulties of accurately counting fish and accounting for chronic “trickle” losses. Although the assessment references publicly available counting data from Cermaq, a company that produces Atlantic salmon exclusively, the information is still relevant to Chinook net pen farming, and the following text is reproduced from the report:

Given the challenges to accurately count and account for the tens of thousands of fish per pen, Skilbrei and Wennevik (2006) noted that small-scale, undetected, or unreported escape events (so-called “trickle” losses) in Norway may make up a large portion of the total number of escapees. 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). Though escape prevention practices have improved on farms since then, a more recent modeling analysis by Skilbrei et al. (2015) suggests that the total numbers of post-smolt and adult escapees (in Norway) have been two- to four-fold higher than the numbers reported to the authorities by farmers. ICES (2016) also supports the notion that the true number of escapees is likely to be significantly higher than reported figures. In BC, Leggatt et al. (2010), also note there is minimal knowledge of the extent of “trickle” escapes from net pens.

The challenge to accurately count the large numbers of fish in any one cage is shown in the concept of “unexplained loss”; [Data] from one company (Cermaq) in BC shows that the realistic counting accuracy available to salmon farming companies (e.g., < 2%) allows large differences in inventory counts (note these are both positive and negative differences). A notable example is shown in Table 5, where an inventory difference of 1.3% represented over 8,000 fish. It cannot be known if this “unexplained loss” is a true loss, or simply due to the inherent inaccuracy of the counting system. Similarly, the positive increases in fish counts cannot be attributed to an actual increase in the number of fish in the net pen. Thus, these figures provide no indication of actual escapes, unless the Inventory Difference exceeds the counting accuracy of the equipment (which is not evident at any site in [the data]).

The difference between these numbers and the reported escapes is stark, but it also cannot be concluded that any of these numbers represent true losses either in unreported events or undetected trickle losses. In the Seafood Watch Aquaculture Standard, a score of 8 out of 10 is justified if “Robust data on fish counting and escape records indicate escapes (catastrophic or trickle) do not occur (e.g., in the last 5 years),” but given the numbers of fish falling within the counting accuracy (i.e., “unexplained losses”), it is clear that the current technology for counting is not yet “robust.”

The debate over the accuracy of escape numbers is likely to continue, and efforts by the industry and the government should continue to improve the quality of these estimates and mandatory reporting (Noakes 2011).

As part of the requirements of the DFO Federal License for aquaculture, the regulations regarding escape prevention are as follows⁵⁰:

- All containment structures must be designed, constructed, installed, maintained and repaired to maintain structural integrity and prevent the escape of cultured fish;
- Any containment structures or system components beyond repair are retired from service;
- All equipment must be designed to be compatible to ensure there is no chafing or weak points;
- Jump nets must be installed at least one meter above the surface of the water;
- Containment nets and anti-predator nets must be kept taut at all times;
- The license holder must be able to demonstrate that net materials are strong enough to resist tearing;
- Nets must be tested, inspected and repaired by a qualified individual prior to being installed and when removed from the water;
- Above-water inspections of nets and containment systems must be conducted daily and any damage repaired immediately;
- Underwater inspections of containment systems by diver or a similar method must be conducted at least every 60 days and prior to fish entry;
- Complete and detailed records must be maintained for the entire life of each net pen;
- The license holder must have in place an Escape Prevention and Response Plan (EPRP) including the means to prevent further escapes, recapture escaped fish, and rectify the deficiency that caused the escape.

To meet these requirements, Yellow Island Aquaculture uses shallow nets to minimize strain caused by currents, double containment netting consisting of completely enclosed predator nets around the primary fish containment nets, and top nets that are tightly laced to the containment nets (J. Heath, personal communication, Yellow Island Aquaculture 2018). Creative Salmon also uses predator nets, grades fish before they leave the hatchery to ensure the net mesh on growout pens is appropriately sized, and before changing nets, and verify fish sizes by feeding cameras, diving inspections, and an underwater fish-sizing camera (T. Rundle, personal communication, Creative Salmon 2018). Given these measures, the risk of escapes is minimized. Nonetheless, Piccolo and Orlikowska (2012) concluded that although the industry continues to improve in regard to escapes, accidental escapes are likely to continue sporadically due to the nature of salmon farming, and more recently, Glover et al. (2017) stated that as long as facilities are not fully contained, the escape of farmed fish into the wild is considered inevitable.

⁵⁰http://www.bclaws.ca/civix/document/id/loo88/loo88/78_2002#section4

Although there is an active Atlantic Salmon Watch Program in BC to engage the general public in reporting Atlantic salmon sightings in BC rivers,⁵¹ it is much more difficult for the public to differentiate farmed Chinook salmon from their wild counterparts than it is to identify Atlantic salmon, so there is no similar public reporting program for escaped Chinook salmon. Anecdotally, escaped Chinook salmon have not been found in the wild, but Ruth Withler (DFO) cautions that there has not been sufficient effort to officially survey farmed fish in the wild to make any evaluation of farm-origin Chinook presence in wild populations at this time (R. Withler, personal communication, DFO 2018).

Though net pen systems are inherently vulnerable to both large-scale escape events and chronic trickle losses, the documented track record of low reported Chinook escapes since 2011, in combination with the escape prevention measures used by farms, demonstrates that the industry has effective management systems in place to mitigate the risk of escape (a score of 4 out of 10). Also, though there is risk associated with counting error and trickle losses, data regarding escape records are considered robust (a score of 8 out of 10). This justifies a significantly lower level of concern than typical open systems using best management practices. As such, an intermediate initial score is given for Factor 6.1 – Escape Risk and is 6 out of 10.

Recaptures

The potential for successfully recapturing escapees depends on many factors that control post-escape dispersal. Most studies generally indicate significant movements of surviving escapees, and according to Chittenden et al. (2011) and Uglem et al. (2013), recapture efforts need to be immediate and widespread to mitigate the impact of escapees. There are no specific recapture data available for BC, and recapture efforts would require the issuance of a fishing permit. Previous references to recapture efforts as a condition of license were complicated by the requirements for fishing permits in BC, and Pacific aquaculture licenses now no longer require recapture efforts. DFO determined that the risk to wild fish outweighed the success of recapture events, and therefore removed this as a requirement except for exceptional circumstances (K. Shaw, personal communication, DFO November 2018). In addition, there have been next to no escaped Chinook salmon over the past fifteen years; therefore, there is no way to evaluate how successful recapture efforts would likely be in the event of an escape. Regardless of the reason, there is no justification for a recapture adjustment, and the final score for Factor 6.1 – Escape Risk is 6 out of 10.

Factor 6.2 Competitive and Genetic Interactions

Salmon escapees have the potential to cause ecological impacts to wild fish by competing with them for resources, like food and habitat (Fleming et al. 2000). In addition, as fish native to the Pacific coast of Canada, Chinook salmon may compete for reproductive opportunities with their wild conspecific counterparts in BC, and genetic introgression may result; interactions between wild and farmed Atlantic salmon in Norway and Ireland, for example, have been shown to reduce wild stock productivity by removing reproductive opportunities from wild salmon and

⁵¹ <http://www.pac.dfo-mpo.gc.ca/science/aquaculture/aswp/index-eng.html>

negatively impacting the genetic structure and diversity of wild populations if farmed fish hybridize with wild fish (Fleming et al. 2000) (McGinnity et al. 2003) (Glover et al. 2017).

Farmed Chinook salmon in BC are currently at least six to seven generations hatchery-reared, and desirable characteristics for farm production, such as growth rate, are artificially selected for (Lehnert et al. 2013) (Ruth Withler, personal communication, DFO 2018). Withler et al. (2007) demonstrated that domesticated strains of Chinook salmon are genetically different from wild strains, and further, that the majority of farmed Chinook stock (fish of Creative Salmon on the west coast of Vancouver Island) originate from and are genetically most similar to the wild Big Qualicum River hatchery-supplemented population on the east coast of Vancouver Island (ECVI); Yellow Island Aquaculture, sited on the east coast of Vancouver Island, also uses broodstock originating from this population. Early strain development, beginning in the 1980s, also included the use of west coast Vancouver Island (WCVI) Chinook from the Robertson Creek hatchery-supplemented population (Withler et al. 2007) (Kim et al. 2004). Today, techniques are available that make it possible to genetically identify farmed stock from both the wild and hatchery stocks they originated from (R. Withler, personal communication, DFO 2018); as such, farmed Chinook in BC are considered genetically distinct from wild conspecifics with clear evidence of selected characteristics and potential for genetic introgression.

On the other hand, DFO's Salmonid Enhancement Program (SEP) has been releasing large numbers of hatchery-reared Pacific salmon into BC rivers for over 40 years.⁵² For example, for fish spawned in the 2016 brood year, DFO reported⁵³ the release of more than 37.5 million Chinook salmon of at least smolt 0+ age. Hatchery fish are either produced as "integrated" populations—where natural- and hatchery-origin fish spawn in both the hatchery and wild environment—or "segregated" populations, where only hatchery-origin fish are included in the hatchery broodstock (DFO 2018). The hatchery environment has been shown to alter the phenotype of hatchery-origin fish; as such, hatchery fish are considerably more domesticated than wild fish, even when part of an "integrated" population, and are often less reproductively successful (DFO 2018). Hatchery production is constant and does not fluctuate in sync with wild populations, leading to a disparity in year-class population sizes between wild and hatchery-origin fish; indeed, the scale and consistency of hatchery production is said to result in wild populations (inclusive of both hatchery-origin and wild-origin fish) that are consistently reproductively inferior, due to the high and persistent presence of hatchery-origin fish (R. Withler, personal communication, DFO 2018).

On an individual fish basis, it is likely that a farmed escape poses a more significant risk than a hatchery-raised fish, given the difference in selected traits and genetic distance from wild counterparts (R. Withler, personal communication, DFO 2018). However, many of these hatchery fish were released into different river catchments from which their parents originated (though current enhancement practices no longer practice this), and tagging studies have

⁵² <http://www.pac.dfo-mpo.gc.ca/sep-pmvs/index-eng.html>

⁵³ <http://www.pac.dfo-mpo.gc.ca/sep-pmvs/data-donnees/2018/SC&NC-IFMP-2018-PSR-eng.htm>

demonstrated that straying into different river systems is higher in these hatchery-reared fish than wild fish (Hard and Heard, 1999) (Candy and Beacham, 2000) (Westley et al. 2013). As a result, it is very unlikely that the very small number of farmed Chinook escapees could adversely affect the fitness of wild offspring as the distinct genetic populations of individual rivers in BC have already been diluted by large and widespread transplantations of hatchery-reared fish. Indeed, Ruth Withler confirmed that it is likely that wild salmon populations in watersheds where Chinook are farmed are likely to be significantly influenced by hatchery production (given the proximity of large DFO hatcheries) though no official metrics are available at this time (R. Withler, personal communication, DFO 2018). The risk of a farmed-wild spawn occurring in place of a wild-wild spawn is considered minimal.

Whether escaped Chinook salmon from farms have found their way into BC rivers and were able to spawn is unknown; it should be noted, however, that several of the Chinook salmon farm sites are in areas that are within the confined migration routes of wild salmon (Figure 3). Though now dated, Moring (1976) reported that of 24,527 Chinook salmon released from net pens in Puget Sound for sport fishermen, only 378 (1.5%) were recovered from rivers over a two-year period. Although these fish were not selectively bred farmed fish and the sampling efficiency of the fishermen is unknown, it does suggest that only a small proportion of released fish will (or escaped fish might) return to rivers. Furthermore, Abbot and Salo (1972) recovered 67.5% of hatchery-reared Chinook salmon where they were released in Puget Sound, suggesting that most of the fish remained in marine waters and did not run up river, and the return rate from hatchery released fish was typically around 1.5% or less (Beckman et al. 1999). More recent work has reiterated the findings that released Chinook generally remain in the area where they are released (Chamberlin and Quinn 2014) (Chamberlin et al. 2011), and as mentioned above, fish that do return to rivers may stray from their natal origins.

In the event that a spawning event does occur, several studies have investigated the potential for escaped Chinook salmon to interbreed with wild Chinook salmon and the resulting fitness of their offspring. Although Lehnert et al. (2012) found that farmed Chinook males have better sperm performance than their wild counterparts, Lehnert et al. (2013) showed that farm-sired fry experience significantly greater mortality than wild-sired fry in semi-natural spawning channels. These findings suggest that the genetic-dilution risks associated with interbreeding of wild and escaped farmed salmon may be mitigated by the potential for hybridized offspring to not survive long enough to contribute to the gene pool. These authors concluded that escaped Chinook salmon pose little genetic risk due to the low survival of their offspring, although there are ecological risks in terms of competition for food, habitats, and mates. One such ecological risk is the notion of potential “egg wastage” in the event of a wild-female, farm-male spawning event; although hybridized offspring have poor survival and pose a low risk for population-level genetic introgression, a successful wild-wild spawn is simultaneously “wasted” and surviving offspring may contribute to the overall reduced reproductive fitness of the wild population, as mentioned above. Partially mitigating this risk, Creative Salmon (roughly 80% of the industry) farms only female fish (K. Shaw, personal communication, DFO November 2018).



Figure 3. Map showing the primary migration routes of wild Pacific salmon in BC and the location of Chinook salmon farms. Map generated using Google Earth.

At least one Chinook producer in BC uses only pressure-induced triploid fish for production (J. Heath, personal communication, Yellow Island Aquaculture 2018), which significantly mitigates the risk of interbreeding; female triploid fish lack the required levels of reproductive hormones to sexually mature, and maintain the physical and behavioral characteristics of immature fish for their entire life (Garner et al. 2008) (Benfey 1999). In doing so, triploid fish are sterile and typically display reduced levels of aggression (Garner et al. 2008). Although polyploidy aims to sterilize fish, rendering them unable to breed, it must be acknowledged that it is not always 100% effective, including for Chinook salmon (Johnson et al. 2004). Since this work was completed, however, further advancements in triploidization at Yellow Island Aquaculture have allowed them to reliably achieve 99.9% triploidy, which, combined with the very low numbers of escapees, eliminates any reasonable potential for this producer's fish to interbreed with wild fish (J. Heath, personal communication, Yellow Island Aquaculture 2018).

In 2005, the DFO initiated the Wild Salmon Policy (WSP), which aims to restore and maintain healthy wild salmon populations and their habitats.⁵⁴ However, Cohen (2012) noted that little progress had been made beyond developing methodologies for assessing salmon stocks and their habitats. Since then, new methodology has been proposed to assess the genetic influence from hatchery fish (DFO 2018) and more recent stock assessments for Chinook in British

⁵⁴ <http://www.pac.dfo-mpo.gc.ca/fm-gp/species-especes/salmon-saumon/wsp-pss/index-eng.html>

Columbia have been completed (DFO 2016), which show that most populations remain at low levels and some continue to decline.

Though there is a theoretical risk of ecological competition with wild salmon, the numbers of escaping salmon (two fish reported since 2011) are insignificant compared to the populations of wild salmon (despite concerns over wild population levels), including those nearly 40 million annually released by DFO for stock enhancement. Therefore, any competition, predation, disturbance, or other impacts to wild species, habitats, or ecosystems that may occur is low. The score for 6.2 – Competitive and Genetic Interactions is 8 out of 10.

Conclusions and Final Score

For this criterion, the risk of escape is balanced against the potential genetic and ecological impacts of escaped fish. Although net pen systems are inherently vulnerable to both large-scale escape events and chronic trickle losses, the documented track record of low reported Chinook escapes since 2011, in combination with the escape prevention measures used by farms demonstrates that the industry has effective management systems in place to mitigate the risk of escape. Data regarding escape records are considered robust, though there exists a risk of trickle losses occurring unaccounted for. This justifies a significantly lower level of concern than typical open systems using best management practices and the score for Factor 6.1 is 6 out of 10.

Farmed Chinook salmon are at least six generations distinct from wild Chinook salmon, and although one producer uses triploid fish, escapes from the other two producers have the capability of spawning with their wild counterparts. Despite farmed Chinook salmon having better sperm performance than wild fish, the survival of their fry when crossed with wild females is low; therefore, the risk of farmed fish contributing to the gene pool of wild fish is low. Though there is a theoretical risk of ecological competition with wild salmon, the numbers of escaping salmon (two fish reported since 2011) are insignificant compared to the populations of wild salmon (despite concerns over wild population levels), including those nearly 40 million annually released by DFO for stock enhancement. These hatchery releases have resulted in widespread genetic dilution and mixing; historically, releases took place in different river catchments than parental origin, and hatchery fish tend to have higher rates of straying into different river catchments than wild-origin fish. Therefore, any competition, predation, disturbance, or other impacts to wild species, habitats, or ecosystems that may occur is low, and the score for Factor 6.2 is 8 out of 10.

Overall, the final score for Criterion 6 – Escapes is a combination of the risk of escape (Factor 6.1) and the risk of competitive and genetic interactions (Factor 6.2), and is 7 out of 10.

Criterion 7. Disease; pathogen and parasite interactions

Impact, unit of sustainability and principle

- Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same water body
- Sustainability unit: 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

Disease Risk-based assessment

Pathogen and parasite parameters	Score	
C7 Disease Score (0-10)	4	
Critical?	NO	YELLOW

Brief Summary

The broad body of literature regarding disease transfer risk between salmon farms and wild salmon in British Columbia is largely focused on Atlantic salmon, and although there is often applicable information in these studies to this assessment of the risk posed by Chinook salmon farms, there are ultimately not enough data available to demonstrate the specific impact (or lack thereof) of Chinook salmon farms on the health of wild salmon in BC; therefore, the Risk-Based Assessment option in the Seafood Watch Aquaculture Standard is used (as opposed to the Evidence-Based option).

According to farm mortality rates, bacterial and viral pathogens cause approximately half, at most, of the 1% to 1.8% monthly mortality rates in BC Chinook aquaculture production (i.e., if all “fresh silvers” and “decomposed” fish died because of these pathogens). Although the actual number is likely to be less, the presence of pathogens on farms (including a chronic presence that may not cause high mortalities) represents a reservoir of potential infection to wild fish. To date, this connection and potential impact has not been fully understood, and the research of the Strategic Salmon Health Initiative (SSHI) and others are advancing this knowledge in BC. Although bacterial kidney disease (BKD) is the primary disease affecting Chinook salmon farms, piscine orthoreovirus (PRV) is of particular focus for the SSHI and in this report. The strain of PRV present in BC is believed to contribute to the development of the incompletely characterized jaundice or anemia syndrome seen in farmed Chinook salmon. At this stage, however, there is no evidence of bacterial or viral pathogens in Chinook salmon farms having an impact on wild salmonids in BC, but importantly, there is also no evidence that there is not an impact. Thus, there is some level of concern, particularly in the context of the ecological importance of vulnerable wild salmonid populations in BC.

Chinook salmon are naturally more resistant to sea lice than Atlantic salmon, and Chinook salmon farms have never had sea lice levels exceed regulatory thresholds for reporting, nor levels that have required intervention or treatment; indeed, there is evidence that lice levels on wild Pacific salmon is commonly higher than that seen on farmed Chinook. Though Chinook salmon farms have the theoretical potential to act as point sources of sea lice infection for wild salmon, sea lice are naturally present in coastal waters throughout the year on non-salmonid hosts. The low level of infection in farmed Chinook salmon and the relatively small size of the industry means that spillback of on-farm lice infection is of low concern.

Chinook farms in BC implement fish health management and biosecurity measures that result in low levels of disease-related mortality, as evidenced by the lack of reported disease events, no therapeutic treatments, and reported low mortality rates. Simultaneously, the majority of the Chinook industry is sited in Clayoquot Sound on the west coast of Vancouver Island (WCVI), where vulnerable wild Chinook stock levels are depressed and are under the lowest possible level of stock status classification by the DFO. Given the multitude and complexity of factors affecting wild fish productivity and survival, and the aforementioned low disease rates on Chinook salmon farms, an intermediate score is warranted, indicating that some disease-related mortality occurs on farms and the production system is open to the introduction and discharge of pathogens. As such, the final score for Criterion 7 – Disease is 4 out of 10.

Justification of Ranking

As disease data quality and availability is moderate (i.e., Criterion 1 score of 5 out of 10 for the Disease criterion), the Seafood Watch Risk-Based assessment was used.

Introduction

The open nature of net pen salmon farms means that fish are readily exposed to pathogens and parasites occurring in the waterbody, on wild fish, or on other natural hosts. If farmed fish are infected, pathogens and parasites may be amplified within the net pens, and farms can act as temporary unnatural reservoirs for a variety of pathogens and parasites, which have the potential to transfer to wild fish (Hammell et al. 2009). Therefore, the expansion of salmon aquaculture has raised concern in regions where narrow inlets occupied by salmon farms are important migratory corridors for wild salmon, such as in BC (Peacock et al. 2014).

Lovy et al. (2013) note the potential for farmed salmon to act as a source of pathogen spillback to sympatric wild fish, but this infection and spillback relationship, though clearly demonstrating a potential impact on wild fish, cannot be inherently assumed to be a significant impact on any species beyond the farm site; similar studies have shown the same potential for the spillback of parasites, namely sea lice, in BC (Peacock et al. 2014) (Price et al. 2012) (Marty et al. 2010). The debate in the scientific literature on viral, bacterial, and parasitic diseases in aquaculture and their impact on the environment is lengthy, voluminous, and frequently polarized. For example, while considering salmon farming as one of a broad range of stressors potentially contributing to the long-term decline of Fraser River sockeye salmon, the Cohen Commission highlighted two key aspects of the debate: the lack of robust evidence of impacts from salmon farms on wild salmon (i.e., no “smoking gun”), and the ongoing risk that poorly

studied impacts have occurred, are occurring now, or will occur at some time in the future (Cohen 2012).

As part of salmon farm license requirements in BC, all farms must monitor and report, at least quarterly, the health status of their fish. In addition, fish veterinarians must report all occurrences of an active disease or a suspected infectious event on a farm that requires veterinary involvement and action, such as a request for a laboratory diagnosis or the use of prescribed medication. With respect to sea lice specifically, monitoring is mandatory within BC and a reporting and treatment threshold set for Pacific salmonids is 3 motile lice per fish at any point throughout the year. Currently, farms raising Pacific salmonids must conduct lice monitoring on a quarterly basis and opportunistically (during handling, for example), as opposed to monthly or biweekly (depending on the season) for Atlantic salmon farms; for Pacific salmon farms, the results of lice monitoring are not required to be submitted, but must be made available to a Fishery Officer or Guardian for inspection during an audit.⁵⁵ If the average number of motile sea lice found during one of the monitoring periods exceeds the 3-per-fish threshold set by the Canadian federal government, DFO must be notified within seven days. Between 2004 and 2016, sea lice counts on Pacific salmon farms were only required to happen opportunistically throughout the production cycle during routine handling events, due to low lice abundance levels and risks associated with handling stress (Saksida et al. 2015). According to Saksida et al. (2015), there is no evidence that monitoring in this way has missed any unexpected increases in lice levels for farmed Pacific salmonids.

Results of fish health audits and industry-reported health inspections by facility from 2011 to 2016⁵⁶ are available on the DFO website.

In Canada, infectious haematopoietic necrosis (IHN), viral hemorrhagic septicemia virus (VHSV), infectious pancreatic necrosis (IPN), and infectious salmon anemia (ISA) are federally reportable diseases, though only IHNv and VHSV (Iva genotype) are present in BC. These diseases are highly contagious and can cause mortality in wild and farmed salmon, but there have been no reports of these diseases in Pacific salmon aquaculture (note that these are aggregated results for Chinook and coho salmon). More recently, piscine orthoreovirus (PRV), and its associated syndrome heart and skeletal muscle inflammation (HSMI) has become a research focus, as it has become more prevalently reported in BC. Further discussion on this emerging disease can be found later in this criterion.

This assessment concentrates on the most recent key datasets and studies with a narrow focus on potential impacts to wild salmon in BC. The analysis first addresses bacterial and viral pathogens, and subsequently, parasitic sea lice. Fish health in BC is managed according to Fish Health Zones, shown in Figure 4 (copied from DFO⁵⁷).

⁵⁵ <http://www.dfo-mpo.gc.ca/aquaculture/management-gestion/mar-rep-rap-2017/health-sante-eng.html#sea-lice>

⁵⁶ <https://open.canada.ca/data/en/dataset/6c891715-317c-4d4d-9fe8-ea425e01d9d2>

⁵⁷ DFO Fish Health Zones <http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/health-sante/zones-eng.html>

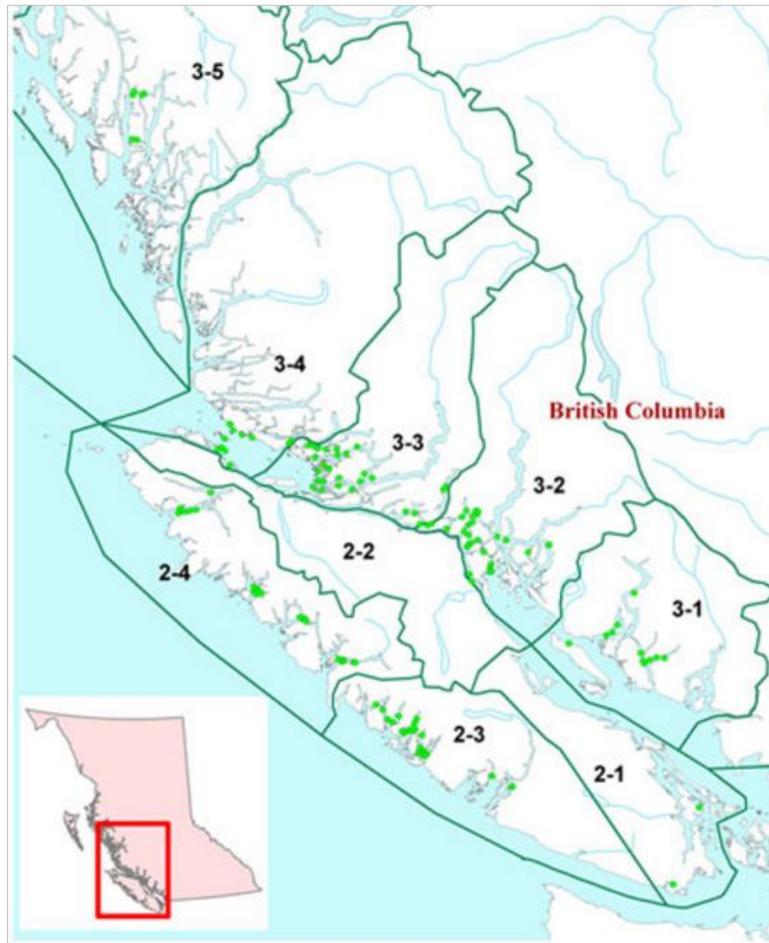


Figure 4: Map of Fish Health Zones in BC. Chinook salmon farms are sited in Zones 2–3 and 3–2. Image copied from DFO.

Bacterial and Viral Pathogens

DFO provides average monthly mortality figures by health zone and a classification of mortalities from 2013 to 2018. Figure 5 shows that average monthly mortality is between just below 1% and 1.8% (average 1.30%) over the 6-year period (i.e., 12 to 22% per year). Figure 6 shows the mortality classification data for the last complete year (2017), of which 53% (24% “fresh silvers⁵⁸” and 29% “decomposed⁵⁹”) are potentially caused by bacterial or viral pathogens.

⁵⁸ The term “fresh silver” implies dead fish for which there are no immediately apparent causes of mortality.

⁵⁹ Fish in the “decomposed” category are not tested to assess the cause of death, either due to environmental or pathogenic causes.

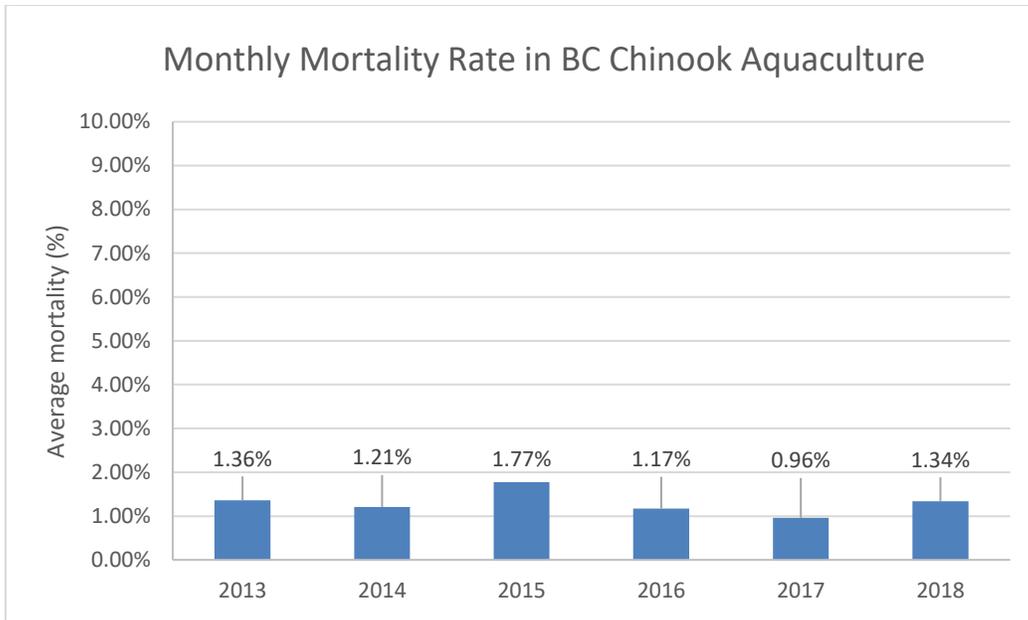


Figure 5. Average monthly mortality rates for all active Chinook salmon farms in BC from 2013 to 2018. Data for 2018 are an average of the first quarter. Data from DFO.

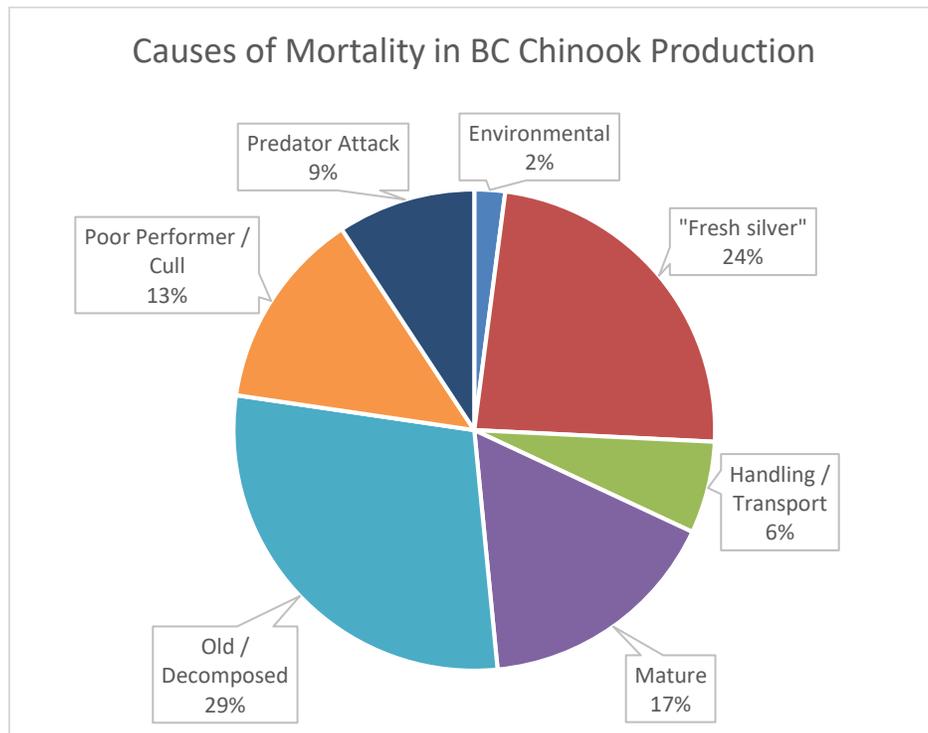


Figure 6. Classification of mortalities in 2017, averaged across all Chinook farms in BC. Data from DFO.

If all the “fresh silvers” and “decomposed” mortalities in Figure 6 died of bacterial or viral pathogens, (i.e., 53% of all mortalities) this would be equivalent to approximately half of the monthly mortality rate of 1% to 1.8%, but according to Korman (2011), in the vast majority of

DFO audits (of all BC salmon farms) where “fresh silver” mortalities were tested, bacterial or viral infections were not found and no sign of disease was observed. Since then, the most recent data detailing DFO fish health audits of Chinook farms specifically that sampled “fresh silvers” show that disease was found in 183 out of 492 sampled fish over seven years (2011 to 2018),⁶⁰ or 37.2% of “fresh silvers” tested. Further, a farm-level disease diagnosis was given 61 times at 98 site audits (i.e., 62.2% of audits) over this seven year period; the primary disease diagnoses were bacterial kidney disease (BKD; 28 diagnoses, 46% of total), microsporidial gill disease (10 diagnoses, 16% of total), salmonid rickettsial syndrome/septicemia (SRS; 8 diagnoses, 13% of total), and jaundice (7 diagnoses, 11% of total). Data for 2018 are complete through the first quarter.

Although this appears high, the industry is required to report mortality events⁶¹ to DFO, and no such events were reported over this time period; further, only ten antibiotic treatment events were reported by the industry from 2011 to 2018, and none since 2014 (see Criterion 4 – Chemicals for more details). Therefore, although the average monthly mortality figures of 1% to 1.8% are aggregated across the several Chinook farms in BC and somewhat inconclusive, data indicate that there have not been any recent serious disease outbreaks and that mortality due to bacterial and viral pathogens is not high. Nevertheless, farms with chronic levels of disease, even with low mortalities, can represent a continuous reservoir of pathogens.

Kent (2011) provides a review of 5 viral, 6 bacterial, 4 fungal, and 19 parasitic pathogens that are known to, or could potentially infect wild salmon in BC; Miller et al. (2017) expanded on this topic and quantified the prevalence of 46 infectious agents (viruses, bacteria, parasites) known or suspected to cause disease in salmon worldwide in a survey of infectious diseases found in juvenile wild Pacific salmon in BC and Washington. Focusing on the pathogens and parasites within both groups that also occur on Chinook salmon farms in BC, the following four diseases are discussed below: bacterial kidney disease, microsporidial gill disease, salmonid rickettsial syndrome/septicemia, and jaundice/marine anemia.

Bacterial kidney disease

Renibacterium salmoninarum is the causative agent of bacterial kidney disease (BKD) and is chronic in Pacific West Coast salmon populations (Miller et al. 2017). Transmitted both vertically and horizontally, clinical signs include external lesions, abdomen distention, exophthalmia, the darkening and mottling of the skin, and pallor and swelling of the liver (BCCAHS 2010) (Wiens 2011) (ICES 2015). The kidney itself is plagued with petechial hemorrhages which increase in number as the condition progresses, and in advanced cases, the entire kidney becomes enlarged, pale, and necrotic (BCCAHS 2010).

An excerpt from BCCAHS (2010), a study prepared for DFO to investigate the impacts of BKD on

⁶⁰ <https://open.canada.ca/data/en/dataset/6c891715-317c-4d4d-9fe8-ea425e01d9d2>

⁶¹ A mortality event is defined as: (a) fish mortalities equivalent to 4,000 kg or more, or losses reaching 2% of the current facility inventory, within a 24-hour period; or (b) fish mortalities equivalent to 10,000 kg or more, or losses reaching 5%, within a five-day period. (DFO)

the Canadian salmon farming industry (and included surveys completed by industry representative), states:

During growout, Pacific salmon producers rated BKD significance as moderate to severe, again identifying stocks with a consistently higher prevalence of BKD. BKD prevalence in Pacific salmon was over 5%. Over the past 5-10 years, Coho producers have seen a decrease in prevalence and Chinook producers have not seen any changes. Respondents that commercially produce Pacific salmon noted that high BKD prevalence in specific Pacific salmon restricts commercial production of these species and limits opportunities to capitalize on specialized markets for niche strains. If BKD disease (and consequently costs) were controlled, these niche strains would be able to take advantage of full market potential.

While the above is somewhat dated—BC Chinook production was much more intensive in 2010 with higher densities—the more recent information regarding prevalence and mortality rates (above) also suggests that while BKD is a significant disease for the industry, it does not often result in widespread mortality. Treatment and control of BKD has been deemed to be difficult, but Chinook producers use low stocking densities and have reduced handling to limit stress (BCCAHS 2010) (T. Rundle, personal communication, Creative Salmon 2018) (J. Heath, personal communication, Yellow Island Aquaculture 2018). Antibiotics have been used to treat BKD in commercial marine Chinook farms in the past,⁶² though currently active producers (Creative Salmon, Saltstream Engineering, and Yellow Island Aquaculture) do not use antibiotics in food production fish (see Criterion 4 for more detail). Additionally, broodstock screening and selection for resistance has significantly decreased the amount of BKD seen in production fish (Dr. Z. Waddington, personal communication, DFO 2018). Overall, as mentioned above, these management techniques have limited BKD's on-farm impact to effectively prevent any mortality events from occurring over the available time-period, 2011 to 2018.

Of note, BKD is also considered a significant disease in salmon enhancement hatcheries (BCCAHS 2010); indeed, the DFO-published “Fish Health Database” contains pathogen test results from cases coming from the “Salmonid Enhancement Program (SEP), Research, Public and I&T submissions” and shows that BKD has been found in these Chinook salmon of all life stages in almost every year since 1974.⁶³ Given the volume of Chinook and other Pacific salmon outplanted each year by the SEP (>50 million individuals), it is important to view the disease risk from Chinook salmon net pens within the broader context, where there are additional significant disease vectors present.

The likelihood of BKD transmission (or retransmission) from farm fish to wild fish is ultimately unknown and has been debated. Although some researchers (e.g., Halstein and Lindstad 1991) (see review by Murray et al. 2011) and the BCCAHS (2010) report concluded that “It is important to make every effort to reduce BKD infection levels in cultured fish from not just a

⁶² <https://open.canada.ca/data/en/dataset/6c891715-317c-4d4d-9fe8-ea425e01d9d2>

⁶³ <https://open.canada.ca/data/en/dataset/2ece9991-62aa-4b7a-bd7d-4f8f1052cd21>

fish welfare perspective, but also from the perspective of reducing point sources of infection that could threaten wild fish,” Cubitt et al. (2006) determined that disease transfer from farmed escapees to wild fish had a “very remote chance.” Ultimately, BKD transmission from farmed Chinook salmon to wild fish is a small, yet contributing factor to the overall risk of impact.

Microsporidial gill disease

Microsporidial gill disease (MGD) is caused by the microsporidian parasite *Loma salmonae*, a common pathogen found throughout British Columbia salmonid fish populations (Kent and Speare 2005) (Becker 2004). This disease has been found in both freshwater and marine populations of primarily rainbow trout (*Oncorhynchus mykiss*) and Chinook salmon, though all species in the genus *Oncorhynchus* are considered susceptible (Kent and Speare 2005). *L. salmonae* is an intracellular parasite and is transmitted horizontally through both freshwater and seawater, with infection resulting in the development of spore-laden xenomas in various organs, but the primary site of infection is the gills (Kent and Speare 2005); the xenoma then ruptures and causes severe gill damage and inflammation, from which released spores can infect another host (Kent and Speare 2005) (Shaw 1999). Free spores can remain in other organs, like the kidney and spleen, for months after infection, and recovered fish show strong immunity against the pathogen for up to one year (Kent and Speare 2005). These spores have been shown to remain viable and infectious to Chinook salmon for up to 95 days in both fresh and saltwater (Kent and Speare 2005).

There are currently no therapeutic drugs licensed for use in controlling these microsporidians, and in general, treatment with antibiotics and antiprotozoals is ineffective (Hurst 2016). An effective vaccine was developed in early 2013 (Harkness et al. 2013), though its current commercial status and use is unknown. In practice, this disease is again controlled using low stocking densities and minimizing stress, and has only resulted in ten farm level disease diagnoses from 2011 to 2018⁶⁴ (T. Rundle, personal communication, Creative Salmon 2018) (J. Heath, personal communication, Yellow Island Aquaculture 2018); indeed, “fresh silvers” sampled during DFO audits having “bronchitis with Loma-like microsporidia” or “splenic Loma-like xenoma” found during histological analysis represented an average of 7.9% of fish sampled, never exceeding 12%. However, given the ability for the parasite to remain active for long periods and be transmitted horizontally through both fresh and saltwater, it is possible that infected farmed fish may shed spores into the environment and infect wild salmonids; there is no evidence, though, to indicate that this is happening, and if it is, that it is causing disease outbreaks in wild salmonids at an elevated rate. Bass et al. (2017), in a survey of microparasites found in adult migrating Chinook salmon in 2013, found *L. salmonae* infection present at “all sampling locations and time periods, with prevalence of infection low to moderate,” and Miller et al. (2014) considered it a low risk to sockeye salmon. As such, microsporidial gill disease on Chinook salmon farms is considered a low disease risk to wild fish in this assessment.

⁶⁴ <https://open.canada.ca/data/en/dataset/6c891715-317c-4d4d-9fe8-ea425e01d9d2>

Salmon rickettsial septicemia

The disease salmon rickettsial septicemia (SRS) is caused by the bacterial pathogen *Piscirickettsia salmonis*. With highly anomalous temperatures in the winter of 2014 and through 2015, there was a substantial increase in cases of SRS in both Atlantic and Pacific salmon in farms during 2015 detected under DFO’s Fish Health Audit and Surveillance Program; Chinook salmon farms are only located in Health Zones 2.3 and 3.2, which also contain Atlantic salmon farms (Figure 7). Grieg Seafood grew Chinook salmon in Health Zone 3.1 during this time period, though no cases of SRS were reported at these sites.

From 2011 to 2018, *P. salmonis* was detected at Chinook salmon farms in histological analyses of “fresh silvers” during DFO audits an average 11.5% of the time, though dramatically increasing and peaking in 2015 (30.76% of carcasses) and declining in 2016 (20.54% of carcasses) and further in 2017 (2.94% of carcasses)⁶⁵; however, a farm-level disease diagnosis of SRS was only given eight times over the same time period, with five of those diagnoses in 2015 and 2016. None of these incidences resulted in mortality events, nor were antibiotics used to treat the disease at any point (T. Rundle, personal communication, Creative Salmon 2018) (J. Heath, personal communication, Yellow Island Aquaculture 2018).

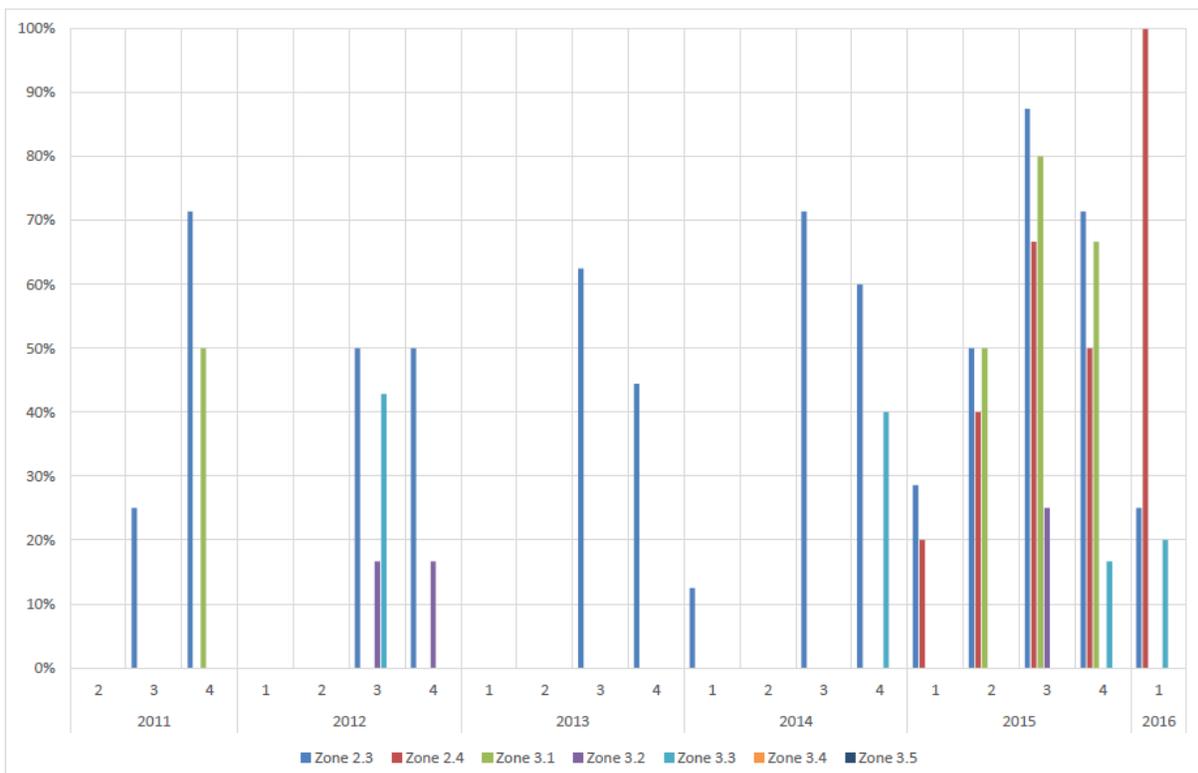


Figure 7: Proportion of cases of SRS in each fish health zone between 2011 and 2016. Graph copied from Keith (2016). The y-axis is the percent of farms sampled with positive SRS cases. Fish Health Zones are mapped in Figure 4 above.

⁶⁵ <https://open.canada.ca/data/en/dataset/6c891715-317c-4d4d-9fe8-aa425e01d9d2>

In Chile, where the disease has been more extensively studied, clinical outbreaks are associated with environmental stressors such as storms, algae blooms, predator attacks, low oxygen, and fluctuations in water temperature, in addition to co-infection with other pathogens, infestation with sea lice, skin damage, and other husbandry-related factors that result in stress or increased contact between fish (Eva et al. 2014, and references therein). It appears likely that the high water temperatures in BC during 2015 were at least one factor responsible for the increase in cases, and the number decreased through 2016 and to date in 2017 (G. Marty, personal communication, DFO 2017).

In BC, DFO monitoring detected SRS in farmed Atlantic and farmed Pacific salmon, and in Chile, the disease is also common in seawater-farmed rainbow trout (Eva et al. 2014). The disease is therefore of potential concern in BC to both wild Pacific salmon and steelhead trout, but there is currently no evidence to demonstrate that the disease is transferring to wild fish, or causing any impact.

Though *P. salmonis* can present a significant on-farm production problem for farms (particularly salmon farms in Chile), there are few studies or data on its occurrence in wild fish; therefore, the epidemiology of the bacterium in natural populations and their interactions with farmed salmon are poorly characterized (Rozas and Enriquez 2014). Despite inevitable concern that an impact on wild fish is occurring undetected in BC, the complex factors leading to outbreaks of SRS on farms cannot be assumed to be happening in the wild.

Piscine orthoreovirus/Jaundice syndrome

Piscine orthoreovirus (PRV) has been highlighted as a concern on farms for both Atlantic and Pacific salmonids (Morton and Routledge 2016). Thus, it has recently become a primary research focus for the Strategic Salmon Health Initiative (SSHI), a partnership between DFO, the Pacific Salmon Foundation, and Genome BC.⁶⁶ The origin of PRV in BC is uncertain; it may have always been there; it could have come from historic introductions of Atlantic salmon into BC, or it could have been introduced with more recent introductions of European fish as salmon farming expanded in BC. Marty et al. (2015) showed that PRV was detected among wild and farmed salmonids in BC from 1987 onward, with the earliest potentially PRV-positive sample from a wild steelhead trout in 1977 (before salmon farming began in BC). Although Kibenge et al. (2013) reported that the strain of PRV in BC had recently diverged from a Norwegian strain (and therefore was considered to have been introduced into BC with movements of salmon into the country from Norway), Siah et al. (2016a and 2016b) note that PRV has been present in BC for a long time, and did not recently diverge from a Norwegian strain as proposed by Kibenge et al. (2013).

This concern is also in reference to the associated disease heart and skeletal muscle inflammation (HSMI) that has been observed in Atlantic salmon, and, more specifically for Pacific salmon species, an incompletely characterized disease called jaundice or anemia syndrome that has been observed on Chinook farms for several years (DiCicco et al. 2018).

⁶⁶ <https://www.psf.ca/what-we-do/strategic-salmon-health-initiative>

HSMI and PRV have been linked in Atlantic salmon in other salmon-producing countries (namely, Norway and Chile), and results of DiCicco et al. (2017) make BC the third location where the two have been linked.

With the ongoing research into the prevalence of PRV and its associated effects, it continues to be an emerging disease of interest to BC Chinook farmers, since there is evidence that it is statistically associated with the appearance of jaundice syndrome that has been reported since at least 2011, though PRV's role in the development of jaundice syndrome has yet to be established (Miller et al. 2017). A farm-level disease diagnosis of "jaundice syndrome" was given six times between 2011 and 2016,⁶⁷ though several additional mentions of jaundice and/or anemia are found in "conditions of note," indicating that symptoms are "present in an unknown proportion of the population due to the uncertainties surrounding the nature of the disease," yet have not contributed to an increase in mortality or morbidity at the farm population level. No farm-level diagnoses or conditions of note mention jaundice and/or anemia in 2017, although one farm-level diagnosis of jaundice was given at a Creative Salmon site in early 2018.⁶⁸ A survey of infectious agents found in dead-and-dying farmed salmon (both *Salmo salar* and *Oncorhynchus spp.*, of which 93% were Chinook) between 2011 and 2013 found PRV prevalence in dead-and-dying Pacific salmon to be roughly 61% in both areas where they are grown (FHZ 2.3 and 3.2) (Laurin et al. 2019). However, the odds of detecting PRV in Atlantic salmon was 1.78 times that of Pacific salmon in FHZ 2.3, and 1.53 that of Pacific salmon in FHZ 3.2 (Laurin et al. 2019).

Though PRV has been detected in multiple salmonid and non-salmonid species the wild,⁶⁹ there is currently no evidence that wild Chinook are showing signs of jaundice or other PRV-related syndromes, though this is a current area of research for SSHI (DiCicco et al. 2018). Miller et al. (2017) detected PRV in only 4% of sampled juvenile Chinook salmon (n=1,876) from 2008 to 2012. As has been recently demonstrated by DiCicco et al., (2018), PRV loads can be quite high within an asymptomatic fish, which can make it difficult to diagnose at an early stage. However, although PRV can be successfully transferred to Chinook, sockeye, and Atlantic salmon when injected with material from a Chinook expressing jaundice syndrome, clinical disease (jaundice for Chinook, HSMI for Atlantic salmon) was not developed and indicated that PRV is not the sole causative factor of the condition(s) (Garver et al. 2016a, b). Though these results have been somewhat refuted, because Wessel et al. (2017) found a causal relationship between one strain of PRV and HSMI in Atlantic salmon, the same has not been found for Chinook salmon and jaundice syndrome; however, DiCicco et al. (2018) believe it is likely. DiCicco et al. (2018), citing other research (e.g., Siah et al. 2015) (Morton et al. 2017) (Purcell et al. 2018) (Tucker et al. 2018), conclude that prevalence of PRV is low (<3%) in wild migrating BC Chinook and sockeye salmon smolts that have not been exposed to salmon farms, though higher prevalence (7%) has been found among Fraser River Chinook salmon yearlings caught in the Georgia Strait and Discovery Islands in the spring that remain resident near salmon farms for up to a year (Tucker

⁶⁷ <https://open.canada.ca/data/en/dataset/6c891715-317c-4d4d-9fe8-ea425e01d9d2>

⁶⁸ <https://open.canada.ca/data/en/dataset/6c891715-317c-4d4d-9fe8-ea425e01d9d2>

⁶⁹ <http://www.dfo-mpo.gc.ca/science/aah-saa/species-especes/aq-health-sante/PRV-rp-eng.html>

et al. 2011, 2012, 2018); however, PRV prevalence in these fish declined to between 0% (summer, winter) and 3% (fall) (Tucker et al. 2018). These fish had never interacted with the Chinook salmon farms in Clayoquot Sound, though it is possible they were in the same waterbodies as the Yellow Island Aquaculture and Saltstream Engineering respective sites. See Figure 8 for catch locations of fish in this study. This same study by Tucker et al. (2018) additionally found that PRV prevalence among sub-yearling fish ranged from 0% (spring, summer, winter) and 2% (fall); sub-yearling winter samples included those caught off of Clayoquot Sound, as they began to migrate to shelf waters off the west coast of Vancouver Island.

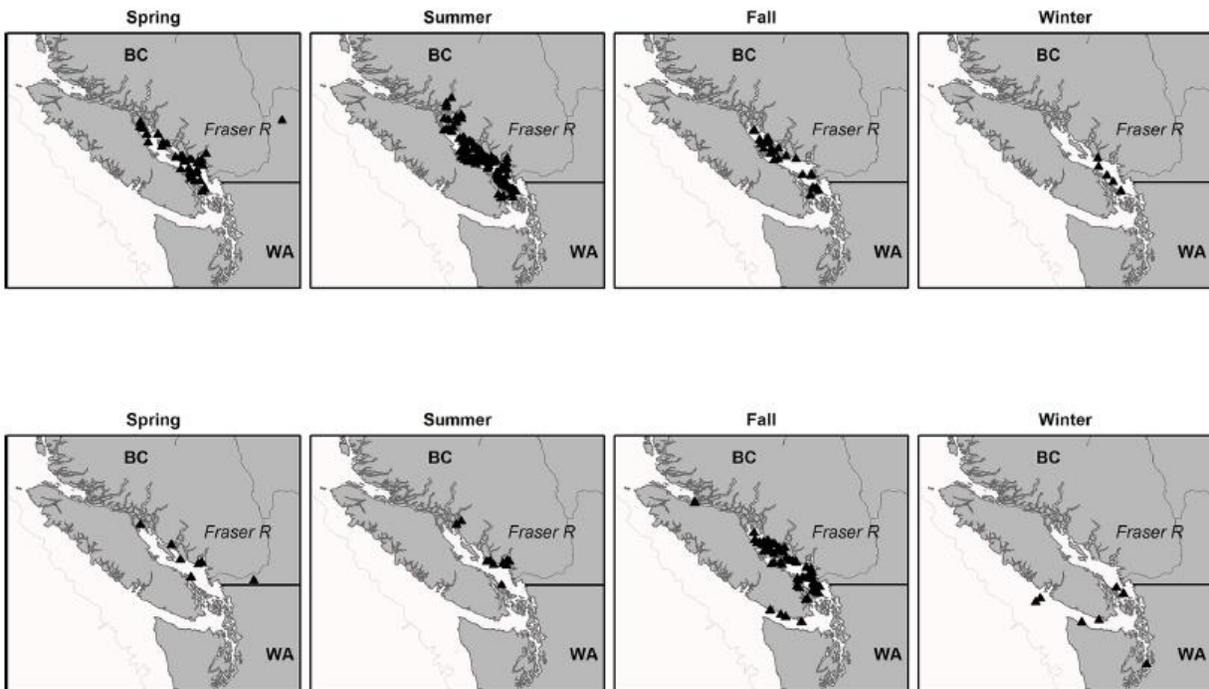


Figure 8. Catch locations of yearling (a) and sub-yearling (b) Fraser river origin juvenile Chinook salmon. Salmon were caught between 2008 and 2012. Figure obtained from Tucker et al. 2018.

Further, Tucker et al. (2018) state that “over the temporal period of our study, loads of PRV [...] did not reach levels that one would generally consider high where fish may show adverse symptoms of infection.” Indeed, recent research in Atlantic salmon report that “neither the presence, nor a high systemic load of PRV is a useful proxy for predicting disease in salmon” after investigating the effect of high-load PRV infections on the cardiorespiratory capabilities of Atlantic salmon (Zhang et al. 2019); to date, no such research has been conducted for Chinook salmon.

Overall, research to understand the relationship between PRV loads and clinical disease is still ongoing, and it appears that PRV is not necessarily the sole factor initiating disease conditions in both Atlantic and Pacific salmon (Zhang et al. 2019). DiCicco et al. (2018) emphasize that a comprehensive epidemiological study is currently underway to assess the role of salmon farms in the transmission of PRV to wild stocks.

Parasitic sea lice

Although sea lice are a major threat to Atlantic salmon production, Chinook salmon are less susceptible to sea lice than Atlantic salmon (Johnson and Albright 1992); as a result, Chinook salmon farms do not experience significant sea lice infections (and do not have to employ lice treatments). Since July 2016, DFO has required all salmon farms to submit quarterly reports of lice counts and maintain lice below a threshold of three motile lice per fish (only required for Atlantic salmon prior to July 2016); if this threshold is exceeded, DFO must be notified and a management response must be initiated. DFO maintains several online datasets for annual lice counts both for DFO audits⁷⁰ and for industry-reported data,⁷¹ yet, these datasets include only information from Atlantic salmon farms, given that sea lice monitoring results are not required to be submitted by Pacific salmon farms.⁷² However, Yellow Island Aquaculture maintain their own sea lice records, and have reported an average of 1.16 ± 0.99 lice per fish for 2006 to 2015, and >50% of fish with no lice (J. Heath, personal communication, Yellow Island Aquaculture 2018). Lice numbers at Creative Salmon farms are reported to have always been “very low” (an average of 0.13 motile lice per fish between 2016 and 2018), and they have never exceeded the aforementioned notifiable threshold (T. Rundle, personal communication, Creative Salmon 2018). These numbers are, in general, lower than lice counts found on wild adult Chinook salmon throughout British Columbia (Saksida et al. 2015); Clayoquot Sound in particular has shown to have low levels of lice on wild salmon.^{73,74}

Despite these naturally low levels of infection in farmed Chinook salmon, Chinook salmon farms have the potential to act as a point source of infection. In their natural cycle, salmon exhibit migratory allopatry, meaning adults and juveniles are spatially separated, protecting the more susceptible juveniles from pathogens and parasites infecting the adults (Krkošek et al. 2007). By the time infected adults return from their oceanic feeding grounds, the juveniles that inhabit coastal areas are more resistant to sea lice and better able to cope with the infection (Krkošek et al. 2007). When salmon are maintained in net pens throughout the year, they can act as a source of infection for naïve wild juvenile salmon entering the ocean when adult salmon harboring sea lice would not normally be present in coastal waters (Krkošek, 2009).

Although farmed Chinook salmon can harbor sea lice infections, their inherently low susceptibility results in typically lower levels of infection than in wild salmon, and therefore, spillback of sea lice from Chinook salmon farms to wild salmon is of moderately low concern. In

⁷⁰ <https://open.canada.ca/data/en/dataset/5cfd93bd-b3ee-4b0b-8816-33d388f6811d>

⁷¹ <https://open.canada.ca/data/en/dataset/3cafbe89-c98b-4b44-88f1-594e8d28838d>

⁷² <http://www.dfo-mpo.gc.ca/aquaculture/management-gestion/mar-rep-rap-2015-2016/health-sante-eng.html#sea-lice>

⁷³ Prevalence and density of sea louse (*L. salmonis* and *C. Clemensi*) infections in juvenile chum salmon (*Oncorhynchus keta*) in Clayoquot Sound, 2004 to 2007; <http://uuathluk.ca/wordpress/wp-content/uploads/2012/08/sealice.pdf>

⁷⁴ Patterns of sea lice (*L. salmonis*) infections in juvenile chum salmon (*Oncorhynchus keta*) in Clayoquot Sound, 2007 to 2009; http://uuathluk.ca/wordpress/wp-content/uploads/2012/07/CSSWG-sea-lice-report-2007-09_Final.pdf

addition, the small size of the Chinook salmon industry in BC, particularly compared to the Atlantic salmon industry, means that the number of farms, which may act as point sources of sea lice infection, is small and it is unlikely that any lice spillback from these farms would have any significant overall impact on wild salmon populations.

Status of wild fish populations

Of particular importance is the status of wild Chinook stocks in Clayoquot Sound, where the majority of the Chinook farming industry is located; wild Chinook escapement and spawner levels within Pacific Fishery Management Area 24 (Clayoquot Sound) are currently and expected to remain low with poor marine survival, and are considered a stock of concern by the DFO (DFO 2018a). The Southwest Vancouver Island Conservation Unit (SWVI CU; CK-31), of which the majority is comprised of stocks originating in Clayoquot Sound, is classified as “red” status, or a score of 1, which is the lowest level of classification possible (DFO 2018a). Promisingly, 2017 escapement of the WCVI Chinook aggregated stocks (CK-31, West Vancouver Island-South; CK-32, West Vancouver Island-Nootka and Kyuquot; CK-33, West Vancouver Island-North) was +164% relative to the 2003 to 2013 average, though the stocks specific to Clayoquot Sound, CK-31, saw a decline in escapement of 12% (DFO 2018b). Despite this, WCVI Chinook stocks are not listed as endangered or threatened under the Species at Risk Act (SARA), though other South Coast Chinook stocks (primarily Fraser and Thompson Rivers) were listed as endangered or threatened following assessment by the federal Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2018.⁷⁵

Broadly, escapement of these stocks have been historically depressed since the early 1990s, following a period of intense recreational and commercial fishing in the 1980s (DFO 2012b); there was simultaneously a rapid expansion of salmon farms in the mid- to-late 1980s reaching 113 operational sites by 1987, primarily farming Chinook salmon in the eastern Strait of Georgia and throughout the west coast of Vancouver Island (King et al. 2013). Overall, the declining productivity of Chinook salmon in the region has been associated with large-scale environmental changes and increasing environmental variability alongside these anthropogenic impacts, such as several major El Niño events in the early 1990s and warming ocean conditions today; thus, it is difficult to assign responsibility to any one factor as the major causative pressure (DFO 2018b) (Riddell et al. 2013). Regardless, for the purposes of this Disease assessment, Chinook salmon farms are considered to be operating in areas with vulnerable wild hosts.

Conclusions and Final Score

The broad body of literature regarding disease transfer risk between salmon farms and wild salmon in British Columbia is largely focused on Atlantic salmon, and although there is often applicable information in these studies to this assessment of the risk posed by Chinook salmon farms, there are ultimately not enough data available to demonstrate the specific impact (or lack thereof) of Chinook salmon farms on the health of wild salmon in BC; therefore, the Risk-

⁷⁵ <https://www.canada.ca/en/environment-climate-change/services/committee-status-endangered-wildlife/assessments/wildlife-species-assessment-summary-nov-2018.html>

Based Assessment option in the Seafood Watch Aquaculture Standard is used (as opposed to the Evidence-Based option).

According to farm mortality rates, bacterial and viral pathogens cause approximately half, at most, of the 1% to 1.8% monthly mortality rates in BC Chinook aquaculture production (i.e., if all “fresh silvers” and “decomposed” fish died because of these pathogens). Although the actual number is likely to be less, the presence of pathogens on farms (including a chronic presence that may not cause high mortalities) represents a reservoir of potential infection to wild fish. To date, this connection and potential impact have not been fully understood, and the research of the Strategic Salmon Health Initiative (SSHI) and others are advancing this knowledge in BC. Although bacterial kidney disease (BKD) is the primary disease affecting Chinook salmon farms, piscine orthoreovirus (PRV) is of particular focus for the SSHI and in this report. The strain of PRV present in BC is believed to contribute to the development of the incompletely characterized jaundice or anemia syndrome seen in farmed Chinook salmon. At this stage, however, there is no evidence of bacterial or viral pathogens on Chinook salmon farms having an impact on wild salmonids in BC, but importantly, there is also no evidence that there is not an impact. Thus, there is some level of concern, particularly in the context of the ecological importance of vulnerable wild salmonid populations in BC.

Chinook salmon are naturally more resistant to sea lice than Atlantic salmon, and Chinook salmon farms have never had sea lice levels exceed regulatory thresholds for reporting, nor levels that have required intervention or treatment; indeed, there is evidence that lice levels on wild Pacific salmon is commonly higher than that seen on farmed Chinook. Though Chinook salmon farms have the theoretical potential to act as point sources of sea lice infection for wild salmon, sea lice are naturally present in coastal waters throughout the year on non-salmonid hosts. The low level of infection in farmed Chinook salmon and the relatively small size of the industry means that spillback of on-farm lice infection is of low concern.

Chinook farms in BC implement fish health management and biosecurity measures that result in low levels of disease-related mortality, as evidenced by the lack of reported disease events, no therapeutic treatments, and reported low-mortality rates. Simultaneously, the majority of the Chinook industry is sited in Clayoquot Sound on the west coast of Vancouver Island (WCVI), where vulnerable wild Chinook stock levels are depressed and are under the lowest possible level of stock status classification by the DFO. Given the multitude and complexity of factors affecting wild fish productivity and survival, and the aforementioned low disease rates on Chinook salmon farms, an intermediate score is warranted, indicating that some disease-related mortality occurs on farms and the production system is open to the introduction and discharge of pathogens. As such, the final score for Criterion 7 – Disease is 4 out of 10.

Criterion 8X: Source of Stock – independence from wild fisheries

Impact, unit of sustainability and principle

- Impact: the removal of fish from wild populations for on-growing to harvest size in farms
- Sustainability unit: 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

Source of stock parameters	Score	
C8X Independence from unsustainable wild fisheries (0-10)	0	
Critical?	NO	GREEN

Brief Summary

The Chinook salmon farming industry in BC is entirely reliant on domesticated, hatchery-raised broodstock, eggs, and smolts. The final score for Criterion 8X – Source of Stock is –0 out of –10.

Justification of Ranking

Due to the industry-wide use of domesticated broodstock (e.g. Kim et al. 2004), the BC salmon farming industry is considered independent of wild salmon fisheries for the supply of fish for production. Farmed Chinook in BC are currently at least six to seven generations hatchery-reared, and desirable characteristics for aquaculture are artificially selected (Lehnert et al. 2013). Therefore, the score for Criterion 8X – Source of Stock is –0 out of –10.

Conclusions and Final Score

Because 0% of farmed stock is dependent on wild broodstock or wild fisheries, the final numerical score for Criterion 8X – Source of Stock is a deduction of –0 out of –10.

Criterion 9X: Wildlife and predator mortalities

Impact, unit of sustainability and principle

- Impact: mortality of predators or other wildlife caused or contributed to by farming operations
- Sustainability unit: wildlife or predator populations
- Principle: preventing population-level impacts to predators or other species of wildlife attracted to farm sites.

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

Criterion 9X Summary

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score (0-10)	-2	
Critical?	NO	GREEN

Brief Summary

Data show that wildlife mortalities as a result of interactions with Chinook salmon aquaculture operations in BC are limited to exceptional cases; only three California sea lion and five harbor seal mortalities have been reported in the previous seven years, and none in the previous five. Though various native fish species are regularly caught as incidental catch, regulations require efforts be made for harmless release, and any mortalities that might result can be considered to be well below a level that could impact population status. Therefore, the final score for Criterion 9X – Wildlife and Predator Mortalities is –2 out of –10.

Justification of Ranking

In Canada, DFO is responsible for the management, conservation, and protection of marine mammals, and the Pacific Aquaculture Regulations allow the department to “license fish farms to undertake predator control of marine mammals that pose an imminent danger to the aquaculture facility or human life, should reasonable deterrent efforts fail.”⁷⁶ The Steller sea lion (*Eumetopias jubatus*) was designated by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as a “Species of Special Concern” in 2003; consequently, they were removed from lethal control licenses. Aquaculture operators are required to apply for special permission to lethally remove any marine mammal species other than harbor seals (*Phoca vitulina*) or California sea lions (*Zalophus californianus*).

⁷⁶ <http://www.dfo-mpo.gc.ca/aquaculture/protect-protege/removal-fish-retraits-poissons-eng.html>

Records of marine mammal lethal control activities and accidental drownings are mandated by the site licenses⁷⁷ and have been published by DFO since 2011.⁷⁸ Since 2011, only California sea lions and harbor seals are reported to have experienced mortality at Chinook salmon farms, and the number of mortalities is low: three California sea lion mortalities were reported in 2011 (all were authorized mortalities at one site), and two harbor seal mortalities were reported in 2011 (both were authorized mortalities), two in 2012 (one authorized mortality, one accidental drowning), one in 2013 (one accidental drowning), and none since (database is current to April 2018).

Having been depleted by overhunting prior to the species being protected in 1970, the BC harbor seal population has increased considerably from approximately 10,000 in 1970 to around 105,000 in 2009 (DFO 2010). The Steller sea lion population was estimated to be between 20,000 and 28,000 in 2008 (DFO 2008). DFO currently has stock assessments underway for both species, and both are believed to be increasing and healthy (K. Shaw, personal communication, DFO November 2018). California sea lions are migrants in BC waters from more southerly breeding populations; the abundance of the US stock of California sea lions is estimated to be 238,000 and is considered to be approaching the carrying capacity of its environment (NOAA 2012). Consequently, the exceptional cases of reported mortalities at fish farms of apparently stable marine mammal populations indicate that they do not significantly impact the population sizes of these species.

In addition to marine mammal mortalities, DFO also records incidental catches from salmon net pens. It must be noted that “incidental catch” does not necessarily mean “mortality,” since the Pacific Aquaculture Regulations require efforts to be made for the harmless release of incidentally caught fish; however, it must also be assumed that not all harmless-release attempts are successful. Nevertheless, although various native species are regularly reported, including a small number of Pacific salmon (roughly 0.42% of all bycatch 2011 to 2017), the number of incidentally caught fish at Chinook salmon farms is relatively minor. For example, the largest quarterly reported catch since 2011 was 2,197 Pacific herring (*Clupea pallasii*) from one site in 2015,⁷⁹ which is well below a level that could be considered to have an impact on wild fish populations (the spawning biomass of the West Coast Vancouver Island herring stock was estimated to be around 32,000 MT in 2017⁸⁰).

DFO does not record bird mortalities at fish farms, although salmon farmers do not use lethal methods for controlling avian predators in BC (T. Rundle, personal communication, Creative Salmon 2016) (B. Hicks, personal communication, Taplow Feeds 2016). However, all salmon net pens have bird netting installed as standard, which is widely accepted to deter avian predators, and birds are considered a minor problem (and conservation concern) compared to seals and sea lions (Quick et al. 2004).

⁷⁷ <http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/docs/licence-cond-permis-mar/licence-cond-permis-mar-eng.pdf>

⁷⁸ <https://open.canada.ca/data/en/dataset/a7b3fdfb-5917-4ca6-b29c-093e3f65d6ba>

⁷⁹ <https://open.canada.ca/data/en/dataset/0bf04c4e-d2b0-4188-9053-08dc4a7a2b03>

⁸⁰ http://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2018/2018_002-eng.pdf

Humpback Whales

DFO public reporting on marine mammals shows three humpback whales (*Megaptera novaeangliae*) became entangled in fish farm equipment in BC during 2016; two of the whales died, and the third was released injured but alive. None of these incidences involved Chinook salmon farms.

A news report by Thomas (2016),⁸¹ quoting Jackie Hildering from the Marine Education and Research Society, notes that increased entanglements can be attributed to an unprecedented number of humpback whales in coastal BC waters. 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 COSEWIC.⁸² According to the SARA Species profile,⁸³ the most recent population estimate (2011) for the North Pacific humpback whale was 18,302 individuals, suggesting the population is making a strong comeback, recovering 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, neither of which occurred at Chinook sites, will not contribute to further declines, or prohibit recovery.⁸⁴ Although the growing presence of humpbacks in BC indicates that additional mortalities are possible in the future, and considering the very small number of Chinook salmon farm sites relative to the number of Atlantic salmon sites, the concern for humpback whale mortalities increasing at Chinook salmon farm sites is limited.

Conclusion and Final Score

Data show that mortalities of seals and fish interacting with Chinook salmon farms has been limited in recent years to exceptional cases, and these numbers are not considered to significantly affect the population sizes of these species. For Criterion 9X – Wildlife and Predator Mortalities, the final score is –2 out of –10.

⁸¹ Thomas 2016. CBC News. November 30, 2016. <http://www.cbc.ca/news/canada/british-columbia/humpback-whale-deaths-1.3874915>

⁸² Species at risk public registry. http://www.registrelep-sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=148

⁸³ http://www.registrelep-sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=148

⁸⁴ See the Seafood Watch Aquaculture Standard, Criterion 10X.

Criterion 10X. Escape of secondary species

Impact, unit of sustainability and principle

- Impact: movement of live animals resulting in introduction of unintended species
- Sustainability unit: wild native populations
- Principle: avoiding the potential for the accidental introduction of secondary species or pathogens resulting from the shipment of animals.

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

Criterion 10X Summary

Escape of secondary species parameters		Score
F10Xa International or trans-waterbody live animal shipments (%)		10
F10Xb Biosecurity of source/destination		10
C10X Escape of secondary species Final Score		0.00
		GREEN

Brief Summary

Chinook salmon are native to BC and broodstock are maintained in local hatcheries; thus, there is no risk of exotic pathogens being introduced by Chinook salmon farming. Furthermore, all transfers of fish occur within the government-mandated “salmonid transfer zones” whose boundaries constitute related watersheds. The final score for Criterion 10X – Escape of secondary species is –0 out of –10.

Justification of Ranking

Factor 10Xa International or trans-waterbody live animal shipments

Given that Chinook are native to the waters of British Columbia and the origins of their culture in the region began on Vancouver Island (Clarke and Pennell 2013), there has been no import of Chinook eggs from outside of the country. Furthermore, British Columbia has constructed “salmonid transfer zones.” All three companies currently producing Chinook salmon in BC are within the same zone (Southern Coast Zone 7)⁸⁵ and have their own local hatcheries,⁸⁶ so all production fish originates from within-zone, hatchery-reared broodstock. Therefore, there is no risk of exotic pathogens being introduced by Chinook salmon farming. Because 0% of production is reliant on international/trans-waterbody animal movements, the score for Factor 10Xa is 10 out of 10.

⁸⁵ <http://www.dfo-mpo.gc.ca/aquaculture/bc-cb/maps-cartes-eng.html>

⁸⁶ <https://open.canada.ca/data/en/dataset/522d1b67-30d8-4a34-9b62-5da99b1035e6>

Factor 10Xb Biosecurity of source/destination

Since there are no international or trans-waterbody shipments of live animals, there is no risk of transferring organisms between ecologically distinct environments. Thus, the score for Factor 10Xb is 10 out of 10.

The final score for Criterion 10X – Escape of secondary species is a deduction of –0 out of –10.

Conclusions and Final Score

Chinook salmon are native to BC and broodstock are maintained in local hatcheries; thus, there is no risk of exotic pathogens being introduced by Chinook salmon farming. Furthermore, all transfers of fish occur within the government-mandated “salmonid transfer zones” whose boundaries constitute related watersheds. The final score for Criterion 10X – Escape of secondary species is a deduction of –0 out of –10.

Overall Recommendation

The overall final score is the average of the individual criterion scores (after the two exceptional scores have been deducted from the total). The overall ranking is decided according to the final score, the number of red criteria, and the number of critical scores as follows:

- **Best Choice/Green** = Final score ≥ 6.6 AND no individual criteria are Red (i.e., < 3.3)
- **Good Alternative/Yellow** = Final score ≥ 3.3 AND < 6.6 , OR Final score ≥ 6.6 and there is one individual “Red” criterion
- **Red/Avoid** = Final score < 3.3 , OR there is more than one individual Red criterion, OR there is one or more Critical score

Criterion	Score	Rank	Critical?
C1 Data	8.18	GREEN	
C2 Effluent	6.00	YELLOW	NO
C3 Habitat	6.27	YELLOW	NO
C4 Chemicals	9.00	GREEN	NO
C5 Feed	7.17	GREEN	NO
C6 Escapes	7.00	GREEN	NO
C7 Disease	4.00	YELLOW	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife mortalities	-2.00	GREEN	NO
C10X Introduced species escape	0.00	GREEN	
Total	45.61		
Final score (0-10)	6.52		

OVERALL RANKING

Final Score	6.52
Initial rank	YELLOW
Red criteria	0
Interim rank	YELLOW
Critical Criteria?	NO

FINAL RANK
YELLOW

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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 Standard document for a full explanation of the criteria, calculations and scores. Yellow cells represent data entry points.

Criterion 1: Data quality and availability

Data Category	Data Quality (0-10)
Industry or production statistics	10
Management	10
Effluent	7.5
Habitats	7.5
Chemical use	7.5
Feed	7.5
Escapes	7.5
Disease	5
Source of stock	10
Predators and wildlife	7.5
Unintentional introduction	10
Other – (e.g. GHG emissions)	n/a
Total	90

C1 Data Final Score (0-10)	8.18	GREEN
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Criterion 2: Effluent

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0-10)	6	YELLOW
Critical?	NO	

Criterion 3: Habitat

Factor 3.1. Habitat conversion and function

F3.1 Score (0-10)	7
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Factor 3.2 – 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	4.8

C3 Habitat Final Score (0-10)	6	YELLOW
Critical?	NO	

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	Score	
C4 Chemical Use Score (0-10)	9	
C4 Chemical Use Final Score (0-10)	9	GREEN
Critical?	NO	

Criterion 5: Feed

5.1. Wild Fish Use

Feed parameters	Score
5.1a Fish In : Fish Out (FIFO)	
Fishmeal inclusion level (%)	50
Fishmeal from by-products (%)	95
% FM	2.5
Fish oil inclusion level (%)	15
Fish oil from by-products (%)	100
% FO	0
Fishmeal yield (%)	22.5
Fish oil yield (%)	5
eFCR	1.72
FIFO fishmeal	0.19
FIFO fish oil	0.00
FIFO Score (0-10)	9.52
Critical?	NO
5.1b Sustainability of Source fisheries	
Sustainability score	-5
Calculated sustainability adjustment	-0.19
Critical?	NO
F5.1 Wild Fish Use Score (0-10)	9.33
Critical?	NO

5.2 Net protein Gain or Loss

Protein INPUTS	
Protein content of feed (%)	40
eFCR	1.72
Feed protein from fishmeal (%)	
Feed protein from EDIBLE sources (%)	26.82
Feed protein from NON-EDIBLE sources (%)	73.18

Protein OUTPUTS	
Protein content of whole harvested fish (%)	18.5
Edible yield of harvested fish (%)	67
Use of non-edible by-products from harvested fish (%)	100
Total protein input kg/100kg fish	68.8
Edible protein IN kg/100kg fish	18.45
Utilized protein OUT kg/100kg fish	22.92
Net protein gain or loss (%)	24.21
Critical?	NO
F5.2 Net Protein Score (0-10)	10

5.3. Feed Footprint

5.3a Ocean Area appropriated per ton of seafood	
Inclusion level of aquatic feed ingredients (%)	65
eFCR	1.72
Carbon required for aquatic feed ingredients (ton C/ton fish)	69.7
Ocean productivity (C) for continental shelf areas (ton C/ha)	2.68
Ocean area appropriated (ha/ton fish)	29.08
5.3b Land area appropriated per ton of seafood	
Inclusion level of crop feed ingredients (%)	35
Inclusion level of land animal products (%)	0
Conversion ratio of crop ingredients to land animal products	2.88
eFCR	1.72
Average yield of major feed ingredient crops (t/ha)	2.64
Land area appropriated (ha per ton of fish)	0.23
Total area (Ocean + Land Area) (ha)	29.30
F5.3 Feed Footprint Score (0-10)	0

Feed
Final
Score

C5 Feed Final Score (0-10)	7.17	GREEN
Critical?	NO	

Criterion 6: Escapes

6.1a System escape Risk (0-10)	6
6.1a Adjustment for recaptures (0-10)	0
6.1a Escape Risk Score (0-10)	6

6.2. Invasiveness score (0-10)	8	
C6 Escapes Final Score (0-10)	7	GREEN
Critical?	NO	

Criterion 7: Disease

Disease Evidence-based assessment (0-10)		
Disease Risk-based assessment (0-10)	4	
C7 Disease Final Score (0-10)	4	YELLOW
Critical?	NO	

Criterion 8X: Source of Stock

C8X Source of stock score (0-10)	0	
C8 Source of Stock Final Score (0-10)	0	GREEN
Critical?	NO	

Criterion 9X: Wildlife and predator mortalities

C9X Wildlife and Predator Score (0-10)	-2	
C9X Wildlife and Predator Final Score (0-10)	-2	GREEN
Critical?	NO	

Criterion 10X: Escape of secondary species

F10Xa live animal shipments score (0-10)	10.00	
F10Xb Biosecurity of source/destination score (0-10)	10.00	
C10X Escape of Secondary Species Final Score (0-10)	0.00	GREEN
Critical?	n/a	