Monterey Bay Aquarium Seafood Watch®

Atlantic salmon

Salmo salar

British Columbia, Canada

Net Pens

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Peter Bridson – Seafood Watch

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Final Seafood Recommendation

The final score for farmed Atlantic salmon from British Columbia farmed in net pens is 4.3, which is within in the yellow “Moderate” category, but with two red criteria for chemicals and disease the final result is a red “Avoid” recommendation.

Criterion	Score (0-10)	Rank	Critical?
C1 Data	7.5	GREEN	
C2 Effluent	5.0	YELLOW	NO
C3 Habitat	6.1	YELLOW	NO
C4 Chemicals	2.0	RED	NO
C5 Feed	5.8	YELLOW	NO
C6 Escapes	4.0	YELLOW	NO
C7 Disease	2.0	RED	NO
C8 Source	10.0	GREEN	
C9X Wildlife mortalities	-4.0	YELLOW	NO
C10X Introduced species escape	-4.0	YELLOW	
Total	**34.4**		
Final score	**4.3**		

OVERALL RANKING

Final Score	4.3
Initial rank	YELLOW
Red criteria	2
Interim rank	RED
Critical Criteria?	NO
Final Rank	**AVOID/RED**

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

Executive Summary

British Columbia (BC) on Canada's Pacific coast currently produces an annual average of approximately 85,000 metric tons (mt) or 187 million pounds of farmed salmon. Although this is relatively small in comparison to (for example) Norway's 1.24 million mt, BC is a major source of farmed salmon on the U.S. seafood market.

Salmon aquaculture in BC initially grew slowly in the early 1980s, producing less than 2,000 mt of Atlantic and Pacific salmon a year, but production increased rapidly in the late 1980s and 1990s reaching approximately 50,000 mt by the year 2000. From an initial focus on Pacific salmon species, production became increasingly dominated by the non-native Atlantic salmon over the same period. The industry is concentrated in the northern Georgia Strait and southern Johnstone Strait region between Vancouver Island and the mainland, and also to a lesser extent on the west coast of Vancouver Island. Approximately 70 to 80 farm sites are active at any one time. This area (particularly the Georgia/Johnstone Straits) is an important migratory corridor for wild Pacific salmon populations and the debate surrounding the interaction between these two salmonid groups (i.e., farmed and wild) has been a key characteristic of the industry's recent development in BC. The industry body, the British Columbia Salmon Farmers Association (BCSFA), has announced plans to substantially expand the group's current production by 43% by 2020 and, potentially, by another 50% by 2025 (to 150,000 mt).

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[1]. As a result of the controversy and polarity of opinions relating to some of these aspects, this report has been reviewed by seventeen experts representing a variety of stakeholders.

With historic and ongoing concern over net pen production systems and their environmental impacts, the considerable scrutiny and scientific study means that data availability in BC is generally good in comparison to many aquaculture industries globally. Limited detail and/or gaps in public data availability remain in some key areas. The BC Salmon Farmers Association (BCSFA) provided information from their databases (particularly on fish health and chemical use) for this assessment. While both government and company statistics are typically aggregated and to a greater or lesser extent reliant on industry self-reporting, salmon farming in BC has also been the subject of substantial scientific study. In addition, the detailed analysis of the three-year Cohen Commission enquiry (although focused primarily on Fraser River sockeye salmon) provided voluminous information and analysis on several aspects of relevance to this Seafood Watch assessment. There is sufficient data available from various institutions to have high confidence that the majority of the industry's operations and impacts are relatively

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

well understood within the current limitations of scientific understanding. The Data Criterion score is 7.5 out of 10.

The salmon industry globally has increased efficiency and made significant reductions in nutrient loss per ton of fish production, yet 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 the feed (approximately 60%–70% of the nitrogen, carbon and phosphorous supplied in feeds is considered to be lost to the environment). Although the floating net pens themselves have a minimal direct habitat impact, the operational impacts on the benthic habitats below and in the immediate vicinity of the farm (i.e., within a regulatory allowable zone of effect) have the potential to be profound. 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 the water column are assessed in the Effluent Criterion.

The Seafood Watch Effluent Criterion calculates the total amount of waste released per ton of salmon production and combines it with an assessment on the effectiveness of the management and regulatory process with respect to potential cumulative impacts from the total tonnage produced at any one site, or of multiple sites in close proximity. The total waste discharged (using nitrogen as a proxy) is estimated to be 50.3 kg N t^{-1}. Benthic monitoring results show approximately 80% of BC farms are in compliance with regulatory requirements (based on no significant impact at 30m from the edge of the net pens, and no detectable impact at 125m for soft bottom depositional environments); and while individual sites are regulated in terms of maximum biomass of fish and require annual monitoring and reporting, regulatory control is lacking in robust measures relating to potential cumulative impacts of multiple farms. Combining the relatively minor impacts beyond the immediate farm location with some ongoing uncertainties regarding potential cumulative impacts gives this fishery a moderate final score of 5 out of 10.

Direct habitat impacts within the farm area may cause dramatic shifts in species diversity and abundance, but the total habitat area impacted by salmon farms in BC is small compared to the total coastal resource. While some uncertainties remain, the potential for cumulative impacts from adjacent sites or from the industry's total impact area appears low. Benthic habitat impacts below any one salmon farm site are relatively and rapidly reversible by fallowing or by breaks in production. The combination of the lack of irreversibility and the relatively rapid reversibility of these impacts, as well as a moderately good regulatory effectiveness results in a "moderate" habitat score of 6 out of 10.

The number of seals and sea lions reported killed as a result of interactions with salmon farms in BC has fallen from a peak of several hundred per year in the late 1990s to sixteen in 2012, and to less than ten for the first three quarters of 2013. Despite a substantial upturn in 2010 and 2011 when over 300 were killed (mostly shot), the recent reduction appears to be due largely to improved management practices, which lead to less lethal control. While these wildlife mortalities are distasteful from an anthropomorphic perspective, from an ecological perspective they are not considered to significantly affect the population size of these species. This results in a moderate penalty score of -4 in the Seafood Watch criteria.

Pesticide use in BC is low (compared to other salmon farming regions) at 10-20 kg active ingredient used per year, and BC is unusual among global salmon farming regions in maintaining the effectiveness of emamectin benzoate as a sole treatment. Antibiotic use in BC has decreased over the last ten years, but the total amount continues to be substantial (3.6 mt in 2012) and there is no regulatory limit in place on total use should a disease outbreak occur. Evidence of direct environmental impacts from the use of these chemicals is limited, but environmental monitoring and research is also limited. Over 80% of the antibiotics (by volume) used in BC are listed by the World Health Organization as highly important to human health, and antibiotic resistance continues to be a severe global concern. Multiple pathways exist for the transfer of antibiotic resistance between microbial communities and also from animals to humans, and therefore the use of substantial quantities of these antibiotics in open net pen systems (which provides no barrier to infection from environmental pathogens that subsequently require treatment with antibiotics highly important to human health) remains a high concern. The score for the Chemical Use Criterion is 2 out of 10.

Two feed companies in BC provided the required information on their salmon feeds for this assessment, and the values provided are consistent with the peer reviewed literature. With approximately 17% fishmeal and 12% fish oil in the feeds (partially sourced from fish processing byproducts), the average Fish In: Fish Out ratio (a simple measure of wild fish use) was 2.14. Ignoring other uses of associated fishmeal, this means 2.14 mt of wild fish would need to be caught to produce the fish oil needed to produce one ton of farmed salmon in BC. With a moderate source fishery sustainability score, the final adjusted wild fish use score for salmon farming continues to be relatively low at 3.37 out of 10. The trend in decreasing use of fishmeal and fish oil in salmon feeds (on a per ton of production basis) has been due to the use of alternative ingredients and the majority of the protein in the BC feeds is now supplied by both non-edible sources (non-edible from a human perspective; i.e., from rendered byproducts of land animals and fish) and plant-derived sources. This results in high scores for a net edible protein gain and a relatively small feed footprint area. Overall, despite the low wild fish use score, the high use of byproduct ingredients in BC results in a moderate final Feed Criterion score of 5.8 out of 10.

Reported salmon escape numbers in BC have been highly variable over the last twenty years, but there have been improvements in net pen design and management. Reported escapes in 2011 and 2012 have been low (only 12 fish reported in 2011), however, 15,700 fish escapes during a single event in 2010 and the highest total escapes on record (over 100,000 fish) occurred in 2008. While additional years without large escapes could reduce the assessed risk score, the ongoing concerns regarding unreported trickle losses in addition to the recent large escape events demonstrate an ongoing high escape risk.

There have been many deliberate attempts to establish the non-native Atlantic salmon in the Pacific in North and South America. Although none of these attempts have been successful and few farm escapees appear to feed successfully beyond the farm, Atlantic salmon escapees (potentially from Washington State as well as from BC) have repeatedly been found in the North East Pacific as far north as northern Alaska. There is some evidence of successful reproduction in BC rivers from the late 1990s, but while dedicated monitoring efforts have decreased, no further evidence of reproducing Atlantic salmon populations in BC has been detected since.

It can be argued that increasing generations of farmed salmon in BC will either become better acclimated to the Pacific and therefore more likely to establish, or they will become increasingly domesticated and therefore less likely to establish in the wild. While many species of salmonid have become established beyond their native ranges in a global context, Atlantic salmon have not been successful anywhere, and results from similar, deliberate introductions and farm escapes of Atlantic salmon in Chile support the conclusion that this species performs poorly in the wild outside of its native range. This assessment currently considers Atlantic salmon to be highly unlikely to become established in BC and that escapees have limited direct ecological impacts; however, the final score also reflects an inevitable, ongoing concern of the possibility of establishment and that the consequences could be profound. The Escape Criterion score is 4 out of 10.

BC has become largely independent of international imports of eggs (none since 2009); however, the available evidence indicates that a newly identified European virus, piscine reovirus (PRV), was introduced into BC in approximately 2007. The presence of infectious salmon anemia virus (ISA) in BC continues to be debated as does its source and pathogenicity status. The ongoing risk of introducing non-native species is also considered to be low while the import of eggs into BC remains low. The recent and potentially ongoing movements of PRV infected fish from freshwater hatcheries to marine grow-out sites continue to be a concern, and although these movements are occurring within healthy zones, the potential impacts of PRV remain unknown in BC. The potential impacts of previously introduced pathogens such as PRV are assessed in the Disease Criterion below, but a penalty score of -4 (out of -10) is applied to the moderate to low ongoing risk of introduction and/or spread of novel non-native species in BC.

The interaction of farmed and wild salmon with respect to pathogens and parasites is perhaps the most complex and contentious aspect of salmon farming among the broad range of stakeholders in BC. The frequency of “fish health events” has declined on salmon farms in BC, but disease outbreaks resulting from bacteria and viruses of moderate to high pathogenicity to wild salmon are reported continually by the industry. Accepting that wild fish may be the primary route of infection for farmed fish with respect to these endemic pathogens, the available evidence also suggests (as noted above) that at least one non-native pathogen (PRV) has been introduced into BC with, as yet, largely uncertain consequences.

While it has been easy to make a correlation between the declines in many of the region’s wild salmon populations and the increase of disease and parasite pressure from the rapidly growing salmon farm production in BC during the 1990s, long-term monitoring of oceanographic and biological conditions in the Georgia Strait (also the greater Georgia Basin and the NE Pacific in general) now show it to be an enormously complex ecosystem with large stochastic (i.e., unpredictable) fluctuations of numerous key parameters and competing species. These natural variables can easily be correlated with the patterns of wild salmon production. For example, a period of low ocean productivity in the region was apparent over the same period of wild salmon declines beginning in the 1990s. Importantly, these long-term data sets also distinguish the Georgia Strait region as a substantially different ecosystem from that of the open ocean to the west of Vancouver Island through which some sub-populations of wild salmon migrate instead of following the dominant route past the fish farms in the Georgia/Johnstone Straits.

Despite an ongoing infection prevalence of parasitic sea lice of approximately 10%–30% on wild pink and chum salmon in BC, the infection pressure from farms has decreased over the last decade. Since 2007, sea lice are considered to be sufficiently well managed by the industry, and that levels are below those likely to cause significant population declines in wild salmon. Ongoing concerns remain with regard to poorly studied sub-lethal effects and increased predation vulnerability. There is currently no clear evidence that pathogens or parasites are causing significant population declines in wild salmon, but it is clear that the stochastic variability of wild salmon populations are associated with a variety of complex ecological variables in the region (the Cohen Commission concluded there was no "smoking gun" with respect to a large number of stressors on wild salmon populations). Yet many uncertainties remain concerning diseases in wild salmonid populations, along with key data and knowledge gaps (also highlighted by the conclusions of the Cohen Commission), and the potential for serious harm still exists. With consideration of the geographical overlap between the salmon farming industry and critical migratory habitats of juvenile wild salmon, a precautionary approach requires an ongoing high concern for the potential disease impacts in BC. The Disease Criterion score is 2 out of 10.

Overall, many production aspects in BC have improved; there is well documented improvement in feed efficiency and a reduction in the use of wild fish in salmon feeds. Additionally, antibiotic use has declined; sea lice numbers have been reduced and, although continuing to cause negative impacts on wild salmon, now appear to be managed to below significant population-level concerns. Predator mortalities have dramatically decreased and BC is unique among major salmon farming regions in maintaining the efficacy and low overall use of key pesticides. Siting, monitoring and management of biomass with respect to benthic impacts have also improved. Ongoing scientific study and longer term datasets have provided a better understanding of the role of environmental variables in the population of wild salmon and of the risk of Atlantic salmon becoming established in BC.

However, it must also be emphasized that salmon farming in BC continues to have a number of concerns; while arguably more efficient than other forms of intensive (terrestrial) livestock, it still consumes substantially more wild fish than it produces. It uses substantial quantities of antibiotics highly important to human health in open production systems, it continues to have escapes of a non-native species for which a (small) risk of establishment remains, and it continues to represent a source of sea lice infection for juvenile wild fish. At least one non-native pathogen appears to have been introduced into the region for which the impacts, as yet unknown, remain a high concern. The industry representative body has articulated plans for a large increase in production, and an application of a precautionary principle dictates that the impacts, and potential impacts, of ongoing disease outbreaks on wild salmon farms, along with the ongoing substantial use of antibiotics listed as highly important to human health, remain high concerns in BC.

In summary, the final numerical score for net pen farming of Atlantic salmon in BC, Canada is 4.3 out 10, but the two high concern criteria (Chemical Use and Disease) mean that the overall recommendation is “Avoid/Red.”

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Introduction

Scope of the Analysis and Ensuing Recommendation

Species

Atlantic salmon (*Salmo salar)*

Note— a small amount of King (or Chinook) salmon (*Onchorynchus tshawytscha)* is also grown in BC (5% of total farmed salmon production) but is not included in this assessment[2].

Geographic Coverage

British Columbia (BC), Canada.

Production Methods

While juvenile salmon are raised in freshwater hatcheries, the bulk of the salmon growth and potential impacts occur during the saltwater grow-out phase, and this forms the basis of the assessment. Therefore, the scope of this assessment is farmed Atlantic salmon, in British Columbia, in net pens.

Species Overview

Atlantic salmon are native to the North Atlantic Ocean with high numbers of discreet genetic sub-populations through Western Europe in the NE Atlantic and the North America landmass in the NW Atlantic. It is non-native in British Columbia. Atlantic salmon is an anadromous species; that is, birth and early life stages occur in freshwater rivers and streams followed by a migration downstream and over long oceanic distances where the bulk of feeding and growth take place. After one or more years in the ocean, they return upriver to their original spawning ground to complete the cycle.

Production Statistics

Canada's Department of Fisheries and Oceans (DFO) oversees aquaculture in BC and lists 123 active licenses with a potential maximum biomass of 289,304 mt (DFO, 2012a). Approximately 70 sites are in active production at any one time (BCSFA, 2013). Annual production has been approximately 84,000 mt over recent years; 85,202 mt in 2011 83,490 mt in 2012 (BCSFA, 2013[3]). According to DFO, approximately 95% of farmed salmon production in BC is of Atlantic salmon[4], and 68.8% of Canadian aquaculture was exported in 2010 (DFO, 2012a). Three Norwegian-owned companies control 95% of BC's allocated sites (based on biomass limits), with the largest (Marine Harvest) owning 58% of the total maximum biomass; BC represents 58% of total Canadian aquaculture, and salmon represents 98% of the value of BC aquaculture (DFO, 2012a).

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[2] Note - data were not made available from chinook farms and this species is therefore not possible to robustly assess.

[3] British Columbia Salmon Farmers Association, personal communication, August 2013.

[4] http://www.env.gov.bc.ca/omfd/fishstats/graphs-tables/farmed-salmon.html

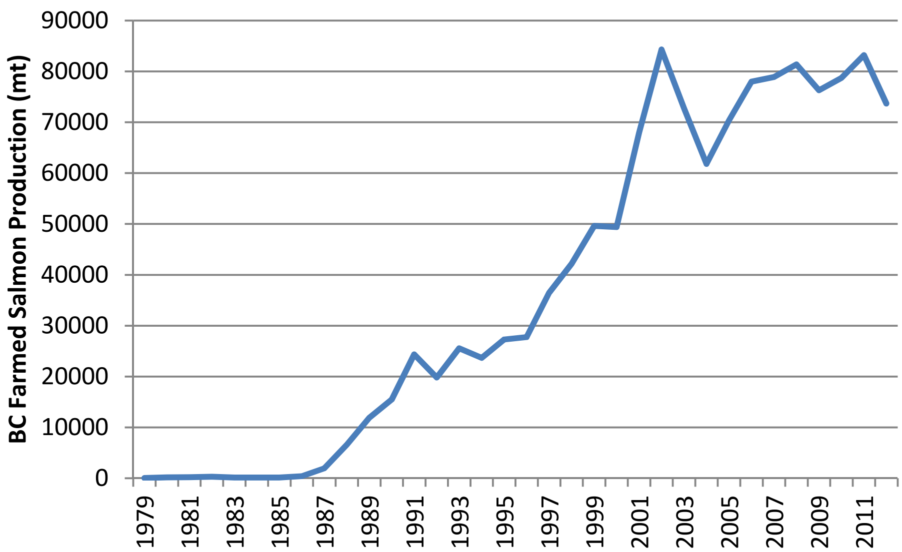

Figure 1: Approximate annual production of farmed salmon (all species) in BC. Data provided by the BC Ministry of Agriculture.

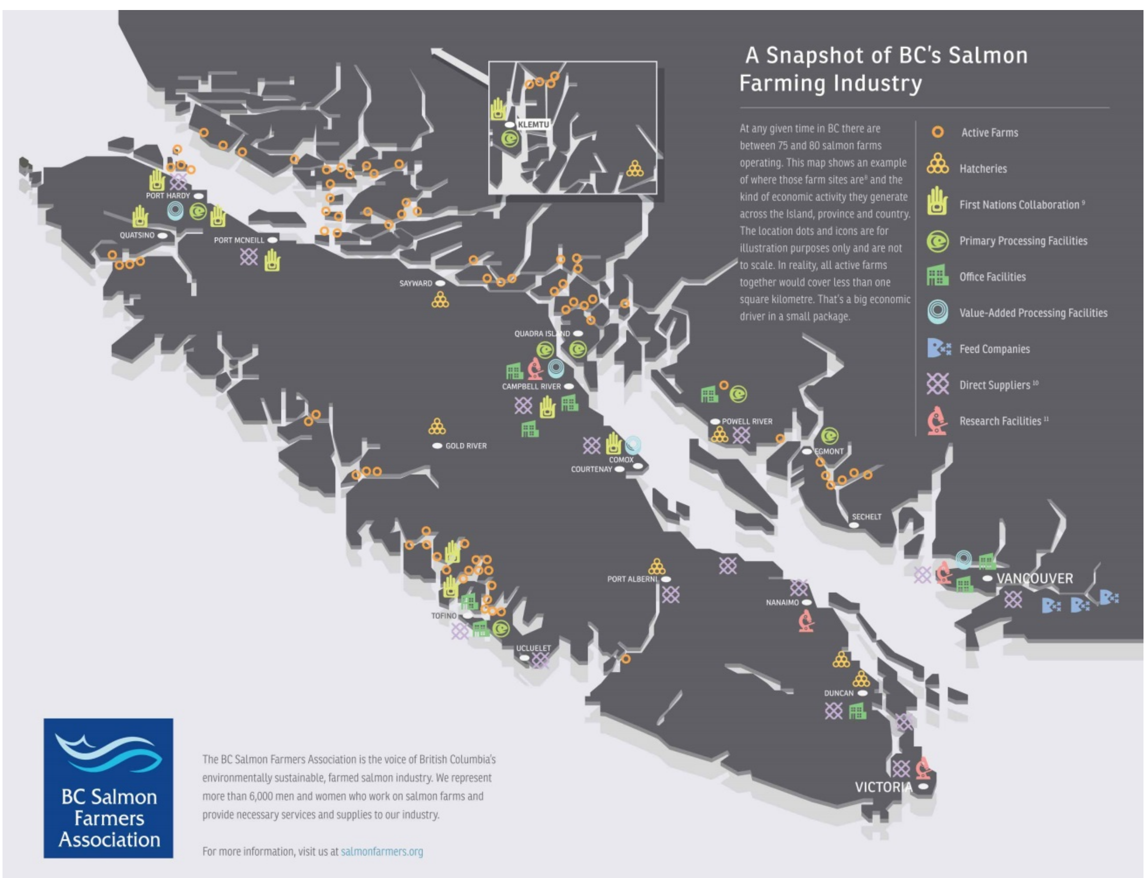

Figure 2: Map of the production region in British Columbia showing Vancouver Island, and the mainland. Map downloaded from British Salmon Farmers Association http://www.salmonfarmers.org/map-gallery

In an interview with Intrafish[5], the BCSFA described a goal of a 43% increase in production by 2020 and a further potential increase of 50% from 202 to 2025 (to 150,000 mt total).

Common and Market Names
Atlantic salmon. Packaging and marketing may imply wild capture, but Atlantic salmon originating from BC on the U.S. market will be farmed.

Product Forms
Atlantic salmon is available in all common fish presentations— whole, fillets, steaks, smoked, caviar, pate and more.

[5] Intrafish March 28 2014: BC salmon farmers target 43% increase by 2020. www.intrafish.com

Analysis

Scoring Guide

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

Criterion 1: Data Quality and Availability

Impact, unit of sustainability and principle

- *Impact: poor data quality and availability limits the ability to assess and understand the impacts of aquaculture production. It also does not enable informed choices for seafood purchasers, nor enable businesses to be held accountable for their impacts.*
- *Sustainability unit: the ability to make a robust sustainability assessment*
- *Principle: robust and up-to-date information on production practices and their impacts is available to relevant stakeholders.*

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	Yes	7.5	7.5
Effluent	Yes	7.5	7.5
Locations/habitats	Yes	10	10
Predators and wildlife	Yes	7.5	7.5
Chemical use	Yes	7.5	7.5
Feed	Yes	7.5	7.5
Escapes, animal movements	Yes	5	5
Disease	Yes	5	5
Source of stock	Yes	10	10
Other – (e.g. GHG emissions)	No	n/a	n/a
Total			**67.5**

C1 Data Final Score	**7.5**	**GREEN**

With historic and ongoing concern over net pen production systems and their environmental impacts, the considerable scrutiny and scientific study means that data availability in BC is generally good in comparison to many aquaculture industries globally. Some key areas still have limited detail and/or gaps in public data availability. The BCSFA provided information from their databases (particularly on fish health and chemical use) for this assessment. While both government and company statistics are typically aggregated and, to a greater or lesser extent, reliant on industry self-reporting, salmon farming in BC has been the subject of substantial scientific study. In addition, the detailed analysis of the three-year Cohen Commission enquiry (although focused primarily only on Fraser River sockeye salmon) provided voluminous information and analysis on several aspects of relevance to this Seafood Watch assessment. The Data Criterion score is 7.5 out of 10.

Justification of Ranking

Key public sources of information or data include:

- Site names, companies and maximum biomass available from the Department of Fish and Oceans Canada (DFO) (Note that maximum biomass is not the same as production for which site-specific data are not publically available) http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/mar-eng.htm
- Regional site maps and a snapshot of other industry component (hatcheries, processing, feed companies and so on) are available from the BC Salmon Farmers Association website. http://www.salmonfarmers.org/map-gallery
- Aquaculture in Canada 2012: A Report on Aquaculture Sustainability http://www.dfo-mpo.gc.ca/aquaculture/lib-bib/asri-irda/asri-irda-2012-eng.htm
- DFO's "Aquaculture in British Columbia page (http://www.pac.dfo-mpo.gc.ca/aquaculture/index-eng.html) includes:
    - Benthic monitoring data. This is industry self-monitored and self-reported, but audited by DFO
    - Fish health management including total aggregated therapeutant (antibiotic and sea lice pesticide) use
    - Sea lice data – monthly by site. This is industry self-monitored and self-reported, but audited by DFO
    - Authorized Marine Mammal Control Activities, current and historic, by company and site
    - Incidental catch of fish in salmon net pens
    - Salmon egg imports
    - Escape data are based on farm reports and have some gaps during the transition to DFO regulatory control. Only recent data (for 2011 and 2012) are available
    - Marine Finfish Transfer activities in BC
    - Use of lights
- Aggregated annual amounts of antibiotic and sea lice pesticides usage, up to 2008, is available from BC government website http://www.agf.gov.BC.ca/ahc/fish_health/antibiotics.htm
- Marine Finfish Transfer activities BC http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/intro-trans-eng.htm

- Fish health events are available http://www.agf.gov.BC.ca/ahc/fish_health/BCsfa_reports.htm with data up to 2010. At the time of this writing, DFO has not published these results, but is expected to begin doing so shortly
- The Canadian Food Inspection Agency (CFIA) reports confirmed (and suspected) cases of federally reportable diseases on its website. http://www.inspection.gc.ca/animals/aquatic-animals/diseases/reportable/isa/backgrounder/eng/1330100651673/1330100817464
- Government medical records from the majority of BC salmon farms (from 2001 to September 2010) are available from the Cohen Commission (most of the records are in Exhibits 1548 and 1549); No records are available post-2010 http://www.commissioncohen.ca/en/Exhibits.php
- Map of fish health zones http://www.agf.gov.BC.ca/ahc/fish_health/Sealice/Map_of_Fish_Health_Zones_August_2009.pdf
- Annual "State of the Pacific Ocean" Science Advisory Reports produced by DFO and the Canadian Scientific Advisory Secretariat contain impressive amounts of physiochemical and biological data for the Strait of Georgia, the greater Georgia Basin, the ocean west of Vancouver Island and the larger NE Pacific region. http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm
- There is a considerable body of scientific literature on many aspects of salmon farming in BC and internationally, which can be used with appropriate caution with respect to (or in comparison to) BC

Canada has established an "Aquaculture Sustainability Reporting Initiative" as part of its "National Aquaculture Strategic Action Plan Initiative" and despite some loss of data during the transition of regulation in BC from regional government to DFO, data availability is relatively good and there is significant ongoing monitoring and scientific research. It must be emphasized that public data availability is subject to Canada's Access to Information Act and Privacy Act, which may substantially restrict commercial information. In addition (or perhaps as a result of this), much of the data from sources specified below are aggregated to some extent.

The following data were made available directly to Seafood Watch by the BCSFA and their members (extending the timeline of data provided up to 2009 listed above, and not currently made publicly available by DFO):

- Total antibiotic data from 2009 to 2012 including the breakdown of different antibiotics used
- Total sea lice pesticide use (emamectin benzoate) from 2009 to 2012
- Disease data from the BC Salmon Farmers Association company databases

Detailed information on feeds, feed ingredients and feed formulations are typically considered proprietary information by feed manufacturers, and while academic research is available, due to the evolving nature of feed formulation and ingredient selection, it is not considered to dependably reflect actual commercial production practices within the time frame of publication dates. Two feed companies provided the detailed data required (to be reported anonymously) for this Seafood Watch assessment.

The BCSFA provided substantial amounts of data and expert opinion, and BC's largest salmon producing company, Marine Harvest Canada, openly provided data on all aspects of their operations. The three-year Cohen Commission[6] enquiry investigated many potential causes of the long-term decline in the Fraser River sockeye salmon populations, of which salmon farming was one. It provided a unique forum to study the effects of a multitude of stressors on Pacific salmon, and enabled public scrutiny of the multitude of stakeholders under oath. The findings of this study (published in 2012) have been used extensively in this assessment.

There remain some significant data gaps in BC, and significant controversy remains within the scientific literature on topics such as sea lice impacts. Noakes (2011) stated "*Some of the publications are highly speculative for a variety of reasons including but not limited to the absence of data from government and industry as well as assumptions used by the researchers. In some cases, the publications were deficient to the point that they were neither objective nor scientific and they generally lack credibility.*" Remaining data limitations in BC include:

- A predominance of industry self-reported data
- Aggregation or averaging of data sets
- Limited information on trickle losses of escapes, recaptures, and the fate of escapees
- Detailed public data on disease outbreaks
- A lack of publically available data on antibiotic use by treatment
- The potential for cumulative impacts of the increasing size of farm sites and areas of close-siting proximity

Data Criterion—Conclusions and Final Score

In conclusion, data availability in BC is variable according to the topic, but mainly good. Most categories are considered to give a reliable representation of the operations and/or their impacts within the current limitations of scientific understanding (scores of 7.5 or above).

The overall, final score for the Data Criterion is an average of the scores for applicable data categories and is 7.5 out of 10.

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[6] The Cohen Commission Enquiry, led by The Honourable Bruce Cohen www.cohencommission.ca/en. For further information see the Disease Criterion

Criterion 2: Effluents

Impact, unit of sustainability and principle

- *Impact: aquaculture species, production systems and management methods vary in the amount of waste produced and discharged per unit of production. The combined discharge of farms, groups of farms or industries contributes to local and regional nutrient loads.*
- *Sustainability unit: the carrying or assimilative capacity of the local and regional receiving waters beyond the farm or its allowable zone of effect*
- *Principle: aquaculture operations minimize or avoid the production and discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges beyond the immediate vicinity of the farm.*

Effluent Full Assessment

Effluent parameters	Value	Score	
F2.1a Biological waste (nitrogen) production per of fish (kg N mt^{-1})	50.336		
F2.1b Waste discharged from farm (%)	80		
F2 .1 Waste discharge score (0-10)		5	
F2.2a Content of regulations (0-5)	2		
F2.2b Enforcement of regulations (0-5)	3.75		
F2.2 Regulatory or management effectiveness score (0-10)		3	
C2 Effluent Final Score		**5.00**	**YELLOW**
Critical?	NO		

The Seafood Watch Effluent Criterion considers impacts of farm wastes beyond the immediate farm area or outside a regulatory allowable zone of effect. It calculates the total amount of waste released per ton of salmon production and combines it with an assessment of the effectiveness of the management and regulatory process with respect to potential cumulative impacts from the total tonnage produced at any one site, or of multiple sites in close proximity. The total waste discharged (using nitrogen as a proxy) is estimated to be 50.3 kg N t^{-1}. Individually, approximately 80% of BC farms are in compliance with regulatory benthic impact requirements (based on no significant impact at 30m from the edge of the net pens and no detectable impact at 125m for soft bottom depositional environments); and while individual sites are regulated in terms of maximum biomass of fish and require annual monitoring and reporting, regulatory control is lacking in robust measures relating to potential cumulative impacts of multiple farms. The relatively minor impacts beyond the immediate farm location combined with some ongoing uncertainties regarding potential cumulative impacts results in a moderate final score of 5 out of 10.

Justification of Ranking

Salmon excrete both soluble and particulate wastes primarily as a result of incomplete digestion and absorption of their feeds. Although the salmon industry has increased efficiency and made significant reductions in nutrient loss per unit of fish production (Bureau and Hua 2010), these wastes clearly represent a substantial loss of the ecologically costly and globally-sourced feed ingredients and their discharge at farm sites represents a substantial point source of nutrients. Both waste streams have the potential to impact areas beyond the immediate farm area.

The majority of a salmon farm's effluents are soluble nutrients that are dispersed in the water column; salmonids excrete 75%–90% of their ammonia and ammonium waste across gill epithelia (Gormican 1989) or in concentrated urea (Persson, 1988; Gowen et al. 1991). Nitrogen and phosphorus are also dissolved from waste feed and feces during and after descent to bottom sediments. Silvert (1994) suggested that 66%–85% of phosphorus in feed is lost in a dissolved form at salmon farms, and more recent figures from the use of similar feeds in Norway show the loss of as much as 70%, 62% and 70% of the total carbon, nitrogen and phosphorous (respectively) provided in the feeds (Wang et al. 2013). All these dissolved nutrients are available for uptake by phytoplankton or macroalgae (i.e., seaweeds) if farms are located close to shorelines or shallow areas.

Particulate wastes (feces and uneaten food) settle on the seabed in an area controlled largely by the settling speed of the particles, the water depth and the current speed, as a result, they generate a localized gradient of organic enrichment in the underlying and adjacent sediments (Black et al. 2008).

In BC, Brooks (2007) calculated that salmon farms contributed approximately 15.8 mt of dissolved inorganic nitrogen per day (in 2005) to coastal British Columbia and Puget Sound, which he considered negligible in comparison to the approximate 2,000 mt of dissolved inorganic nitrogen delivered to the coast via upwelling. Research in Norway also suggests the total amount of waste discharged from salmon farms in that region can be considered somewhat insignificant compared to the natural transport of nutrients in the coastal currents (FHL 2011). Nevertheless, despite these regional assessments, the potential for local impacts at any farm site appears significant; for example Strain (2005) concludes "*Given the right combination of the intensity of farming and the carrying capacity of the receiving environment, finfish aquaculture can produce eutrophication impacts on scales of kilometers to tens of kilometers and can change the structure and functioning of the ecosystem in significant ways on these scales.*"

It should also be noted that the production and subsequent fate of organic waste at fish farms is more complex than is often assumed (Mayor et al. 2010), while Bureau et al. (2010) report the type and magnitude of any impacts will be highly dependent on the biological, chemical and physical characteristics of the receiving ecosystem and state "*The release of wastes cannot be systematically equated to deleterious environmental changes as it is frequently assumed in much of the literature or popular press.*"

The Seafood Watch criteria assess the environmental impacts of these wastes in both the Effluent and Habitat Criteria as follows:

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

While the two criteria cover different impact locations, there is inevitably some overlap between them in terms of monitoring data and scientific studies. 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.

Particulate Wastes

Of the two waste streams (i.e., soluble and particulate), salmon farming impacts are considered to stem primarily from the latter, that is, the release of particulate matter (feces and uneaten food) into the water column (Wilding 2011). In terms of the deposition of particulates, Keeley et al. (2013) describe the major pathways of biodeposition (Figure 3). This shows that of the total particulates leaving the net pen, some will dissolve or release nutrients before reaching the seabed. Of the portion settling on the seabed in the primary area of deposition, some will be consumed directly by benthic organisms, some will accumulate and consolidate, and some will be resuspended and transported to far field locations. During that transport, further nutrients will be dissolved, diluted and assimilated and the remainder will finally settle in far field locations.

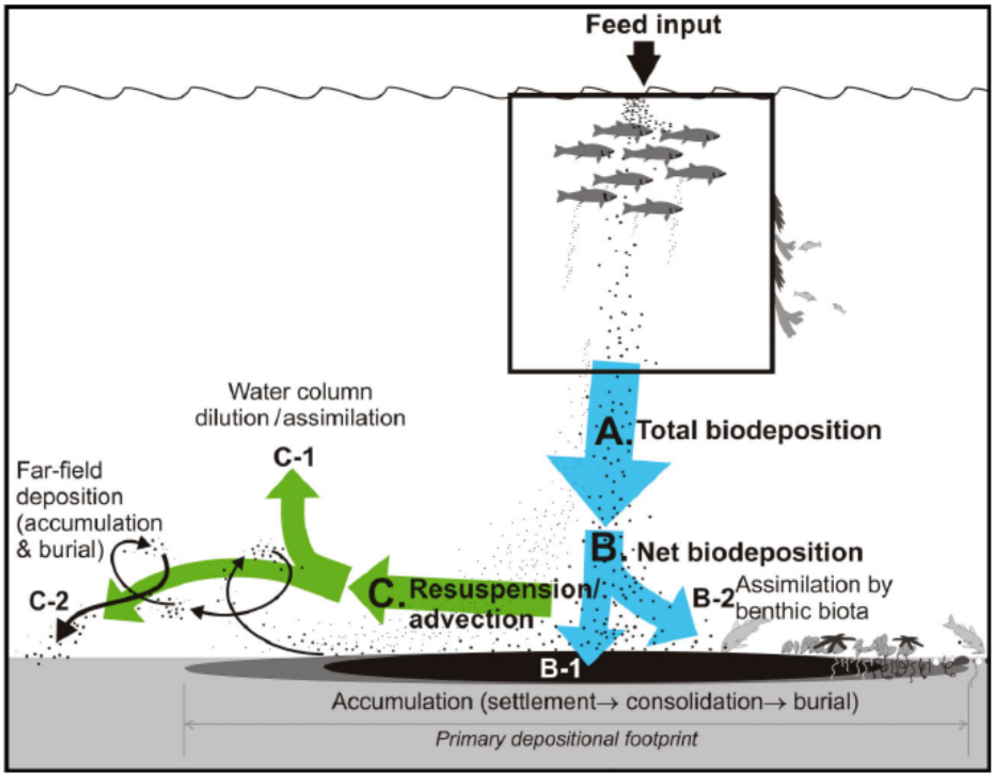


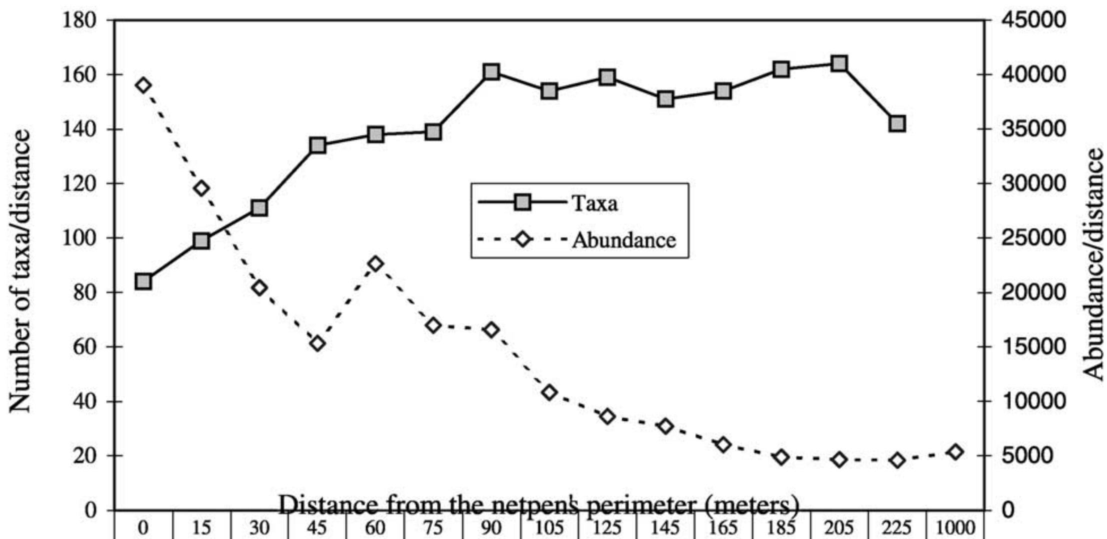
Figure 3: Summary of major pathways for salmon farm feed-derived biodeposition. A: total biodeposition = all waste particulates produced by the farm (feed and feces, ignoring dissolved organic component). B: net biodeposition includes the particulates that settle, accumulate and/or are used (assimilated)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

Lander (2013) reported daily levels of particulate organic matter (POM) in the water column are higher at salmon farm cages than reference locations, and showed an increase in POM of 2 to 4 times over ambient levels adjacent to cages, however, spatially they also reported a drop to ambient levels after distances of only 10 m from the net pens. In this context, there are unlikely to be significant impacts beyond the immediate farm area, however, depositional studies demonstrate a larger area of impact in practice, which is controlled primarily by the settling speed of the particles, the water depth and the current speed (Black et al. 2008).

The primary depositional area is typically localized and limited to the close proximity of the farm. Studies examining the spatial extent of fish farming impacts generally report that their effects on the benthic environment rapidly dissipate and decrease exponentially with increasing distance from their edge (Keeley et al. 2013; Chang et al. 2011; Mayor and Solan 2011; Mayor et al. 2010; Brooks and Mahnken 2003).

Mayor et al. (2010) suggest, that the immediate benthic impact of the fish farms examined extended to somewhere between 25 m and 50 m from the cage edge, while Mayor and Solan (2011) reported that the effects of the fish farms examined in Scotland were only statistically discernible at less than 50 m from the cage edge.

Figure 4 from Brooks and Mahnken (2003) shows that while the number of taxa present is reduced up to approximately 90 m from the net pens (i.e., the number of taxa increases with increasing distance away from the net pens), the abundance of the present taxa is frequently (but not always) higher closer to the farm, due to the nutrient enrichment, and abundance therefore decreases with increasing distance from the net pens.



	0	15	30	45	60	75	90	105	125	145	165	185	205	225	1000
Taxa	84	99	111	134	138	139	161	154	159	151	154	162	164	142	
Abundance	39035	29590	20430	15340	22645	16978	16568	10828	8613	7720	6041	4893	4665	4588	5363

Figure 4: Cumulative number of taxa and total abundance of infauna observed at focused study salmon farms in 2000 as a function of distance (m) from the perimeter of the net pen. Image copied from Brooks and Mahnken (2003).

Considering these far-field effects, Brooks and Mahnken (2003) reported detectable impacts at peak production at distances of between 90 m and 205 m from the net pen perimeters and subtle changes in macrobenthic communities have been documented to distances of 205–225 m downcurrent from salmon farms during peak production. It should be noted that impacts at these distances occur at peak production and are at the limit of detection.

As noted above, site characteristics (i.e., primarily the depth and current speeds) are important in defining depositional or erosional sites and, therefore, in defining the site-specific impacts. Keeley (2013) reports that at non-dispersive (i.e., depositional) sites, total deposition from the farm is almost entirely processed by settlement, assimilation by benthic biota, consolidation and ultimately burial; there is little or no influence from resuspension. In contrast, at dispersive (i.e., erosional) sites, settlement in the primary footprint (see Figure 4 above) is minimal and the impact is characterized by water column dilution and assimilation by biota with the additional influence of far field deposition and subsequent assimilation and burial.

Depositional models are used in salmon farming jurisdictions to determine, along with physical sampling, the maximum biomass permitted at any one site. Depositional modelling (DEPOMOD)[7] (Cromey et al. 2002a) is probably the most established and widely used model for the purposes of predicting salmon farm effects, largely because it has been proven in a wide range of environments and is considered to be robust and credible (SEPA 2005, ASC 2012, both quoted in Keeley et al. 2013). In the ongoing refinement of DEPOMOD, Keeley et al. (2013) studied flow characteristics and sediment resuspension at low- and high-flow sites (in New Zealand). Although not irrefutably relevant to sites in BC, predicted and observed enrichment at high-flow (erosional) and low-flow (depositional) show dispersal patterns over significant distances, but enrichment levels at the greater distances are very low and have no detectable impacts. Discernable impacts are limited to a smaller area close to the farms, and closer examination of the results shows agreement with the general distances described in the literature above.

According to Brooks and Mahnken (2003), 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. However net pens located in erosional environments with fast currents and sediments dominated by rock, cobble, gravel, and shell hash the nutrient fertilization can dramatically increase macrobenthic production.

Interactions of metals such as copper (used in antifouling paints and net treatments) and zinc (used as a mineral supplement in feeds) on organisms beyond the farm site have been noted as having potential impacts on net pen salmon farming. Burridge et al. (2011) note these elements are found in close association with a buildup of organic material and they likely play a role in cumulative effects associated with aquaculture activity. Metals may be present in high concentrations on sediments associated with aquaculture activity, but because of the chemical nature of the sediments, the metals may not be available to non-target organisms. According to Burridge et al. (2011), several papers have shown that effects reported are not necessarily consequences of elevated metal concentrations (see further information in the Chemical Use Criterion).

Russell et al. (2011) showed that sediment samples with concentrations of copper that might cause adverse effects in the environment were all from within 25 m of the net pens and concluded that any impact on the environment from organic pollutants or trace metals is of a local nature. Roberts et al. (2010) addressed earlier concerns regarding the effects of metals and other trace elements on local shellfish beyond the immediate farm site and confirmed that salmon farms are a source of trace elements in the marine environment. However, while these authors concluded that ongoing monitoring would be advisable, salmon farms did not appear to be elevating concentrations in nearby clam tissue and sediments. Considering these studies and the focus of this Effluent Criterion on effects beyond the immediate farm area or an AZE,

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[7] DEPOMOD – DEPOsitional MODel. A particle tracking model used for predicting the sinking and resuspension flux of particulate waste material (and special components such as medicines) from fish farms and the benthic community impact of that flux.(Cromey et al. 2002).

the impacts of metals and other chemicals will be addressed in the Habitat (C3) and Chemical Use (C4) Criteria.

Soluble Wastes

Brooks and Mahnken (2003) describe possible changes in the water column associated with the intensive culture of fish, such as:

- Eutrophication associated with nitrogen released across gill epithelia and in urine and feces
- the release of hydrogen sulfide and ammonia from underlying sediments
- Decreases in dissolved oxygen (DO) associated with salmon respiration and/or the oxidation of sedimented waste

As noted above, the release of ammonia and ammonium across the gills and in urea is the largest source of nitrogenous waste from salmon farms entering the water column. Several studies have reported the ability to detect farm-origin nitrogen at considerable distances from salmon or other fish farms (either directly measured in the water column or after uptake in seaweeds). For example the chemical signature of salmon farm nitrogen was detected at 200 m in seawater (Sanderson et al. 2008), and from 1 km (Sanderson, 2006) up to 3-5 km (Karakassis, 2005) in seaweeds. Olsen et al. (2012) show soluble wastes from salmon farms are diluted and dispersed relatively rapidly in the water column, but are detectable hundreds of meters from the farms for extended periods of time. However, these results are at the limit of detection and indications of measureable ecological effects beyond the farm (for example enhanced growth of seaweeds) are limited to much shorter distances on scales of tens of meters compared to reference sites at 150 m (e.g., Sanderson et al. 2012, Troell et al. 1997 and FHL 2011).

Agreeing with the quote from Mayor et al. (2010) (i.e., "it should also be noted that the production and subsequent fate of organic waste at fish farms is more complex than is often assumed") a modeling study described as "*a first step toward understanding the complex plume dispersion dynamics in the vicinity of aquaculture farms in nearshore coastal waters,*" (Venayagamoorthy et al. 2011) concluded that under oscillatory (i.e., tidal) flow conditions, plumes of waste with relatively high concentration occur at considerable distances from the source. These authors emphasized "*Based on our results, dilution as a solution to pollution" should not be prescribed for marine aquaculture, particularly in nearshore systems."* Although the levels described were "relatively high," in absolute terms they were typically an order of magnitude lower than at the immediate farm site, and therefore (with respect to the studies mentioned above) unlikely to trigger an significant ecological response.

More specifically, despite the large total loss of nutrients from salmon farms, Brooks and Mahnken (2003) reported a statistically significant increase in dissolved inorganic nitrogen measured at only six meters downcurrent from the net pens was recorded at only one of eight BC farms studied. In no case was dissolved inorganic nitrogen significantly increased at 30m downcurrent when compared with the upcurrent reference. Authors Brooks and Mahnken conclude the concentration of dissolved inorganic nitrogen added to marine water at salmon farms in BC is low on the perimeter of net pens, and essentially undetectable at 30 m.

Although Navarro et al. (2008) suggest an increase in the heterotrophic bacterial community (rather than phytoplankton) is the primary ecological response to salmon farm effluent, changes to planktonic communities or associations with harmful algal blooms have generally been the focus of the limited number of studies. In the most recent comprehensive review conducted for the WWF Salmon Aquaculture Dialogue, Buschmann et al. (2007) highlighted the lack of papers, stating "*The limited efforts made is most likely a result of the problems to detect clear environmental signals of wastes from salmon farms in the water masses and the fact that there is no general applicable scientific concept established for assessing and judging impacts of nutrients released from fish farms in water column."* A recent example highlights this challenge; Marie George and Parrish (2013) showed significant declines in dissolved organic carbon over distances of 1 km from farm sites and conversely reported lower levels of the essential fatty acid DHA in shellfish near farms; however, the different (i.e. non-significant) declines in carbon at 10 m depth, combined with some questionable regressions[8] and a lack of detection of any relationship with distance from the farm for nitrogen would urge caution in the interpretation of these results.

Overall, although Buschmann et al. (2007) noted that studies to date had generally failed to detect an ecological response from the plankton around salmon farms because of the lack of indicators on how to trace or measure any potential changes, these authors also concluded that only stagnant sites will exhibit increased phytoplankton biomass locally, and Sara (2007) also stated "*impacts on pelagic ecosystems from nutrient releases from salmon aquaculture as well as for other cultured species have generally revealed a lack of ecological response by the plankton community."* The Norwegian Institute for Marine Research (IMR) calculated a maximum 4.8% increase in phytoplankton growth in the most heavily impacted area of Norway and concluded that this remains within the threshold for very good water quality (Taranger et al. 2011). IMR considers the risk of regional eutrophication in the pelagic zone of Norway to be low. The review by Brooks and Mahnken (2003) supported a thesis that, with the exception of a few shallow poorly flushed embayments, the potential for net pen enhancement of phytoplankton populations is remote or non-existent.

A recent study of the regional impacts of finfish farming in the Hardangerfjord in Norway (Husa et al. 2014) provides another useful example; although one of the world's largest fjords, it contains salmon farming production levels (70-80,000 mt) approximately equivalent to the entire BC industry. It is relevant to note that at this (very large) scale of production in Norway:

- There were no indications of elevated levels of nutrients (nitrogen or chlorophyll-a) in the area of the fjord, which produces the higher biomass of salmon.
- The chlorophyll-a values measured in this study give no indication of any ongoing eutrophication processes.

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[8] For example, at 1 m depth, there is clearly no significant decline in dissolved organic carbon indicated out to 800 m from the farm (i.e., the farm is not having a measureable effect on dissolved organic carbon), and the sample at 1,200 m is potentially anomalous.

- Overall, the benthic and pelagic communities beyond the immediate proximity of fish farms in Hardangerfjord seemed to be little affected by the effluent nutrients and deposition of organic matter from the salmon farming industry.
- However, although considered unlikely, these authors "cannot rule out that local impacts on macroalgal communities might occur in the vicinity of farms (up to 1 km away)."

Effluent management and regulatory effectiveness in BC

The BC Aquaculture Regulatory Program (BCARP)[9] is "a program within Fisheries and Oceans Canada (DFO) that manages, administers and regulates aquaculture in BC and governs the activities of the aquaculture industry on the West Coast, including finfish, shellfish and freshwater/land-based operations."

Regulatory monitoring of effluent impacts in BC is restricted to benthic compliance criteria from samples taken at 0 m, 30 m and 125 m from the edge of the net pen array. In common with other major salmon producing regions, there is no monitoring or regulatory limits for dissolved nutrients in the water column.

The British Columbia Ministry of Environment (MoE) monitored the sediment chemistry and biology in the vicinity of finfish farms from the mid-1990s (Obee 2009), but since the transfer of authority to DFO in 2010, industry self-conducted and self-reported monitoring data (audited by DFO) is used. Benthic monitoring requirements vary between the two benthic habitat types; for soft bottom (depositional) locations, grab samples are assessed as follows:

At zero meters from the cage edge:
- free sulfides
- redox potential
- metals package (including copper, zinc and lithium)
- total volatile solids (TVS)

At 30 m from the cage edge:
- free sulfides
- redox potential
- sediment grain size (SGS) and/or
- moisture content
- TVS

At 125 m from the cage edge:
- free sulfides
- redox potential

[9] http://www.pac.dfo-mpo.gc.ca/aquaculture/about-ausujet-eng.html

- TVS.

For hard bottom (erosional) locations, transects extending beyond the farm are sampled visually by remote operated vehicles assessing the following parameters:

- habitat type
- percent cover of *Beggiatoa*[10] sp. and/or opportunistic polychaete complexes (OPC)
- location and type of farm litter and debris
- percent cover of fish waste and feces
- presence and relative abundance of sensitive, opportunistic and resource/conservation taxa.

The full regulatory requirements and conditions of license are available from the DFO website[11].

Monitoring results are available quarterly from DFO[12], and 45 sites sampled in 2012 show 9 sites (20%) where sulfide levels at 30 m would be considered sufficient to decrease species diversity, or where benthic habitats were not considered normal at 125 m. Sampling during the first half of 2013 available at the time of this writing show similar results. Actions required at these sites are additional surveys to demonstrate recovery and compliance before restocking the site is permitted. A review of production strategy in one site was required to identify changes necessary for the site to return to compliant conditions.

There is minimal mention of soluble wastes or pelagic impacts in terms of regulation or monitoring in DFO's 2012 aquaculture sustainability report (DFO 2012a), and soluble wastes dispersed in the water column are not measured in BC as part of DFO's conditions of license. As a result of the British Columbia Salmon Aquaculture Review (BCSAR 1998), the BC Ministry of Environment Lands and Parks (MELP) developed aquaculture standards based on an expanded Washington State National Pollution Discharge Elimination System (NPDES) system (Brooks 2001). However, two years prior to this, in 1996, Washington State eliminated all requirements for water column monitoring in compliance with NPDES permits issued to salmon farms (Brooks and Mahnken 2003), based on the literature and 10 years of monitoring dissolved nutrients at salmon farms (over which period there were no significant increases in nitrogen observed at any of the 30 m downstream sampling stations, according to Brooks (2007)).

As described in previous sections, a potential for regional impacts exists for large farm sites, and a potential for multisite or regional cumulative impacts exists in cases where sites are located close together or in poorly flushed areas. Siting permit applications in BC enquire if the nearest site is more than 3 km distant, but this is not a regulatory requirement. Sites in BC are typically a minimum of 3 km apart but there are a number of exceptions. Some sites owned by the same company may be located at a distance of approximately 1 km (but are not necessarily

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[10] "*Beggiatoa*" is a genus of bacteria that forms white mats on the sediment surface in areas of organic enrichment.

[11] http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/docs/licence-cond-permis-mar-eng.pdf

[12] DFO Benthic impacts from aquaculture sites http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/benth-eng.htm

in production at the same time), and the Okisollo Channel has multiple companies operating sites located closer than 3 km apart but with a management agreement in place[13]. Considering the distances mentioned above with respect to the limits of detection of farm-origin nitrogen, cumulative impacts are possible but, in general, soluble wastes appear unlikely to have significant cumulative ecological impacts in BC.

While the industry in BC can be considered relatively small compared to other major salmon farming regions (e.g., Norway, Chile and Scotland), the industry has active applications to expand[14], and there is some concern with respect to the transparency of this process[15].

Assessment and Final Score

The Seafood Watch assessment calculates the amount of nitrogen waste produced per ton of fish, and then assesses the effectiveness of the management and regulatory system to prevent cumulative impacts from the total tonnage produced at any one site, and to prevent cumulative impacts from multiple sites.

Using a protein content of 39%, a feed conversion ratio (FCR) of 1.24, a protein: nitrogen content conversion of 0.16, and a whole body protein content for harvested farmed salmon of 16.9%, the total nitrogen waste produced per ton or production is 50.3 kg (see Feed Criterion for references).

The Seafood Watch criteria considers 80% of this waste (i.e., 40.3 kg N) to have the potential to impact beyond the immediate farm area (in both soluble and particulate forms). This is considered a moderate discharge score of 5 out of 10.

While the major apparent impacts of salmon farm effluent are primarily benthic, the larger proportion of the nitrogen discharges are in the form of soluble wastes, which have the potential for impacts beyond the immediate farm area. Although the studies referenced above indicate that this is unlikely, the lack of soluble effluent monitoring in BC's regulations, and uncertainties regarding the industry's expansion means that the regulatory content is scored 2 out of 5, while the enforcement of benthic monitoring is good and scored 3.75 out of 5. Combining these two scores gives a management effectiveness score of 3 out of 10.

Combining the waste discharge score with the management effectiveness score gives a moderate final effluent score of 5 out 10, reflecting uncertainties with respect to potential cumulative impacts in areas with large sites sharing the same water body.

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[13] http://www.salmonfarmers.org/salmon-farmers-show-commitment-best-practices-with-important-new-agreement

[14] http://arfd.gov.bc.ca/ApplicationPosting/index.jsp?PrimaryStatus=any&keyword=aquaculture+%2F+fin+fish&Submit=Submit

[15] http://www.livingoceans.org/media/releases/dfo-cloaks-salmon-farm-expansion-secrecy-bar-public-input

Criterion 3: Habitat

Impact, unit of sustainability and principle

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

Habitat parameters	Value	Score	
F3.1 Habitat conversion and function		7.00	
F3.2a Content of habitat regulations	3.25		
F3.2b Enforcement of habitat regulations	3.25		
F3.2 Regulatory or management effectiveness score		4.22	
C3 Habitat Final Score		**6.08**	**YELLOW**
Critical?	NO		

Floating net pens have a minimal direct physical habitat impact, but the immediate benthic habitat impacts from settling particulate wastes within their allowable zones of effect may be profound. Farm sites occupy habitats critical to juvenile wild salmon, but the total area impacted is small compared to the total coastal resource in BC and the potential for cumulative impacts from adjacent sites or from the industry's total impact area also appears low. Despite the significant benthic habitat impacts below any one salmon farm site, they are relatively, rapidly reversible by fallowing or by breaks in production, and the combination of the lack of irreversibility, relatively, rapidly reversibility and moderately good regulatory effectiveness results in a "moderate" habitat score of 6 out of 10.

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/or within an AZE can be profound.

As discussed in the Effluent Criterion, there is inevitably some overlap in the information used between the Effluent and Habitat Criteria because the source of the impact in both cases 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.

- The 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 uneaten food and feces, and strongly influences 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 (see Black et al. 2008, for a review of these impacts). 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 (Brooks and Mahnken 2003).

According to DFO (2012a), BC's 174 marine finfish site tenures, of which only 70-80 are actively producing salmon at any one time, covered 4,575 hectares of lease area in 2010/2011. The BC Salmon Farmers Association calculates the total net pen footprint of salmon farming in BC to be less than one square kilometer and, without performing a specific calculation, this area can be considered to be relatively small compared to the total area of BC's inshore waters. It must be emphasized that the farms occupy areas highlighted as being particularly important habitats for the confined migration routes of wild salmon.

Changes in sediment chemistry result in changes in macrobenthic communities; many taxa can be excluded as sediment concentrations of sulfide increase, and the number of taxa is consistently reduced on the perimeter of operating salmon farms (and therefore also directly under the cages). However, as noted in the Effluent Criterion, the effects vary according to the depositional or erosional nature of the site. 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, while 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).

As discussed in the Effluent Criterion above, at many salmon aquaculture sites metal concentrations are elevated, but this 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. In BC, regulatory monitoring of copper and zinc levels is required at the edge of the net pen array (i.e., directly under the edge of the net pens at 0 m) and elevated concentrations require subsequent recovery (fallow). Noting the findings of Burridge et al. (2011) of values in excess of regulatory guidelines, the regulations are intended to ensure that metals do not accumulate over multiple production cycles.

As described in the Effluent Criterion above, industry self-conducted and self-reported benthic monitoring data (audited by DFO) show a low number (approximately 20%) of monitoring stations where the samples indicated pollution sufficient to decrease species diversity at 30 m from the net pen's edges. These benthic monitoring assessments appear to accept that the area within 30 m, and particularly the area directly below the net pens, may be severely impacted (as indicated by Black et al. 2008) as an AZE. The time taken for recovery of this area is highly variable, but is frequently a substantial 2-3 years (Black et al. 2008). According to Brooks and Mahnken (2003), chemical and biological remediation in BC has been shown to occur naturally during fallow periods at every salmon farm studied. Chemical remediation has occurred as soon as harvests were complete at some sites, while it has taken several years at a few sites where waste was allowed to accumulate under the net pens.

While full recovery may take much longer in some extreme cases (for example the atypical Center Cove site assessed by (Obee 2009), a 2-3 year period is considered to be relatively short, indicating the impacts are not irreversible, relatively, rapidly reversible and could be recovered by fallowing and/or removing the farm.

With respect to the provision of ecosystem services assessed in the Seafood Watch criteria, while there are indications of potentially longer term concerns with (for example) accumulation of metals, or sea lice pesticides (i.e., emamectin benzoate, DFO 2012b), Macleod et al. (2008) reported that the main ecological functions in affected benthic habitats were reestablished after 12 months, although it is noted that this study was of a relatively small Australian salmon farm and, therefore, may not be directly applicable to BC farm sites.

Overall, although localized benthic impacts under the net pens may be substantial, due to the relatively rapid reversibility (i.e., a lack of irreversible impacts) and localized nature (i.e., largely within an AZE) there is considered to be only a moderate habitat impact on the provision of ecosystem services at any one farm site and, thus, the score is 7 (out of 10).

Factor 3.2. Habitat and farm siting management effectiveness (appropriate to the scale of the industry)

As the regulator of the aquaculture industry in BC, 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 Finfish Aquaculture Waste Control Regulations. DFO states[16] "*Through careful assessment of siting proposals for new salmon farms, DFO manages benthic impact away from sensitive or critical species and habitats. Siting criteria encourage the license holder to ensure the majority of impact falls in areas deeper than 30 meters, in order to protect the intertidal and photic zones. The goal is to avoid impacts to eelgrass beds, kelp beds, shellfish beds, glass sponge reefs, juvenile rockfish nurseries and other sensitive habitats.*" Details of DFO's siting strategy and monitoring protocols for both soft and hard bottom habitat can be found on their website (see footnote). The full regulatory requirements and conditions of license are available from the DFO website[17].

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[16] DFO Benthic impacts from aquaculture sites http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/benth-eng.htm

[17] http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/docs/licence-cond-permis-mar-eng.pdf

While it is clear that sites in BC are located in habitats important for wild salmon, it is not considered likely that habitat impacts at the sites themselves (i.e., nutrient enrichment of the seabed and immediate water column) would affect these species. According to Noakes (2011) "*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)*."

Environmental impact assessments of new aquaculture sites under the Canadian Environmental Assessment Act (CEAA, 1992) are now uncertain as the transfer of regulatory control to DFO resulted in the classification of aquaculture as a "fishery" and, therefore, it does not need an environmental assessment. Where environmental assessments have been made, the reports have not been available to the public.

In terms of predicting direct benthic habitat impacts at the site level (for new sites, or modifications to existing licenses), DFO utilizes the widely used DEPOMOD model accompanied by physical sampling during every production cycle. DFO does not currently assess cumulative impacts of multiple farms, but is looking at the addition of area management parameters to farms licenses to address and mitigate cumulative impacts (MHC (define), personal communication 2012).

Internal DFO emails submitted during the Cohen Commission enquiry[18] provide anecdotal evidence that compliance with the Finfish Aquaculture Waste Control Regulations had fallen in the "*past couple of years*" (in an email dated September 12, 2010) because the DEPOMOD model was not identifying the areas of highest waste concentrations; the email stated "*problems were found on about 25% of farms*." While anecdotal, it indicates the reliance on a relatively simple model, which in this case was attributed to a prediction, based on aged current flow information and (from the same email) "*do not necessarily reflect[19] the present footprint reality.*" In practice, benthic monitoring results from 2012 show approximately 20% of sites with noncompliant benthic samples (i.e., 80% are compliant), but these trigger requirements to fallow the site and require further monitoring to demonstrate a return to compliance before production can begin again. The intent is to avoid the accumulation of wastes over multiple production cycles. Further details are presented in the Effluent Criterion (C2).

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, but there are a number of exceptions. The range of benthic impacts described above indicate that direct cumulative (i.e., overlap) impacts between sites is unlikely, but Husa et al. (2014) noted the cumulative effect of numerous impacted areas of an industry's multiple farms must be taken into consideration when further evaluating the

[18] Cohen Commission document reference \\Nats01 \NSD\CDCI NCR lnquiry\Second Review\Sharon Ford\Aquaculture Regulation & Policy\Email\cohen_ sharon_ford - 2011 0613.pst\cohen_sharon_ford\lnbox \Cohen_ Commision_Found\

[19] The original email states "reflext"

total impact from fish farming on ecosystem functioning. However, it is important to note that this study (Husa et al. 2014) was based on one large fjord in Norway, the Hardangerfjord, which contains production of 70-80,000 tons, a volume approximately equivalent to the entire BC industry (80—85,000 mt).

There are no specific regulations relating to cumulative impacts of multiple sites and the industry has active applications to expand, however, the small total area of impact of salmon farm sites in BC (specifically, or in comparison to the total inshore area) indicate the potential for cumulative direct habitat impacts from the industry as a whole are currently limited. Based on the Seafood Watch criteria, BC scores 3.25 out of 5 for regulatory effectiveness and 3.25 for enforcement, resulting in a final management score of 4.22 out of 10.

Habitat Criterion—Conclusions and Final Score

The final score for the Habitat Criterion is a combination of the habitat conversion score (Factor 3.1) and the effectiveness of the regulatory system in managing potential cumulative impacts (Factor 3.2). The combination of the lack of irreversibility, relative rapidly reversibility and moderately good regulatory effectiveness results in a “moderate” habitat score of 6 out of 10 (calculated value is 6.08).

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

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

Chemical Use parameters	Score	
C4 Chemical Use Score	**2.00**	
C4 Chemical Use Final Score	**2.00**	**RED**
Critical?	NO	

Pesticide use in BC is low (compared to other salmon farming regions) with 10-20kg active ingredients used per year, and BC is unusual among global salmon farming regions in maintaining the effectiveness of emamectin benzoate as a sole treatment. Antibiotic use in BC has decreased substantially over the last ten years, but the total amount continues to be substantial (3.6 mt in 2012). There are no regulatory limits on total antibiotic use should a disease outbreak occur. Evidence of direct environmental impacts of these chemicals is limited, but environmental monitoring and research is also limited. Over 80% of the antibiotics (by volume) used in BC are listed by the World Health Organization as highly important to human health. Antibiotic resistance continues to be a severe and escalating global concern. Antibiotic use always selects for resistance, and multiple pathways exist for the genetic transfer of resistance to other pathogens and from animals to humans. Therefore, the use of substantial quantities of these antibiotics in open net pen systems that provides no barrier to infection from environmental pathogens and that subsequently require treatment with antibiotics highly important to human health remains a high concern. The score for the Chemical Use Criterion is 2 out of 10.

Justification of Ranking

<u>Antibiotics</u>

According to the Lancet Infectious Diseases Commission (Laxminarayan et al. 2013), within just a few years we might be faced with dire setbacks, medically, socially, and economically as a result of antibiotic resistance unless real and unprecedented globally coordinated actions are immediately taken. The same authors note that while many drivers of antibiotic consumption are based in human medicine, antibiotic use in veterinary medicine and for growth promotion and disease prevention in agriculture, aquaculture, and horticulture is also a major contributing factor. Unnecessary antibiotic use in all sectors needs to be removed and the spread to the environment minimized (Laxminarayan et al. 2013). Therefore, the use of antibiotics in open salmon farms is a source of concern.

A pause in public availability occurred after the transfer of regulatory control to DFO in 2010, but aggregated total antibiotic use data in BC is now (as of late 2013) available on the DFO website[20] in units of grams in active ingredient per ton of production. Total use must therefore be calculated based on total annual farmed salmon production (see Table 1 below). For this assessment, the BCSFA provided a breakdown of total antibiotic use by treatment type for the four years from 2009 to 2012 inclusive. In addition, Marine Harvest also publishes their total antibiotic use by region in their annual sustainability reports; data are available from 2008 to 2012[21], and a recent paper by Morrison and Saksida (2013) provides further detailed information on the antibiotic use of Marine Harvest Canada.

Four antibiotic products containing six active compounds are used in BC (BC Ministry of Agriculture and Lands (BCMAL) 2009): florfenicol, oxytetracycline, Romet-30 (a 5:1 combination of sulphadimethoxine and ormetoprim), and Tribrissen (Sulphadiazine and trimethoprim; 5:1). Also, a small amount of erythromycin is used on broodstock fish before spawning (Marine Harvest Canada, personal communication 2012). While their use is overseen by veterinarians, there is no regulatory limit in place in BC to limit the total use should a disease outbreak occur.

Table 1 below shows antibiotic data for 2009 to 2012 for each chemical provided by the BCSFA. The totals have been used with the following annual production values to calculate use-per-ton of production: 2009 = 69,000 mt; 2010 = 84,098 mt; 2011 = 85,202mt; 2012 = 83,490 mt.

Table 1: Antibiotic use in BC from 2009 to 2012 (data provided by British Columbia Salmon farmers Association 2013).

Total antibiotic usage (kg active ingredient) on all farms				
	2009	**2010**	**2011**	**2012**
Oxytetracycline	1884	4012.20	1080.20	2920.28
Sulfadiazine	636.43	394.18	395.83	48.34
Trimethoprim	130.11	80.40	79.70	9.76
Florfenicol	76.72	540.47	616.14	672.12
Sulfadimethoxine	0	18.05	50	3.13
Ormetoprim	0	3.70	10	0.63
TOTAL	**2727.26**	**5049**	**2231.87**	**3654.26**

[20] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/health-sante-eng.html
[21] Marine Harvest sustainability reports are available on their website: http://marineharvest.com/en/CorporateResponsibility/Sustainability-Reports/

The complete data series from 1995 to 2012, including both the BCMAL and BCSFA data, is shown graphically in Figure 5 and 6 below[22]. In discussing the most recent antibiotic use (i.e., 2009 to 2012), this Seafood Watch assessment has used the more detailed data provided directly from the BCSFA (i.e., the same data that will eventually be recalculated and published by DFO). Figure 5 shows the antibiotic use-per-ton of production has declined substantially despite a significant increase in production over the same period.

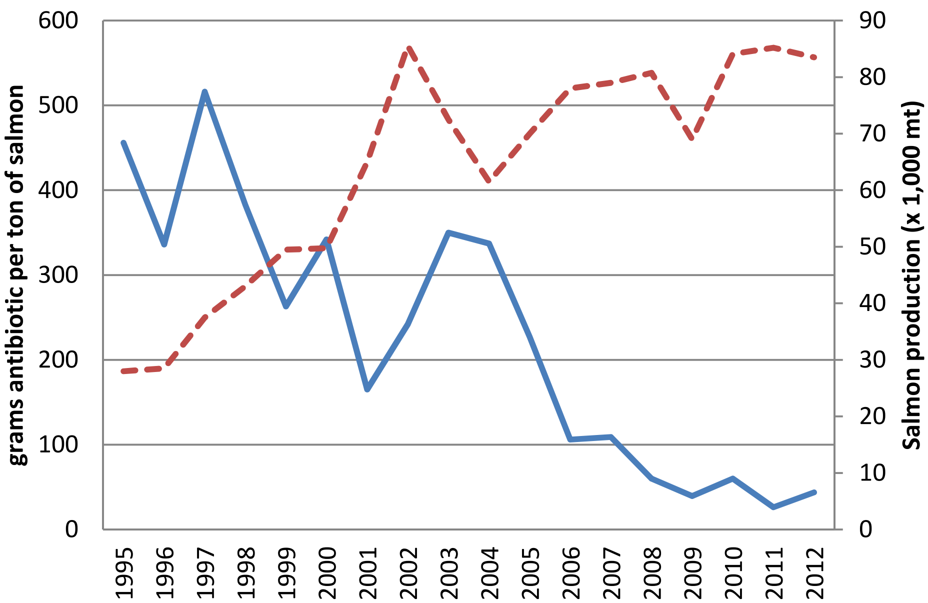

Figure 5: Antibiotic use-per-ton of production (blue solid line) and total farmed salmon production (dashed red line) in BC from 1995 to 2012. Data from 2005 to 2008 from BCMAL (2009). Data from 2009 to 2012 from BCSFA (BCSFA, personal communication, 2013).

Total antibiotic use over the same period, presented in Figure 6, shows an overall decline, but includes a spike in total use in 2003 and 2004. This increase was due to the use of oxytetracycline to treat outbreaks of bacterial kidney disease in farmed Chinook salmon, not Atlantic salmon. For example, between 2003 and 2006, oxytetracycline accounted for over 90% of Marine Harvest's total antibiotic use and was used to treat BKD in Chinook salmon (Morrison and Saksida, 2013). In 2006, there were a total of only five oxytetracycline prescriptions written for BKD, two for Chinook salmon and three for Atlantic salmon; and according to Morrison and Saksida (2013), the largest drop in antibiotic use followed the switch from Chinook to Atlantic salmon.

[22] Note there are slight variations in the antibiotic use data calculated per ton of production between the DFO data (not shown) and the BCSFA data due to differences in the total weight of production calculated from whole or partially processed fish (e.g. head-on-gutted and subsequent conversion factors to whole weight)

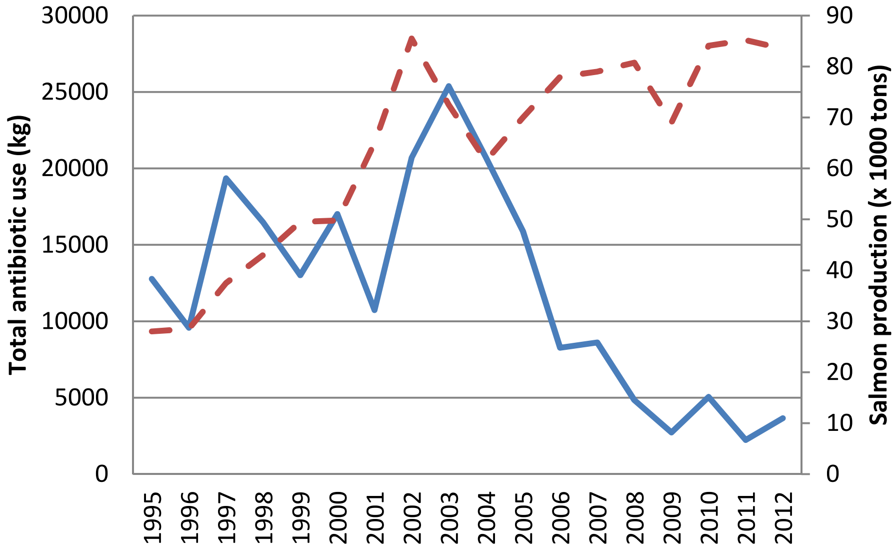

Figure 6: Total calculated antibiotic use in kg from 1995 to 2012. Data sources as Figure 5. Note the peak between 2003 and 2004 is largely due to treatments for Pacific salmon, not Atlantic salmon.

Of the 3,656 kg of antibiotics used in 2012, the majority (2,920 kg) was of oxytetracycline. The dose rate of this antibiotic is 100mg/kg fish/day for 10-14 days, and therefore treating a farm site with (for example) 500 mt of salmon biomass would require 600kg of oxytetracycline (using a 12-day treatment). The total used in BC in 2012 would therefore treat less than five sites per year. If the biomass treated was 1,000 mt, then it would represent only 2.4 sites per year (note as above, that the higher total use in 2006 represented only five treatments of oxytetracycline). These calculations are consistent with Marine Harvest Canada, BC's largest company, which, on average, treats less than one of their 35 sites with oxytetracycline per year (Paula Galloway, Marine Harvest Canada, personal communication, 2012). The higher potency and therefore smaller dosage rates of the remaining antibiotics represent a larger number of treatments across more sites in BC.

The 2012 total antibiotic use in BC is more than double the amount used in Norway despite the fact that the overall salmon production in Norway is several times higher than in BC (1,591kg in Norway in 2012, Norm/NormVet (2012)), but is dramatically lower than Chile, which used 209.5 mt (i.e., 209,500kg) to produce approximately 195,000 mt of farmed salmon in 2012, and an estimated 343.6 mt in 2013 (Sernapesca 2013, 2014). However, it should be noted that the type of antibiotics used in Norway are different from those used in BC and the dose required for the dominant treatment in Norway (oxolinic acid[23]) is less than one tenth of that required for oxytetracycline, which is the dominant antibiotic in BC (and Chile) (Sonja Saksida, Centre for Aquatic Health Sciences, personal communication, 2013). A direct comparison between regions must therefore be made with caution.

[23] Oxytetracycline – 100mg/kg fish weight/day. Treatment duration 10-14 days
Florfenicol – 10mg/kg fish weight/day. Treatment duration 10 days
Oxolinic acid – 12 mg/kg fish weight/day. Treatment duration 7 days

The different potencies of dominant treatments in various countries means quantifying the scale of use of antibiotics and, therefore, the scale of concern is challenging; in the 2008 Salmon Aquaculture Dialogue review, Buschmann et al. (2008) described the current annual use of antibiotics as follows:

- Norway: 340 kg was described as “negligible”
- Chile: 133,000kg was described as “large”
- Scotland: 5,406 kg was described as “relatively small”

Accepting that these descriptors ignore the variability in potency, comparing these terms to BC’s 3,656 kg of antibiotic use would imply perhaps a “small” total use of antibiotics. For comparison, tetracyclines (including chlortetracycline, oxytetracycline and tetracycline) are another dominant antibiotic group used in terrestrial livestock and companion animals in Canada. An approximate estimate of total tetracycline antibiotics produced and used for this group in Canada (actual use will be higher due to imports of these antibiotics) in 2011 is 633 mt (Jean Szkotnicki, Canadian Animal Health Institute, personal communication, 2012)[24]. Tetracycline use in BC salmon farming, therefore, represents less than 0.5% of that used in livestock and pets in Canada. However, it must be noted that the circumstances and the environment in which antibiotics are used across these different animal groups (i.e., salmon, terrestrial livestock, or pets) are very different. Laxminarayan et al. (2013) emphasize that the spread to the environment must be minimized.

Of the six antibiotics that make up the four products used in BC (see Table 1), all but florfenicol[25] are listed as highly important to human health by the World Health Organization (WHO 2011). Four review papers provide an excellent overview of the concerns relating to the development of microbial resistance to antibiotics, particularly in those organisms causing diseases in humans, and especially the development of resistance to chemicals critically- or highly-important to their treatment in humans (Cabello et al. 2013; Miranda 2012; Buschmann et al. 2012, and Smith 2008). Genetic components of resistance in microbial populations are naturally occurring (collectively referred to as the resistome[26]) and the pathways through which mobile elements (collectively referred to as the mobilome) can transfer through microbial populations and across species (e.g., from animals to humans) are well defined (Laxminarayan et al. 2013). Although Miranda (2012) stated, “*There is currently no solid evidence available to demonstrate a direct link between the use of either antibacterial in fish farming and the occurrence of human pathogens resistant to that antibacterial agent,*” there appears to be very little research on the topic and, therefore, although the use of antimicrobials in salmon farming

[24] Based on production by Canadian Animal Health Institute members (603 mt) plus a 5% allowance for non CAHI members (30 mt), but not including antibiotics produced outside (and imported into) Canada.
[25] Florfenicol is a fluorinated derivative of thiamphenicol; thiamphenicol is listed as highly important, but florfenicol is only used for human treatment if a small number of countries of which Canada is not one. As a different chemical compound from thiamphebnicol, Florfenicol is not considered to be highly important to human health according to the WHO’s 2009 list.
[26] defined as the assemblage of chromosomal genes that are involved in intrinsic resistance and whose presence is independent of previous antibiotic exposure (Miranda, 2012).

is lower than in terrestrial livestock, the additional selective pressure from using antibiotics highly important to human health in aquaculture remains a high concern.

Miranda (2012) also concludes "*Further studies are necessary to understand how antibacterial resistance spreads among environmental microbiota and the ecological significance of the occurrence of multidrug-resistant bacteria in fish farm environments, but our current lack of knowledge on elements involved in these resistances emphasizes the necessity of maintaining a strict surveillance of emergence and spread of antibacterial resistance.*" In addition, Laxminarayan et al. (2013) states, "*A global system for surveillance of antibiotic use and resistance and its health and economic burden is urgently needed. Surveillance should include environmental sampling in addition to examination of clinical isolates."* While it will be immediately clear from a veterinary perspective if resistance develops with respect to the clinical effectiveness of antibiotics to treat salmon diseases, monitoring resistance in the environment is not currently carried out in BC.

There is evidence that antibiotic resistance has occurred previously in BC. For example, Sheppard (1992) documented *Aeromonas salmonicida*[27] antibiotic resistance to oxytetracycline in BC prior to the adoption of vaccination, and Morrison and Saksida (2013) expressed concern with recent occurrences of a need to repeat antibiotic treatment for stomatitis (treated with florfenicol) as well as the limited range of antibiotics available in general.

As noted above, the severity of the global crisis of antibiotic resistance is not in dispute. For example the World Health Organization highlights an "urgent need for action" (WHO, 2011), yet pragmatic solutions in food-producing animals are still somewhat undeveloped. For example, the United States Food and Drug Administration recently issued a "*Guidance for Industry*" document (FDA 2012) representing their "*current thinking on the topic.*" The WHO list of principles for responsible and prudent use (available in Appendix 1) identifies several requirements of best practices and the two strategies (WHO 2011 and FDA 2012) agree on the following two key points:

1) eliminate the use of antibiotics as growth promoters in food animals
2) require that antibiotics be administered to animals only when prescribed by a veterinarian

While it is noted that these documents relate primarily to terrestrial livestock, there is broad similarity with a number of other initiatives including the World Organization for Animal Health (OIE)[28], the Alliance for the Prudent Use of Antibiotics[29] (which supports the FDA's guidance), and in an aquatic context the Responsible Use of Medicines in Agriculture Alliance's "Responsible Use of Antimicrobials in Fish Production" (RUMA 2007).

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[27] *Aeromonas salmonicida* causes the bacterial disease Furunculosis
[28] OIE - Chapter 6.9 Terrestrial Animal Health Code - http://www.oie.int/index.php?id=169&L=0&htmfile=chapitre_1.6.9.htm
[29] http://www.tufts.edu/med/apua/news/policy_antibiotic_food_animals.shtml

Antibiotics are not used prophylactically in BC salmon farming (Morrison and Saksida 2013), but a food production system whose open nature leaves the fish inherently vulnerable to infections, which then require treatment with highly important antibiotics, does not appear to be prudent, judicious or justified. In addition, it can be argued that prescribing veterinarians are often either employed by salmon farming companies, or cannot be considered independent from the needs and perhaps commercial incentives of the industry (point 9 of the WHO principles states "*Economic incentives that facilitate the inappropriate prescription of antibiotics should be eliminated")*.

Miranda (2012) provides a comprehensive review of the fate and persistence of antibacterial agents, including oxytetracycline, in salmonid farming, and it is clear that the antimicrobials used in aquaculture typically end up in the environment, regardless of the production system (even potentially in land-based closed containment hatchery systems, (Lalonde et al. 2012). Figures vary by treatment type, but Cabello et al. (2013) estimate up to 80% of applied treatments can pass into the environment where they can accumulate in the sediments under and around the pens, or can be carried by water currents to sediments at distant sites. The longevity and fate of these chemicals in the environment in terms of their accumulation, degradation, activity (or loss of activity when bound to organic matter) is complex and somewhat contested depending very much on the initial quantities applied and on the characteristics of the site.

Miranda's 2012 review highlights the complexity, firstly stating "*The environmental effects of administering antibacterial agents in aquaculture are of great concern and include antibiotic resistance, residues in organisms and persistence in aquatic environments near salmonid farms."* But added (with respect to oxytetracycline) "*In general terms the real fate of antibacterials used in fish farming is an unsolved issue, mainly due to the studies that report a usual lack of correlation between the administered amount of oxytetracycline and the detected concentration in undercage sediments,"* and "*Another aspect of great relevance to be considered is [….] the fact that various antibacterials are inhibited by certain environmental parameters,"* which include conditions in enriched sediments under fish farms.

Residues of some types of antimicrobials can remain in sediments for over a year in locations where "large" amounts have been used, and despite their low toxicity and decreased activity when bound to organic matter in the sediments, antibiotics may affect the biological diversity of the phytoplankton and the zooplankton communities. These changes in diversity may potentially affect the health of animals and humans (Burridge et al. 2010). Additionally, Christenssen (2006) noted the potential for increased toxicity of multiple antibiotics if present at one location.

<u>Pesticides</u>

The term "pesticide" is used below in the general context of a substance used for destroying organisms harmful to cultivated plants or animals. The terms "therapeutant" or "drug" or "medication" are commonly used and may be used specifically in the registration of some "pesticide" compounds. The primary use for this group of compounds is the treatment of parasitic sea lice

As for the antibiotics above, after a pause in public availability and after the transfer of control to DFO in 2010, aggregated total pesticide use data in BC was (as of late 2013) available on the DFO website[30] in units of grams active ingredient per ton of production. Data from 2009 to 2012 was provided for this assessment from the BCSFA. The term "pesticide" is used below in the general context of a substance used for destroying organisms harmful to cultivated plants or animals.

Emamectin benzoate (EB— trade name "Slice") has been the only pesticide used in BC since the year 2000 (Burridge et al. 2010; Saksida et al. 2011, and DFO data), but in January 2014 Marine Harvest Canada was granted permission to use hydrogen peroxide as an alternative treatment for sea lice[31]. EB is administered in the feed, whereas hydrogen peroxide is a bath treatment. Canada limits the number of sea lice pesticide treatments during a grow-out cycle to three (Burridge et al. 2010), while up to five treatments may take place in Norway and the UK, and between four and eight in Chile. According to Burridge et al. (2010) in 2008 data, the total use of EB was substantially lower in Canada than other salmon farming regions (14.3kg in Canada compared to 81kg in Norway, 63.5kg in Scotland, and 285kg in Chile in the same year). Although it is much less effective than EB, hydrogen peroxide has recently been reintroduced into other salmon farming regions due to the reduced effectiveness of existing treatments, or to reduce the use of existing, highly toxic pesticide treatments (e.g., teflubenzuron in Norway). This does not appear to be the case in BC where it has been introduced as a measure to achieve aquaculture certification compliance[32]. As it breaks down rapidly to hydrogen and oxygen, there is not considered to be a significant environmental concern with the use of hydrogen peroxide.

Figure 7 and 8 show EB use in units of grams per ton of production (Figure 7) and total active ingredient in kilograms (Figure 8); data from 1996 to 2008 is from BCMAL, extended with data from BCSFA from 2009 to 2012.

[30] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/health-sante-eng.html
[31] www.intrafish.com Jan 17 2014 Marine Harvest gets OK for new lice treatment.
[32] www.intrafish.com Jan 17 2014 Marine Harvest gets OK for new lice treatment

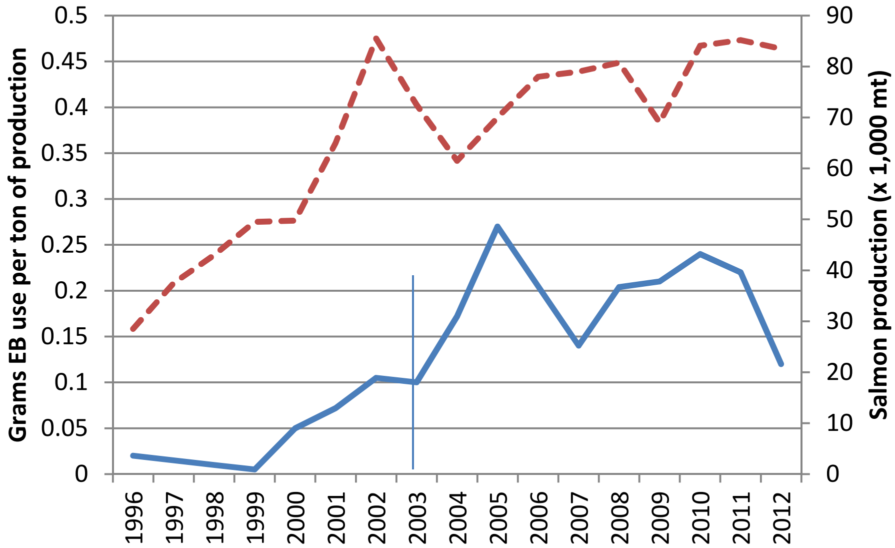

Figure 7: Use of emamectin benzoate (Slice) per ton of production in BC between 1999 and 2012 (blue solid line). Note values from 1996 to 1999 are for Ivermection. Red dashed line shows total salmon production. The vertical line shows the 2003 introduction of sea lice limits. Data from BCMAL to 2008, and BCSFA from 2009 to 2012.

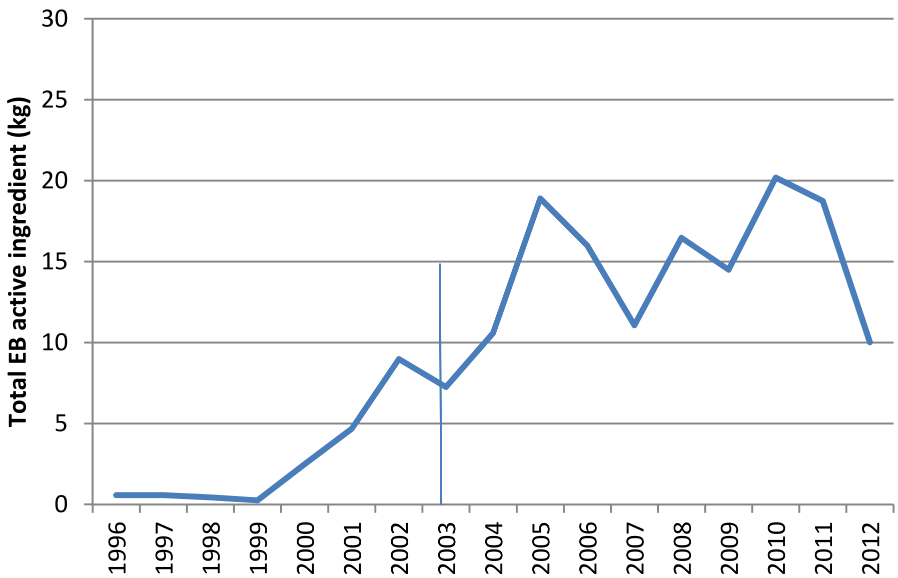

Figure 8: Total EB use in kg of active ingredient from 1996 to 2012. Vertical line shows the 2003 introduction of sea lice limits. Data sources are as Figure 7 above.

The quantity of EB increased from the year 2000 with an increased desire to control sea lice numbers due to increasing concern about the transfer of sea lice from farms to wild fish. In 2003, government regulatory authorities established requirements that farms maintain lice abundance below a threshold of three motile *L. salmonis* sea lice (i.e., adult and preadult stages) between March and June (Saksida et al. 2007). The restrictions were enacted as part of the Sea Lice Management Strategy (BCMAL 2009) and required more frequent treatments with EB than had previously been necessary from a purely production perspective. Since 2004, the total amount used has been variable, within a range of 10kg and 20kg active ingredient across BC.

Emamectin benzoate is effective at very low concentrations; for example, the active dose is 50 µg/kg of fish biomass over a seven-day treatment period and the 10 kg used in 2012 is sufficient to treat 28,000 mt of salmon. Data provided by Marine Harvest indicate that while some fish will not be treated with pesticides at all, BC salmon farms receive on average 1.2 treatments of pesticides per production cycle during the marine phase (MHC, personal communication 2012).

Total pesticide use in BC (i.e., 10 to 20 kg of EB per year) is small compared to other salmon farming regions. For example, the total pesticide use in Norway (across several different chemical treatments) increased from 132 kg in 2007 to 218 kg in 2008, and then leapt to 5,516 kg in 2009 and 6,454 kg in 2010 (FHL 2011). While it is important to note that due to varying potencies across different treatments, the numbers are not directly (i.e., linearly) comparable. These figures reflect the introduction and rapid increase in the use of alternatives to EB in Norway due to previous overuse and development of resistance in Norwegian sea lice populations. This has been the case in other salmon farming regions too, where the efficacy of historically successful treatments has been on the decline in recent years (Jones et al. 2013; Covello et al. 2012). Although EB is the only pesticide used in BC, there is no evidence of resistance developing and sea lice control appears to be effective (Saksida et al. 2012; Jones et al. 2013).

The unique situation in BC has been partially attributed to:

- Differences within the dominant sea lice species (*Lepeoptheirus salmonis)* between Atlantic and Pacific populations (Yazawa et al. 2008)
- An annual influx of sea lice that have never experienced pesticidess accompanying the return of wild salmon (BCMAL 2009)
- The relatively low chemical use in BC (compared to other regions) (BCMAL 2009)

The long-term stability of this situation is not certain; for example Peacock et al. (2013) questioned the long-term sustainability of this approach because of the unknown ecological effects of parasiticides and the potential for parasite resistance to chemical treatments. In addition, Rogers et al. (2012) warned of potential climate change and increasing temperature effects including lice population growth and reduced tissue retention times of EB in fish. It is also interesting to note a warning from Jones et al. (2013), "*Typically, by the time drug resistance becomes evident in a population through documentation of multiple treatment failures, the resistant alleles are already prevalent in the population. Genes conferring resistance to a particular parasiticide likely already exist in the population and resistance emergence is inevitable because the use of the treatment selects for these resistance factors. Once resistance frequency is sufficiently high enough to detect, resistance is already rapidly spreading through the population*."

With regard to direct impacts of the pesticide EB, a Scottish study suggested that negative impacts from anti-louse treatments would be restricted in spatial and temporal scale and are considered unlikely provided these treatments are used responsibly (SEPA, 2011). Burridge et al. (2010) noted "*The environmental effects of sea lice control chemicals have seen a considerable amount of research attention. The use of in-feed treatments, such as emamectin benzoate* [the only treatment used in BC] *and teflubenzuron are generally believed to present a lower risk to the environment than bath treatment pesticides […] Currently, most hazard information is based on acute exposures; however, they do not indicate a high level of risk."*

Nevertheless, Burridge et al. (2010) went on to say, "*The in-feed chemicals emamectin benzoate and teflubenzuron are known to be ephemeral in the water surrounding net pens but are relatively persistent in adjacent sediments and there is the potential for accumulation with continual use."* A recent, specific study in BC highlights the difficulty of assessing impacts of this type on non-target organisms; in 2011, a Canadian Science Advisory Process was held to assess the impact of EB near aquaculture facilities in British Columbia and its effect on a native spot prawn *Pandalus platyceros* (DFO, 2012b). The DFO study detected substantial levels of EB under the farm and a low level at the limit of detection up to 150 m from the farm. The study indicated the potential for EB to remain in sediments close to the farm for 1.5 years after treatment and, therefore, to accumulate over multiple treatments. It concluded, "*(i) EB can remain and so potentially buildup in benthic sediments close to salmon farms, depending on the frequency and extent of SLICE® usage and the local site conditions; and (ii) EB is bioavailable and can be measured in the muscle tissues of spot prawns collected near salmon farms treated with SLICE®."*

Short term laboratory experiments in the same DFO study indicated an alteration of gene expression in muscle tissues of spot prawns after relatively high (compared to the levels found at the farm sites) exposure to Slice in sediments, but they unfortunately did not assess the likely real-world situation of longer term exposure to lower concentrations. Pacific spot prawns were studied due to their commercial importance, but the study also stated that "*Other species may be more susceptible to biological effects caused by EB. Relevant studies of these effects in other species (e.g., crab, shrimp, and planktonic crustaceans) are therefore warranted*." Unfortunately, the study also concluded that it "*does not provide sufficient information for assessing the potential impacts of EB at the ecosystem level*" and highlighted the need for many aspects of further research.

Burridge et al. (2010) added a warning about potential cumulative impacts of coordinated treatments on multiple farms, stating, "*No studies (lab or field) have adequately addressed cumulative effects. Salmon farms do not exist in isolation*." A key strategy of sea lice management in all regions is the increased use of coordinated area treatments during which time the likelihood of cumulative impacts from treatments on multiple farms in the same area appears to be greatly increased. Therefore, while effects from a single farm may be negligible, this may not be the case where there are cumulative impacts from multiple farms treating at the same time in close proximity (Dill 2011). No evidence of routine monitoring of potential direct or cumulative impacts in BC from antibiotic or pesticide treatments was encountered during this assessment.

Future updates of this Seafood Watch report and reassessments will continue to monitor the total use and evidence of impacts of emamectin benzoate in BC.

Use of Other Chemicals

Anesthetics: Anesthetics are used infrequently and in low doses, and are generally considered to be of little risk to the environment (Burridge et al. 2010). According to the same authors, the use of disinfectants could be significant in areas of focused use such as wharves or small sheltered coves, and there appear to be no regulations regarding the use of disinfectants; in most cases they are released directly to the surrounding environment. The effects of disinfectants in the marine environment appear to be poorly studied. All of the compounds used are quite water soluble and should be of low toxicity depending on quantities used, but the risk of aquatic biota being exposed to the disinfectant formulations is dependent not only on how much is being used but where it is being released. Without information on what compounds are being used and in what quantities it is extremely difficult to assess risk to salmon and to non-target organisms (Burridge et al. 2010), but this (Seafood Watch) assessment reflects the conclusions of these authors that they are of lesser concern than pesticides and antibiotics.

Metals: According to Burridge et al. (2011), copper and zinc have been measured near salmon aquaculture sites at concentrations above regulatory guidelines, and the link between the salmon operations and concentrations appears to be strong. Copper-based antifoulant treatments (used on the nets) are the most prevalent chemicals by volume used in the salmon farming industry and their use 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. (2011) described numerous concerns regarding copper, including toxic levels in sediments below the pens leading to changes in population structure, including an absence of certain species. Obee (2009) noted (on an atypical site in BC) that if farms are fallowed to allow recovery from organic enrichment, but not long enough to allow recovery from metal contamination, metals may accumulate in high concentrations over subsequent production cycles. Loucks et al. (2012) reported levels of copper in both sediments and sea surface microlayers exceeded guidelines for protection of marine life and persisted in the sediments for 27 months at a site in Nova Scotia, but the farm had been continuously active for 15 years, and current industry fallowing practices and the increased use of remote net cleaning locations indicate that these results are likely to be at the extreme end of the spectrum. Zinc is a mineral nutritional supplement added to salmon feeds, and the portion not assimilated by the salmon is deposited in the environment according to the site characteristics as discussed in the Effluent Criterion.

It must also be noted that because of the chemical nature of the sediments, the metals may not be available to non-target organisms, and according to Burridge et al. (2011), several papers have shown that reported effects are not necessarily a consequence of elevated metal concentrations. For example, references quoted in Hambrey and Nickell (2011) show there is good evidence that copper is unavailable to infaunal organisms in anoxic conditions (Brooks & Mahnken 2003); similarly Brooks et al. (2004; 2003) concluded that both zinc and copper were unlikely to be toxic when sulfides were abundant in marine sediment (for example, under salmon farms).

Russell et al. (2011) showed sediment samples with concentrations of copper, which might cause adverse effects in the environment were all samples from within 25 m of the net pens. As noted in the Effluent Criterion, regulatory monitoring of copper and zinc levels is required in BC at the edge of the net pen array (i.e., directly under the net pens at 0 m) and elevated concentrations require subsequent recovery (fallow). The regulations in BC are intended to ensure that metals do not accumulate over multiple production cycles.

Roberts et al. (2010) addressed previous concerns regarding the effects of metals and other trace elements on local shellfish beyond the immediate farm site and confirmed that while salmon farms are a source of trace elements in the marine environment and ongoing monitoring would be advisable, salmon farms did not appear to be elevating concentrations in nearby clam tissue and sediments. With the increasing use of in-situ and remote net cleaning operations by the salmon farming industry the use of copper is declining. BC's largest company (Marine Harvest Canada) has stopped using copper on new nets and is phasing out existing treated nets as they are retired.

The presence of regulatory benthic monitoring of metal levels at the edge of the net pens in BC, and of requirements for recovery and further monitoring to achieve compliance, suggest significant impacts of metals beyond the immediate farm area are limited in extent and frequency of occurrence.

Chemical Criterion - Conclusions and Final Score

Although antibiotic use in BC has decreased substantially over the last ten years, the total amount used continues to be significant (3.6 mt in 2012) and there is no regulatory control on total use in the event of a disease outbreak. Over 80% of these antibiotics are listed by the WHO as highly important to human health, and while they are not used prophylactically in salmon aquaculture, the development of antibiotic resistance has occurred in the past, and the recent need for multiple antibiotic applications for effective treatments against stomatitis in BC indicate that the development of clinical resistance continues to be a concern. While the pathways for the transfer of mobile antibiotic resistance from aquatic to human pathogens are clearly defined, little is known about the actual risk of impact from their use in salmon farming. Routine environmental monitoring for antibiotic residues or for resistance does not occur, and the scale of the problem necessitates that the use of substantial quantities in open net pen salmon farming continues to be a high concern.

Pesticide use in BC is low (compared to other salmon farming regions) at 10-20 kg active ingredient used per year, but has increased in response to a regulatory requirement to restrict sea lice numbers in order to protect wild salmon imposed in 2003. BC is unusual among global salmon farming regions in maintaining the effectiveness of EB as a sole treatment, however, there is no assurance that this situation will continue and/or pesticide treatment will remain low.

The open nature of the production system provides no barrier to infection from environmental pathogens that then subsequently require treatment with substantial quantities of antibiotics that are highly important to human health. Thus, antibiotic usage remains a fundamental weakness of the net pen salmon farming system and, due to the global concerns regarding antibiotic resistance, the final score for the Chemical Use Criterion is 2 out of 10.

Criterion 5: Feed

Impact, unit of sustainability and principle

- *Impact: Feed consumption, feed type, ingredients used and the net nutritional gains or losses vary dramatically between farmed species and production systems. Producing feeds and their ingredients has complex global ecological impacts, and 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: This is the amount and sustainability of wild fish caught for feeding to farmed fish, the global impacts of harvesting or cultivating feed ingredients, and the net nutritional gains or losses from the farming operation.*
- *Principle: Aquaculture operations source only sustainable feed ingredients, convert them efficiently and responsibly, and minimize and utilize the nonedible portion of farmed fish.*

Feed parameters	Value	Score	
F5.1a Fish In: Fish Out ratio (FIFO)	2.14	4.65	
F5.1b Source fishery sustainability score		-6.00	
F5.1: Wild Fish Use		3.37	
F5.2a Protein IN	115		
F5.2b Protein OUT	169		
F5.2: Net Protein Gain or Loss (%)	+47.7	10	
F5.3: Feed Footprint (hectares)	8.84	6.5	
C5 Feed Final Score		**5.8**	**YELLOW**
Critical?	NO		

With approximately 17% fishmeal and 12% fish oil in the feeds (partially sourced from fish processing byproducts), the average Fish In: Fish Out ratio (a simple measure of wild fish use) was 2.14. This means from first principles (i.e., ignoring other uses of associated fishmeal), 2.14 tons of wild fish would need to be caught to produce the fish oil needed to produce one ton of farmed salmon in BC. With a moderate source fishery sustainability score, the final adjusted wild fish use score for salmon farming continues to be relatively low at 3.37 out of 10. The trend to decrease use of fishmeal and fish oil in salmon feeds (on a per ton of production basis) has been due to the use of alternative ingredients, and the majority of the protein in the BC feeds is supplied now by both nonedible sources (nonedible from a human perspective; i.e., from rendered byproducts of land animals and fish) and by plant-derived sources. This results in high scores for a net edible protein gain and a relatively small feed footprint area. Overall, despite the low wild fish use score, the high use of byproduct ingredients in BC results in a moderate final Feed Criterion score of 5.8 out of 10.

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

Two feed companies in BC provided thorough data for this report, and although other feed companies will have different feed formulations and use different ingredient sources, the limited number of feed companies supplying the salmon industry in BC means that there is a risk that these two company's data are not representative of the industry in general, but are considered to be acceptable risks that are, to a large extent, unavoidable at present).

Alternative data are available from Tacon et al. (2011), Tacon and Metian (2008) and from Sarker et al. (2013), but these relate to Canada as a whole and are missing some data points needed for this assessment. It is noted that data provided by the feed companies are not verified, but the reality is that data in any peer reviewed publications on feed use would typically be based on a similar interview/survey basis with the feed companies and, therefore, would not be robustly verified. The BC-specific data provided by the feed company is used for this Seafood Watch assessment, and values from Tacon et al. (2011) and Sarker et al. (2013) have been used as checks where relevant.

For a full explanation of the calculations, see the Seafood Watch Aquaculture Criteria document[33].

Factor 5.1. Wild Fish Use
This factor combines an estimate of the amount of wild fish used to produce farmed salmon with a measure of the sustainability of the source fisheries.

Table 2: Feed data points and calculations for wild fish use.

Parameter	Feed company "a"	Feed company "b"
Fishmeal inclusion level	12%	17%
Percentage of fishmeal from byproducts[34]	15 %	17%
Fishmeal yield (from wild fish)	Not specified 22.5 % used	Not specified 22.5 % used
Fish oil inclusion level	12%	12%
Percentage of fish oil from byproducts	0 %	10%

[33] http://www.montereybayaquarium.org/cr/cr_seafoodwatch/sfw_aboutsfw.aspx
[34] While it can be argued that byproducts of wild caught fish processed for human consumption (heads, guts, skin, fins etc.) have the same ecological cost of production as the fish fillets that humans value as food, the current socially logical use of byproducts to grow more food (farmed fish) means that they do not currently contribute to the FIFO scores.

Fish oil yield (from wild fish)	Not specified 5% used	9.5%[35]
Economic Feed Conversion ratio (FCR)	1.24	1.15
Calculated values		
Fish In : Fish Out ratio for fishmeal	0.56	0.72
Fish In : Fish Out ratio for fish oil	2.98	1.31
Seafood Watch FIFO score (0-10)	**2.56**	**6.73**

For comparison, the fishmeal, fish oil and eFCR levels in Sarker et al. (2013) are very similar; 17%, 12% and 1.2 respectively. The economic feed conversion ratio is an important aspect of these calculations. The values provided by the feed company are also broadly consistent with the estimates and predictions of Tacon et al. (2011) of 1.3 in both 2010 and 2015.

Note – Seafood Watch accepts there are different methods of calculating FI:FO values (for a review, see Sarker et al. 2013). The calculation used here is the same as those used in reference papers by Tacon and Metian (2008), and the multi-stakeholder Salmon Aquaculture Dialogue (otherwise called Forage Fish Dependency ratio[36]).

The fish oil inclusion level typically drives the FI:FO value for farmed salmon and, due to the use of byproducts and the higher fish oil yield value (Table 2), the FI:FO values and scores are quite different. The average of the two FIFO values is 2.14 and a score of 4.65 out of 10. This is consistent with Tacon and Metian (2008)'s forecast for salmon FI:FO values to drop from 3.0 in 2010 to 2.0 by 2015.

A FI:FO of 2.14 means that from first principles, 2.14 tons of wild fish would need to be caught to supply sufficient fish oil to grow one ton of farmed salmon.

Source fishery sustainability
The source fishery for fishmeal and fish oil was only provided by one feed company; anchovy, hake, menhaden, pollock. Fishmeal and oil from these fisheries is certified by the International Fishmeal and Fish oil Organization, but without specific geographic fisheries information, is scored -6 out of -10 (this would be the same for the other feed company).

Wild Fish Use Score
The sustainability penalty is applied to reduce the FI:FO score, and generates a final Wild Fish Use score of 3.37 out of 10—on the borderline between high and moderate conservation concern.

[35] 9.5% is the average value, although the majority of the fish oil used is menhaden; average yield is 12-14%
[36] The alternative method (e.g. Jackson, 2009) does not produce reliable values across a range of typical aquaculture feeds (due to the use of the combined fishmeal and fish oil yields in the equation's denominator).

Factor 5.2. Net Protein Gain or Loss

Table 3: Feed data points and calculations for protein gain or loss.

Parameter	Feed company "a"	Feed company "b"
Protein content of feed	38-40% (39% used)	40%
Percentage of total protein from non-edible sources (byproducts etc.)	76%	66.8%
Percentage of protein from edible sources	24%	33.2%
Percentage of protein from crop sources	7%	22%
Feed Conversion ratio	1.24	1.15
Protein INPUT per ton of farmed salmon	106kg	124 kg
Protein content of whole harvested salmon[37]	16.9%	16.9%
Percentage of farmed salmon byproducts utilized	100%	100%
Utilized **protein OUTPUT** per ton of farmed salmon	169kg	169kg
Net protein gain	58.9%	36.5%
Seafood Watch score (0-10)	10	10

Data from the feed company (Table 3) show that a large percentage of the total protein in BC salmon feeds comes from nonedible land animal byproducts, largely poultry and feather meals, which are high in protein. Relatively little of the total protein comes from fishmeal or edible crop ingredients. For comparison, this agrees with Sarker et al. (2013) who state 46% of the total raw materials in Canadian feeds are from plant proteins and rendered animal protein ingredients (compared to 17% fishmeal). All of the protein in the harvested 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. Therefore, due to use of nonedible protein ingredients, BC farmed salmon produces a net gain in edible protein (47.7% on average between the two data sets) and receives a score of 10 for this factor. Note the use of rendered animal byproduct ingredients is currently limited to Canadian and Chilean salmon farming (Sarker et al. 2013) due to market and regulatory restrictions in Europe.

Factor 5.3. Feed Footprint

By considering the grouped inclusion levels of marine, terrestrial crop and terrestrial land animal feed ingredients, this factor provides an approximate guide to the ocean and land area used per ton of farmed salmon.

Table 4: Feed data points and calculations for feed footprint.

Parameter	Feed company "a"	Feed company "b"
Marine ingredients inclusion	24%	29%
Crop ingredients inclusion	31%	32%
Land animal ingredients inclusion	40%	34%

[37] Nofima (2011). "Resource utilisation and eco-efficiency of Norwegian salmon farming in 2010." Report 53/2011,Published December 2011., quoting unpublished Marine Harvest data

Ocean area (hectares) used per ton of farmed salmon	7.74ha	8.67 ha
Land area (hectares)	0.69 ha	0.57 ha
Total area (hectares)	8.43ha	9.24 ha
Footprint score (0-10)	7	6

Due to the relatively high use of terrestrial ingredients in BC salmon feeds, the total feed footprint is relatively small and scores 6.5 (averaged) out of 10. For comparison (and due to the high land animal ingredient use in BC compared to Norway), these values for BC are double the land area, but substantially less ocean area than the values (0.33 ha of land area and 11.5 ha of ocean) calculated for Norway by Nofima (2011).

Feed Criterion- Conclusions and Final Score

The final feed score combines the three factors with a double weighting on the FIFO score. The high FIFO value shows that, on average, more than two tons of wild fish are used to produce one ton of farmed salmon in BC. This leads to a low score for the wild fish use factor, but the substantial use of terrestrial feed ingredients in BC (particularly of land animal byproducts) means that in contrast, the protein retention and feed footprint scores were good. Combining these scores results in a moderate score of 5.8 out of 10 for feed use.

Criterion 6: Escapes

Impact, unit of sustainability and principle

- *Impact: competition, genetic loss, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations*
- *Sustainability unit: affected ecosystems and/or associated wild populations*
- *Principle: aquaculture operations pose no substantial risk of deleterious effects to wild populations associated with the escape of farmed fish or other unintentionally introduced species*

Escape parameters	Value	Score	
F6.1a Escape Risk		2.00	
F6.1a Recapture and mortality (%)	13		
F6.1b Invasiveness		6	
C6 Escape Final Score		**4.00**	**YELLOW**
Critical?	NO		

The design and construction of net pens has improved and total reported escape numbers have been low for the last three years, but a risk of escape from catastrophic losses or more chronic "leakage" remains. Long-term survival of escapees is likely to be low and predation may be high, but significant numbers of Atlantic salmon recorded in rivers for many years in BC, and further afield in the North Pacific, indicate some level of survival.

Despite the release of millions of Atlantic salmon in BC over more than a century in deliberate attempts to establish the species for sport fishing, and despite the large numbers of farm escapes over more recent decades, there is currently no evidence of Atlantic salmon becoming established in BC (or anywhere else in the Pacific, such as Chile).

Atlantic salmon are currently considered (in this Seafood Watch assessment) to be "highly unlikely" to establish in BC and, therefore, represent a low impact, yet the potential ramifications should this conclusion be proved incorrect is acknowledged to be very high. Therefore, overall, the ongoing escape risk combined with the current low risk of impact (while not ignoring the inevitable ongoing concern), leads to a final score of 4 out of 10.

Justification of Ranking

The Escape Criterion combines the risk of escape with the potential for ecological impact of the escapees.

Factor 6.1a. Escape risk

On a global basis, hundreds of thousands of domesticated farmed Atlantic salmon escape into the wild each year Glover et al. (2012). DFO has published (industry-reported) escape data[38] since 2011 (2012 data are the latest available – March 31, 2014). Given the concerns regarding the ability to accurately count and account for the numbers of fish involved in large farms (described below), the recent escape numbers have been relatively low (11 fish reported in 2011, and 2,754 in 2012). The longer term data in Figure 9, however, (collected by Piccolo and Orlikowska 2012) show escapes have been highly variable in BC, with very large escapes in 2008 and 2009 totaling over 160,000 fish. It should be noted that 2,745 of the escapes in 2012 were from a novel floating tank system, and not from net pen farms. In addition, published reports also vary; for example, while Piccolo and Orlikowska (2012) reported 111,769 adult fish escaping in 2008, Noakes (2011) reported 29,861 adult escapees in the same year.

Examples from other salmon farming regions show that reported escape numbers may be less than actual escapes for a number of reasons, including the practical difficulty of accurately counting fish and, in particular, the difficulty in accounting for "trickle" or "drip" losses— rather than large-scale catastrophic escape events. According to Bisson et al. (2006), it is "*quite likely that the number of fish claimed by salmon farmers to have escaped is underestimated,"* and the Norwegian Seafood Federation FHL (2011) states, *"many estimates are based on guesswork and more or less plausible estimates."* Taranger et al. (2011) generally considered potentially significant "trickle" or "drip" losses to go unreported, and Skilbrei and Wevennik (2006) note small-scale unreported escape events may make up a large portion of the total escaped farmed fish. The debate over the accuracy of escape numbers is likely to continue, and efforts by industry and government should continue to improve the quality of these estimates and mandatory reporting (Noakes 2011).

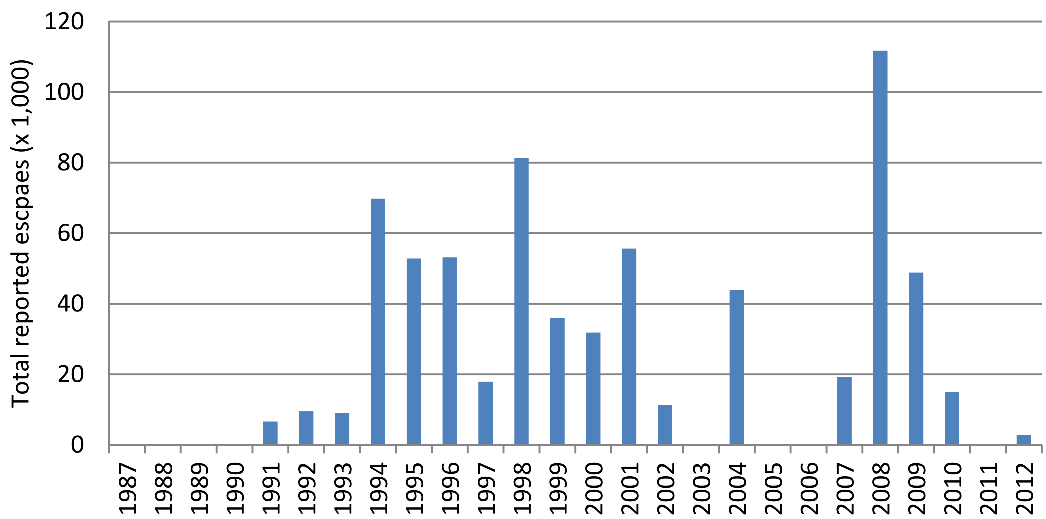

Figure 9: Industry-reported escape figures in British Columbia. Source 1987-2009 Piccolo & Orlikowska (2012), 2011 and 2012 are from DFO, 2010 from John Werring, David Suzuki Foundation, personal communication.

[38] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/escape-evasion-eng.htm

The Pacific Aquaculture Regulations require various escape prevention measures and management practices. While these can help, and the industry itself is considered to be committed to eliminating escapes, the highly variable escapes records demonstrate that the nature of the production system continues to represent a significant escape risk. According to the David Suzuki Foundation (John Werring, personal communication, 2012), in addition to the large escapes in 2008 and 2009, 15,700 salmon escaped in a single event in 2010, which (although correctly reported to the authorities) was not reported publically by DFO during the transition to them of aquaculture control.

These recent events highlight the ongoing potential for the escape of large numbers of fish in any one incident (i.e., hundreds, thousands, or tens of thousands of fish). According to Thomassen and Leira (2012), "*there is still much room for improvement in relation to verified structural design procedures and computerized tools for structural analysis. To a large extent, they* [salmon farm net pens] *can be regarded as not being in accordance with the state-of-the-art of structural analysis and design for more traditional types of marine structures*."

Piccolo and Orlikowska (2012) proposed that the frequency and magnitude of escape events might be expected to decrease as industry practices improve, but concluded that due to the nature of salmon farming, large accidental escapes are likely to continue to occur sporadically. Although nearly all salmon producing countries have established routines for reporting at least large-scale escapes, the magnitude of unreported escapes is unknown and information on low-level leakage from farms and escapes from freshwater hatcheries remains uniformly poor (Thorstad, et al. 2008). The highly variable nature of escapes and the potential for continued large escapes is also a characteristic of the similar production systems used in other salmon producing regions (for example, 175,000 escapes from a Norwegian site[39] and 336,470 escapes from a Scottish site[40] in 2011).

Even ignoring the likelihood of a high number of unreported "trickle" escapes, the very high numbers of fish held in any one net pen, combined with the inherently vulnerable and high risk system means that there continues to be a high risk of significant escapes involving hundreds or thousands of fish. The efforts being made by the industry are commendable but, according to the Seafood Watch criteria, they only reduce the escape risk from high to moderate-high in the Seafood Watch criteria (2 out of 10).

Recaptures and Mortality

Evidence of escapee recaptures or mortality at the escape site can improve the escape risk score on a linear basis (i.e., if escaping fish are recaptured or eaten by predators, they will not be able to have an impact beyond the farm site).

In addition to the actual recapture effort applied, the recapture success depends on many

[39] www.intrafish.com 27 September 2011 "Salmar escape: a tiny affair"

[40] The Scottish Government http://www.scotland.gov.uk/Resource/0039/00397960.pdf

factors that control post-escape dispersal and movements. Although, in at least one study (in Norway) escaped salmon remained at the farm site (Olsen and Skilbrei 2010), studies generally indicate significant movements of surviving escapees and, according to Chittenden et al. (2011) and Uglem et al. (2012), recapture efforts need to be immediate and widespread to mitigate farm-escape events. There is no specific recapture data available for BC, and recapture efforts would require the issuance of a fishing permit. While BC's regulatory requirements and DFO's conditions of license refer to recapture efforts, there is no evidence that these have been effectively enacted to date.

Noakes (2011) reports a small percentage (less than 5% on average) of the escaped Atlantic salmon is observed or reported being caught in ocean fisheries or in freshwater in BC, while largely incomplete data in Piccolo and Orlikowska (2012) show highly sporadic recaptures of Atlantic salmon in Washington State, BC, and Alaska. Although recaptures are most substantial in BC (for example, 7,834 fish in the year 2000), the last figures included were from 2002. The data are not considered sufficiently complete to give any reliable indication that these captures have significantly reduced the potential impacts of any one escape event within the vicinity of the farm sites in BC.

Although Glover et al. (2012) report high mortality of escaping farmed salmon, the 2006 references on which this conclusion is based now form part of a broader literature showing highly variable survival of escapees linked to the size and age at escape, the location, the time of year, and a combination of factors leading to predation susceptibility (for example, Skilbrei and Jorgensen (2010), Hansen and Youngsson (2010), Whorisky et al. (2006) and Olsen and Skilbrei (2010)). Using sonically tagged "escapees," Whoriskey et al. (2006) showed high mortality (56% of the winter releases; 84% of the spring releases) largely as a result of seal predation, while another study (Uglem et al. 2012) reported only 8.5% mortality of smolts in the immediate vicinity of the escape location.

Olsen and Skilbrei (2010) showed that in conditions where fish do not migrate rapidly from the escape site, many continue to feed on feed pellets falling through the net pens and continue to grow. For fish that do leave the escape site, the ability to switch to natural prey seems key to survival and the evidence of long distance migration and subsequent presence of escapees in rivers (this study was conducted for Atlantic salmon in Norway) demonstrates that this does occur. Noakes (2011) reported that of 1,584 recaptured salmon in BC, 80% of them had empty stomachs, leading the author to conclude that "*most escaped Atlantic salmon do not successfully feed and survive for any extended period of time*." However, if salmon escape when close to maturity, a relatively large proportion of these fish may survive and enter nearby rivers (Thorstad et al. 2008 – again, a study based in Norway).

Considering the need to control sea lions and harbor seals by lethal means in BC, it seems likely that direct predation of escapees in BC will be significant, but the variability in the figures above show there is little numerical data in the literature on which to base a confident mortality percentage. The same can be said for the recapture efforts.

In conclusion, there is insufficient evidence to robustly justify a specific recapture and mortality score, even though while the former (i.e., recaptures) is considered to be minimal, the latter (mortality) is likely to significantly reduce the number of escapees leaving the escape locality. Some adjustment of the escape risk score seems justified with respect to mortality, therefore, while maintaining the score in the "high" risk category on a precautionary basis, the escape risk score is improved from 2 to 3 (representing approximately 13% mortality) to acknowledge potentially significant direct mortalities in the farm area. The final escape risk score, therefore, is 3 out of 10, and remains a high concern.

Factor 6.1b. Invasiveness

Atlantic salmon are a non-native species on the Pacific coast of Canada, and as such have the theoretical potential to cause considerable harm to native ecosystems in BC and further afield. Atlantic salmon (presumed to be from BC or Washington State farms) have been caught on multiple occasions in southeast and even northern Alaska (Piccolo and Orlikowska 2012), and adult Atlantic salmon have also been caught or observed in many streams on Vancouver Island, Puget Sound, Frazer River and the Strait of Juan de Fuca (Bisson 2006; Korman 2011).

Figure 10 shows the number of Atlantic salmon sightings or recoveries in BC rivers from 1987 to 2007 (blue line); also shown for comparison are the number of escapes over the same period as blue bars (data from Noakes 2011). The data over this period appear to show that increased numbers of Atlantic salmon are linked to periods of higher escapes. In total, over this twenty year period, there have been 1,099 recordings of Atlantic salmon in 80 rivers in BC.

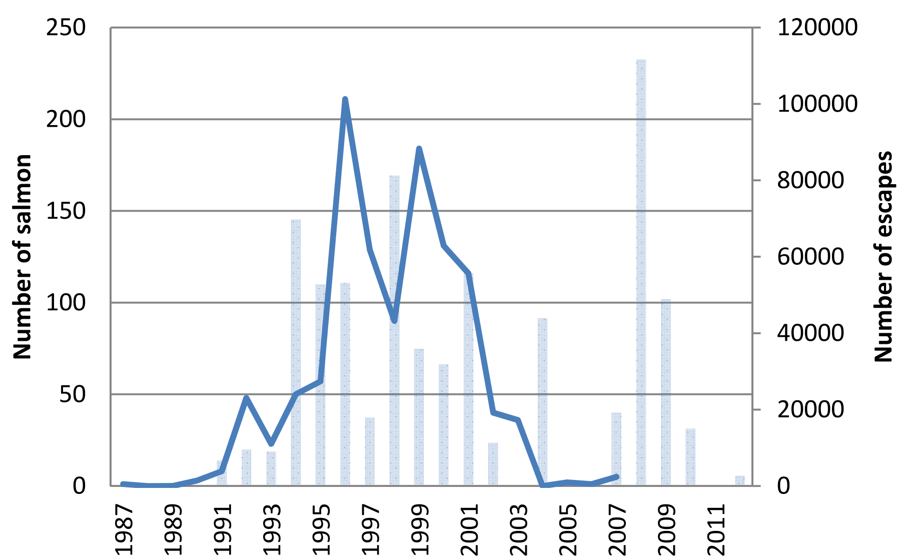

Figure 10: Number of Atlantic salmon recovered in BC rivers between 1997 and 2007 (blue line), with annual escapes (blue bars). Data from Noakes (2011).

Juvenile Atlantic salmon have been captured in freshwater habitats in BC, but of 668 fish reported during 1996-2008 by Noakes (2011), the majority were escapes from freshwater hatcheries. Nevertheless, the successful natural spawning of Atlantic salmon has been reported in BC in the Tsitika River on Vancouver Island in 1997 and 1998 (Volpe, Taylor et al. 2000), and three river systems in BC have been reported to support wild-spawned juvenile Atlantic salmon (Volpe et al. 2001). Yet whether escaped Atlantic salmon have actually established breeding populations in BC streams still remains uncertain (Bisson 2006, in Thorstad et al. 2008) and this cannot be assumed to be evidence of establishment.

According to Noakes (2011), while some streams have been actively surveyed for Atlantic salmon, the majority of the sightings or captures were reported through the passive Atlantic Salmon Watch Program[41]. Referring to the data in Figure 10, Noakes also noted that the decrease in number observed may have been due to the scaling back of efforts devoted to surveying streams specifically for Atlantic salmon because so few were being detected and also because during 2002-2003, efforts by government and other groups were being redirected away from escaped farmed fish to study sea lice. That said, in-river monitoring of Pacific salmon for escapement enumeration and stock assessment purposes continues, so it would be incorrect to say that no one is looking for Atlantics in coastal streams (because the presence of Atlantic salmon would also be reported), (Noakes 2011). DFO conducted surveys in 2011 and 2012 on freshwater systems that were considered most likely to have established Atlantic salmon populations; 12 stream/river systems were manually surveyed, one lake system was surveyed using a lake trap set, and a rotary screw trap program was run on the 'highest likelihood' system (Jon Chamberlain, DFO, personal communication, 2013). All of these surveys were timed to align with periods of highest likelihood of encounter and/or when the highest Atlantic salmon sightings had previously been recorded. While the findings of these surveys remain unpublished at the time of this writing, the survey efforts of 2011 and 2012 failed to identify Atlantic salmon of any life stage in freshwaters of BC (DFO personal communication, as previous).

Despite at least 170 deliberate historic attempts to establish Atlantic salmon in 34 states in North America, Waknitz et al. (2002) reported that none had succeeded, and although Atlantic salmon regularly occur in BC rivers and are caught in Alaska, the numbers are generally sparse and, in the case of Piccolo and Orlikowski (2012), include no data since 2002. The situation in the South Pacific appears similar, and recent research indicates that previous concerns with the impact of "salmonids" (as a species group) in Chile have primarily been driven by species other than Atlantic salmon (e.g., brown and rainbow trout) and that Atlantic salmon shows little evidence of establishing self-sustaining populations and may thus be considered less successful in the wild (Arismendi 2012).

Yet a threat undeniably remains, and in contrast to the historically unsuccessful establishment efforts, farmed Atlantic salmon now escape at multiple life stages and are increasingly acclimated to the Pacific environment with increasing generations of Pacific-raised farm stocks. Bisson (2006) states: *"Despite a long history of failure to establish Atlantic salmon from single or a few deliberate introductions, it seems possible that continuous recruitment of fish escaping from farming operations may eventually lead to locally-adapted stocks. At that point, the*

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

species may rapidly become a dangerous invasive—a pattern that is often seen in other aquatic plants and animals where a prolonged early colonization period is followed by a rapid phase of exponential growth." In relation to possible impacts in Alaska, Piccolo and Orlikowska (2012) continue to support Bisson's (2006) conclusion that a long-term (>5 years) risk remains, particularly in the case of a locally-adapted feral stock spreading along the coast after an initial invasion in WA or BC.

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

It could also be argued that since the time of the failed, deliberate attempts to establish Atlantic salmon on the North West American coast, there has been a major downturn in the populations of wild Pacific salmon in the region and, therefore, conditions may now be more favorable for establishment of Atlantics. While arguably a valid concern, Noakes (2011) counters it with the following: "*Since Atlantic and Pacific salmon share similar life histories and both require high quality freshwater and marine habitat in order to survive, the degradation in habitat that has occurred over time would not preferentially favour either species. If environmental conditions (and subsequently salmon habitat) are unfavourable for Pacific salmon then they will also be unfavourable for Atlantic salmon. Thus, the decline of particular Pacific salmon runs due to environmental or ecological reasons does not create a void or ecological niche for potential invasion by Atlantic salmon. That said, there is still a significant amount of high quality freshwater habitat suitable for salmon in BC and certainly some of that habitat is not fully utilized. The potential for Atlantic salmon to successfully spawn in coastal streams exists but experience and evidence suggests that this is an exceptionally rare occurrence and it (successful spawning) does not constitute sustained colonization (Anonymous 1997; Volpe et al. 2000).*"

The ongoing failure of Atlantic salmon to establish in the Chilean South Pacific (Arismendi, 2012) where there are no wild salmonids (despite the successful establishment of several other non-native salmonid species) would appear to support the argument made by Noakes in the previous paragraph.

This assessment, therefore, needs to address the conflicting realities of the ongoing potential for establishment and the ongoing lack of evidence of establishment in the north (or south) Pacific. With respect to the Seafood Watch criteria and the assessment of the likelihood of establishment in BC (Factor 6.1b, Part B), the key aspects appear to be:

- The lack of apparent establishment despite the historic introduction efforts

- The lack of apparent establishment despite the repeated escapes of tens of thousands of fish of varying ages, at varying times of year and in various locations over the last twenty years
- A similar situation in Chile where Atlantic salmon have not established despite the success of various other salmonids

The score for Factor 6.1b, Part B is 2 out of 5 (i.e., a non-native species, not established and highly unlikely to establish viable populations).

Even if Atlantic salmon do not establish, their repeated introduction into the wild through farm escapes can have similar or additional impacts to those that would occur if the species did become established. It is likely that fish that do not leave the farm site after escape will continue to feed on waste farm feed, but those fish that do disperse successfully from the site are assumed to feed on food other than farm pellets (Olsen and Skilbrei 2010). As noted above, while a small number of recaptured escapes in BC had stomach contents identifiable as fish (3.5% of fish sampled), the vast majority had empty stomachs (Noakes 2011). In addition, although the timing of escapes may introduce salmon into the wild when they would not normally be present in BC inshore waters, the numbers of escaping Atlantic salmon are considered to be small compared to the significant wild populations of wild Pacific salmon, therefore, additional predation pressure or competition is not considered to be a high concern. It is possible that any breeding attempts made by Atlantic salmon could disturb Pacific salmon eggs, but with the exception of evidence in Volpe et al. (2000) and Volpe et al. ((2001), which subsequently has not been observed, currently this is largely hypothetical and there are not considered to be any other habitat effects beyond this. The score for potential ecological impacts (Factor 6.1b, Part C) is 4 out of 5.

Combining the risk of establishment with the potential direct ecological impacts of escapees (even if they do not become established), the overall invasiveness score of Atlantic salmon in BC is 6 out of 10

Escapes Criterion – Conclusions and Final Score

Overall, the continuing risk of escape and the potential for establishment of an increasingly acclimated non-native species must be balanced against the continuing long-term failure to establish, the increasing evidence of the poor establishment potential of Atlantic salmon outside its native range, and its increasing domestication.

Despite improvements in the design and construction of net pens, the risk of escape from catastrophic losses or more chronic “leakages” undeniably remains. The basic escape risk score, therefore, remains low (2 out of 10; i.e., the low score reflects a high escape risk). In the Seafood Watch criteria, the escape risk score can be adjusted using the “Recapture and Mortality” score (i.e., even if a lot of fish escape, the concern is reduced if they are either recaptured or die after escape). While it is impossible to draw any robust conclusions about current recapture numbers in BC, the large proportion of escapees with empty stomachs combined with predation studies from other salmon farming regions indicate that long-term survival is likely to be low and predation may be high. Nevertheless, significant numbers of Atlantic salmon have been recorded in rivers for many years in BC and further afield in the North Pacific, which indicates some level of survival.

Therefore, while a relatively large adjustment to the escape risk score could be justified from a mortality perspective, with little robust data this adjustment has been kept low on a precautionary basis to maintain the escape risk in the “high concern” category (the escape risk score increases to 3 out of 10).

It is now clear that Atlantic salmon, unlike many other salmonid species, is a poor colonizer beyond its native range. While one study reported juvenile Atlantic salmon resulting from spawning in a river in BC in 1999, this has not been repeated since, and despite the release of millions of Atlantic salmon in BC over more than a century in deliberate attempts to establish the species for sport fishing, plus the large numbers of escapes over more recent decades, there has not been any evidence of Atlantic salmon establishing in BC over more than a decade since the 1999 study. Atlantic salmon are, therefore, now considered highly unlikely to establish in BC, and currently there is no evidence of any significant impacts of escaping Atlantic salmon in BC. The invasiveness score is 6 out of 10.

The final score for the Escapes Criterion combines the risk of escape with the invasiveness score and, therefore, combines the ongoing moderate-high risk of escapes with the low apparent invasiveness of Atlantic salmon in BC, and results in a final score of 4 out of 10 (i.e., a “moderate” concern)[42].

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[42] It is noted that the somewhat arbitrary adjustment of the escape risk score from 2 to 3 (while maintaining it in the red high risk category), causes the moderate final score in the Seafood Watch scoring calculations. As discussed, this adjustment is precautionary and could be argued to be higher, which would further improve the score. Considering the global risks from invasive species, the precautionary approach is justified.

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: Aquaculture operations pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.*

Pathogen and parasite parameters	Score	
C7 Biosecurity	2.00	
C7 Disease; pathogen and parasite Final Score	**2.00**	RED
Critical?	**NO**	

The frequency of "fish health events" has declined on salmon farms in BC, but bacterial and viral outbreaks of moderate to high pathogenicity to wild salmon are consistently reported by the industry. Accepting that wild fish may be the primary route of infection for farmed fish with respect to these endemic pathogens, the available evidence also suggests that at least one non-native pathogen (PRV) has been introduced into BC with, as yet, largely uncertain consequences.

Despite an ongoing infection prevalence of parasitic sea lice of approximately 10%–30% on wild pink and chum salmon in BC, the infection pressure from farms has decreased over the last decade. While concerns remain with regard to sub-lethal effects and poorly studied increased predation vulnerability, since 2007 sea lice can be considered to be sufficiently well managed by the industry due to levels that are below those likely to cause significant population declines in wild salmon.

Therefore, there is no current evidence that pathogens or parasites are causing significant population declines in wild salmon, and it is clear that the stochastic variability of wild salmon populations are also associated with a variety of complex short- and long-term ecological variables in the region. Yet large uncertainties remain along with key data and knowledge gaps (as highlighted by the conclusions of the Cohen Commission), therefore, with consideration of the geographical overlap between the salmon farming industry and the migratory habitat of juvenile wild salmon, a precautionary approach requires an ongoing high concern for the potential disease impacts in BC and a score of 2 out of 10.

Justification of Ranking

Introduction

The open nature of salmon farms means the fish are readily infected by pathogens from the surrounding waterbody, from wild fish, or from other natural infection routes, and can act as a temporally unnatural reservoir for a variety of pathogens and parasites that have the potential to impact native salmon species (Hammell et al. 2009).Thus, the expansion of salmon aquaculture has brought conservation concerns into regions where the narrow inlets occupied by salmon farms are important migratory corridors for wild salmon (such as in BC) (Peacock et al. 2014).

Lovya et al. (2013) noted the potential for Atlantic salmon to act as a source of "spillback to sympatric wild fishes" (in this case with respect to viral hemorrhagic septicemia virus, VHSV), but this infection and spillback relationship, while clearly demonstrating a potential mode of impact on wild fish, cannot be assumed to mean there are significant impacts on any species beyond the farms. For example, using the same example of VHSV (from Lovya et al. 2013), Garver et al. (2013) noted that this pathogen is already found throughout the Northern Hemisphere and is capable of infecting and causing mortality in numerous marine and freshwater hosts.

In general, for bacterial, viral and parasitic diseases, the debate in the scientific literature has been 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 up to 2009, the Cohen Commission highlighted two key aspects of the salmon farm debate; first is the lack of robust evidence of impacts from salmon farms on wild salmon (i.e., no "smoking gun"), and second is the ongoing risk that poorly studied impacts have occurred, are occurring now, or will occur at some time in the future.

For clarity, the disease information and its discussion in this criterion has been structured as follows:

1. Occurrence of pathogen and parasites outbreaks in BC salmon farms
    a. Disease records for BC salmon farms
    b. Occurrence of other pathogens of concern
2. Impacts of pathogens on wild fish in BC
    a. Impacts of bacterial and viral pathogens
    b. Impacts of parasites
3. Other factors to consider
4. Drawing conclusions
5. Disease Criterion final score

1. Occurrence of pathogens and parasites outbreaks in BC

1.a Disease records for BC salmon farming

Data from BC's Ministry of Agriculture are available up to 2010[43], but after DFO became the relevant authority in late 2010, health monitoring results have not been made publically available.

For this assessment, the BCSFA provided the relevant information from their databases aggregated for the period July 2010 to July 2013. These data were compiled and analyzed by Ron Lewis, former Chief Veterinary Officer and Director of the Animal Health Branch for the BC Ministry of Agriculture and Lands (BCMAL). For a comparison and/or to extend the timeline of these data if desired, Korman (2011) also provided a review of similar data (annually) from 2003 to 2010.

Table 5, below, shows the total number of fish health events per pathogen for salmon farms in BC from July 2010 to July 2013. Included in Table 5 are also the pathogen's origin and those of a moderate or high risk level to wild salmon as designated by Korman (2011).

Table 5: Number of reported fish health events in BC from July 2010 to July 2013. Data from BCSFA. Origin and pathogenicity to wild salmon from Kent (2011).

Pathogen	Number of events July 2010 – July 2013	Origin of pathogen	Pathogenicity to wild salmon
Viral Hemorrhagic Septicemia (VHS)	1	Endemic	
Piscirickettsia (*Piscirickettsia salmonis*)	0	Endemic	
Stomatitis, *Tenacibaculum maritimum* (formerly reported as myxcobacteria)	156	Endemic	
Loma Salmonis	0	Endemic	
Sea lice	130	Endemic	Moderate
Vibriosis (Vibrio (*Listonella) anguillarum*)	2	Endemic	High
Bacterial Kidney Disease (BKD) (*Renibacterium salmoninarum)*	16	Endemic	High
Infectious Hematopoietic Necrosis (IHN) Virus	4	Endemic	High
Furunculosis (*Aeromonas salmonicida*)	16	Endemic	High
Enteric Redmouth (*Yersinia ruckeri*)	2	Endemic	

It is not the intent of this assessment to provide background information on each disease, but Kent (2011) provides a review of 5 viral, 6 bacterial, 4 fungal, and 19 parasitic pathogens that

[43] http://www.agf.gov.bc.ca/ahc/fish_health/bcsfa_reports.htm

are known to, or could potentially, infect wild salmon in BC. Kent's list includes all the diseases in Table 5 with the exception of *Tenacibaculum maritimum,* which is considered to affect primarily Atlantic salmon and, therefore, is of low concern to wild Pacific salmon populations in BC (Lewis, personal communication, 2013). Note some of the outbreaks in Table 5 may have occurred on Pacific salmon farms rather than Atlantic salmon farms. According to Korman (2011), on-farm mortality attributable to disease is approximately 2.4% of fish per year, but in the vast majority of audit cases where 'fresh silver' dead fish from salmon farms were tested, bacterial and viral infections were not found and no sign of disease was observed.

In Canada, infectious hematopoietic necrosis (IHN), infectious pancreatic necrosis (IPN) and infectious salmon anemia (ISA) are "federally reportable diseases." This means all suspected or confirmed cases must be immediately reported to the CFIA. All three diseases are highly contagious and can cause mortality in wild and aquaculture salmon. Four outbreaks of IHN occurred in 2012 (see impacts section 2.a below for additional information).

It is clear from Table 5, that pathogens of moderate to high pathogenicity to wild salmon are consistently reported in salmon farms in BC. While Korman (2011) reported an annual average of 30 fish health "events" involving pathogens of risk to wild salmon from 2003 and 2010, the data in Table 5 shows 38 events in total occurred in the three years from July 2010 to July 2013 involving pathogens of high risk to Pacific salmon. This indicates a reduction in high risk disease outbreaks with time, and as these pathogens are endemic in BC (and in some cases can be hosted by other species of fish), it is likely that the dominant sources of infection in the farms are wild fish. Nevertheless, infected farms have the potential to serve as static zones of concentration for these pathogens.

Table 5 shows sea lice continue to be reported frequently, and can be considered present in all production regions in all years in BC. In 2003, government regulatory authorities established requirements that farms maintain lice abundance below a threshold of three motile stage (adult and preadult stages) *L. salmonis* between March and June (Saksida et al. 2007). Industry-reported and DFO-audited sea lice monitoring data are reported by DFO[44] on a monthly basis (i.e., reports show monthly average sea lice numbers by site). DFO audited approximately 28% of farms in 2012[45].

Despite the tendency for the monthly averages to hide spikes in parasite numbers, an analysis of 2013 data shows that on a per fish basis, sea lice levels were below treatment trigger levels (intended to reduce lice levels for the benefit of juvenile wild salmon migrating through farm areas) for much of the year for the large majority of sites, and particularly during the important juvenile salmon out-migration period (March – June). However, it must be emphasized that the number of lice per fish is only relevant when the total population of fish (and therefore lice) is considered. Particular problem sites can be identified (in 2013 data) such as Sheep's pass in Fish

[44] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/lice-pou-eng.htm
[45] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/lice-pou-eng.html

Health Zone 3.5 on the Central Coast (located north of the main salmon farming region around Vancouver Island).

1.b. Occurrence of other (introduced) pathogens in BC

The pathogens present on farms as discussed in section 1.a. above are all naturally occurring (endemic) in BC and are present in the wild Pacific salmon populations. Still, with respect to introduced pathogens, aquaculture production of a variety of species worldwide has been heavily impacted by non-native pathogens. In salmon farming, the collapse of Chilean Atlantic salmon production due to the introduction of the ISA virus from Europe is perhaps the clearest example. What is less clear, is the risk of impacts on wild salmon populations (or other susceptible species).

As discussed in Factor 6.2X above, the introduction of non-native pathogens (or non-native strains of endemic pathogens) into BC has been a concern to both industry and wild salmon experts, particularly ISAv and PRV.

The presence or absence of ISA virus in BC continues to be contested, and drawing additional conclusions to those of fish health experts is beyond the remit of this assessment. As previously quoted (in Factor 6.2X), the Cohen Commission enquiry offered, "*I find that the evidence does not allow me to conclude whether the infectious salmon anemia virus (ISAv) or an ISAv-like virus currently exists in Fraser River sockeye. I also do not have sufficient evidence to determine whether such an ISAv or ISAv-like virus, if present, is endemic to BC waters or has been introduced. The most that can be said at present is that a plausible mechanism has been identified.*"

In Canada, ISA is a federally reportable disease, and has not yet been reported on salmon farms in BC (CFIA, 2013). In the US, NOAA's Federal Aquatic Animal Health Task Force published an informational bulletin on the status of ISA in the Pacific Northwest (NOAA, 2012), and under the heading "What we know" is the following:

- *Two Canadian scientists reported this past year that they found evidence of Infectious Salmon Anemia Virus (ISAV) in wild salmon in British Columbia, Canada.*
- *These scientists used molecular tools that detected the presence of segments of RNA that are also found in ISAV. The ISA virus itself has yet to be isolated in BC.*

Under the heading "What we don't know" is the following:

- *It is yet to be determined what the Canadian scientists found in their molecular tests. Did they isolate a new form of ISAV? Did they find a virus that is similar to ISAV? Are they detecting RNA that is similar to that found in ISAV, but not of viral origin?*
- *We don't know if the ISAv–HPR0[46] strain, or ISAv-like virus strains exist in Pacific salmon in Alaska or Washington State, two states adjacent to the province of British Columbia.*

[46] There exists in parts of the world a strain of ISAV, known as HPR0, that does not cause disease and is unable to be isolated using tissue culture methods (NOAA 2012)

ISA-HPRO is a non-virulent strain of ISA considered to be a precursor of more virulent strains of ISA virus (Lynstad et al. 2012). ISA-HPRO has been identified, and is considered enzootic (prevalent) in Scotland, North America, Norway, Chile, Scotland, Iceland, Denmark, Faroe Islands (Godoy et al. 2013); these authors do not report it in BC.

As noted in Factor 6.2X previously, there is evidence that piscine reovirus (PRV) was introduced to BC from Europe sometime between 2006 and 2010 (Kibenge et al. 2013). A number of studies have now linked PRV with the clinical disease heart and skeletal muscle inflammation (HSMI), despite the nature of this type of virus as an "orphan" (REOvirus = respiratory and enteric orphan virus), which are not typically associated with any specific disease (Palacios et al. 2010; Finstad et al. 2012; Kibenge et al. 2013). Tests in BC in 2010 showed PRV was common in farmed Atlantic salmon in the region, but HSMI has not been officially detected (Marty, 2013), and while anecdotal reports of HSMI can be found, Marty (2013) also notes that identification of HSMI requires specialized histopathology testing.

The risk of an as yet unidentified endemic or introduced pathogens in BC remains a significant concern for wild salmon populations in BC, as exemplified by Miller et al. (2011). Although there is no evidence of, nor any implied connection in their paper to salmon farming, they state "*the long-term population viability of Fraser River sockeye salmon (Oncorhynchus nerka) is threatened by unusually high levels of mortality as they swim to their spawning areas before they spawn. Functional analysis raises the possibility that the mortality-related signature reflects a viral infection.*"

It should also be noted that DFO (2012c) reported "*Summer temperatures in the Fraser River have increased and its summer flow decreased (1942-2006), resulting in increased pre-spawning mortality of migrating sockeye salmon*"). It is possible that these aspects (increased temperature and potential viral mortalities) are connected.

A large-scale study run by Genome British Columbia, the Pacific Salmon Foundation and Fisheries and Oceans Canada (DFO) called the Salmon Health Initiative[47] aims to discover the microbes present in salmon in BC that may be undermining the salmon's productivity. The study has a neutral starting point regarding the potential connections between wild salmon, other wild fish populations, and farmed salmon in BC. Results are expected by 2017, although at the time of this writing, funding is uncertain (Jennifer Stoner, Living Oceans Society, personal communication, 2014).

2. Impacts of pathogens on wild salmon in BC

The potential for salmon farms to amplify pathogens above normal background levels and act as a reservoir of pathogens capable of impacting wild fish populations, particularly wild salmonids, continues to be debated. It is important to note that a central component of this debate in BC is the location of salmon farms in areas critical to the migration of juvenile wild Pacific salmon. Appendix 2 has a status summary of wild salmon populations in BC.

[47] http://www.genomebc.ca/media/news-releases/2013/salmon-health-past-present-and-future/

2.a. Impacts of bacterial and viral pathogens

This Seafood Watch assessment did not encounter any studies showing a direct link between bacterial or viral pathogens on salmon farms and the mortality of wild salmon (or any other species) in BC. With reference to "disease and pathogens" in general (on sockeye salmon), the Cohen Commission stated "*too little research has been done on the effects of salmon farms and related diseases and pathogens on Fraser River sockeye for me to reach a conclusion either way. Again, the evidence before me shows plausible mechanisms for harm and many knowledge gaps."*

However, while the Cohen Commission made many statements and conclusions about "disease and pathogens" and their potential impacts on wild salmon (and particularly Fraser River sockeye[48]), the separation of impacts from parasites versus from bacteria and viruses was rarely made. All the bacterial and viral diseases identified on salmon farms in BC are endemic in the region, and therefore identifying any role of salmon farms in any disease outbreaks and mortality in wild fish in BC is challenging. All three "federally reportable diseases" are highly contagious and can cause mortality in wild and aquaculture salmon. The Canadian Food Inspection Agency (CFIA) established a monitoring program[49] in wild fish starting in 2012. A total of 4175 fish were collected and tested in 2012. All of the samples were tested for ISA, 3614 for Infectious Pancreatic Necrosis Virus (IPNV) and 561 for Infectious Hematopoietic Necrosis Virus (IHNV); all samples collected and tested were negative (CFIA, 2013[50]).

With respect to the focused attention on sockeye salmon, Kent (2011) stated: "*At present, there are no direct links between a specific pathogen and sockeye salmon survival at a population level in British Columbia."* Yet Cohen stated, "*I accept the undisputed evidence that there is some risk posed to Fraser River sockeye from diseases on salmon farms, but I cannot make a determination as to the precise level of risk."*

There is also no evidence as yet of mortalities in any wild fish from bacterial or viral pathogens potentially introduced from outside BC, (such as PRV or ISA) however, the long running question remains as to whether this is due to a low infection pressure or if wild fish infected by a virulent agent die rapidly and thus avoid being sampled (McVicar 1997). It is scientifically challenging to demonstrate that there is no impact, and while apparent disease related mortalities do occur in wild fish in BC (e.g., Miller 2011) a substantial concern remains. Several studies have established a link between PRV and HSMI in Atlantic salmon and, according to Palacios et al. (2010), if true, this threatens not only domestic salmon production but also has the potential for transmission to wild salmon populations.

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[48] The technical reports supporting the Cohen Commission's conclusions did cover potential impacts on other salmon species.

[49] http://www.inspection.gc.ca/animals/aquatic-animals/diseases/reportable/isa/backgrounder/eng/1330100651673/1330100817464

[50] http://www.inspection.gc.ca/animals/aquatic-animals/diseases/reportable/isa/wild-anadromous-salmonids/eng/1370960326837/1370960742286

As noted previously in Factor 6.2X, HSMI was first reported in Norway in 1991 and is now reported in 417 Atlantic salmon farms in Norway, causing up to 20% mortality, as well as in the UK, (Palacios et al. 2010). However, Finstad et al. (2012) state that PRV is almost ubiquitously present in Atlantic salmon marine farms, and detection of PRV alone does not establish an HSMI diagnosis, and with respect to wild fish, Garseth et al. (2012) provided no indications that wild salmonids will develop HSMI as a consequence of PRV infection. Nevertheless, the Institute of Marine Research in Norway (IMR, 2013) cautions (as the virus is newly identified) that it would be premature to draw conclusions about the effects on wild fish at the present time.

Overall, the apparent introduction of this pathogen into BC from Europe, along with the as yet unknown implications for wild salmon populations, must continue to be a high concern.

As discussed previously, the detection and identification of ISA in BC is highly contentious, yet even if ISA is present in wild salmon populations in BC, this does not mean clinical disease or mortality will ensue. Quoting further sections from the NOAA Federal Aquatic Animal Health Task Force Informational Bulletin (NOAA, 2012), it states:

- *There has not been a report of mortality in wild fish populations anywhere in the world due to ISA.*
- *There has not been any mortality in BC salmon, wild or farmed, associated with ISAV nor have there been any ISAV isolations in farmed Atlantic salmon in BC.*
- *Previous research in the United States in a controlled laboratory setting demonstrated that Pacific salmon species were relatively resistant to pathogenic forms of ISAV as compared to Atlantic salmon.*

However, (under the heading "What we don't know") it also states:

- We don't know what the impact will be on Pacific salmon or other marine fish if, in fact, ISAV disease causing strains or otherwise, are confirmed in BC or other parts of the Pacific Northwest.

Conclusions to this section will be addressed in tandem within the parasite section and other information below.

2.b. Impacts of parasites

The dominant focus of disease interest (in BC) has been the individual- and population-level impacts of the parasitic sea lice *Lepeoptheirus salmonis* and (to a lesser extent) *Caligus clemensi* on wild salmonids.

Peacock et al. (2014) outline the broader concern stating, "*Outwardly, migrating juvenile salmon are relatively free of sea lice, which cannot survive in freshwater.* [In natural ecosystems] *Juvenile salmon are not exposed to substantial numbers of sea lice until several months into their migration when they encounter returning adult salmon. However, in recent decades, salmon farms have provided a host reservoir population for sea lice that persists year-round in close proximity to salmon-bearing rivers. The high density of hosts on salmon farms can* *amplify natural infestations and sea lice can spill back from farmed salmon to infest juvenile wild salmon very early in the juvenile salmon migration."*

Quantifying the impact has been the subject of much research and much debate; while it is clear that salmon farms are a source of lice infection for wild salmon (e.g. Marty et al. 2010, Price et al. 2012), there remains uncertainty about the magnitude of these effects on wild salmon owing to the potential for unidentified confounding factors affecting salmon survival as well as both process and observation error (Peacock et al. 2014).

A characteristic of the scientific debate has been the use of mathematical models to help identify patterns in sea lice data and wild salmon populations (e.g. Krkosek et al. 2007; Ford and Myers, 2008; Connors et al. 2010a,b 2012; Frazer et al. 2012), but due to the enormous and stochastic complexity of the ecosystem being modeled and the necessary simplifications and assumptions, it is somewhat inevitable that the models and their conclusions can be questioned and/or criticized. Conflicting reports (e.g., Krkosek et al. 2011; Marty et al. 2010; Saksida et al. 2012; Jones and Beamish 2012; Marty et al. 2010, Price and Reynolds 2012) highlight the sensitivity of these results to model assumptions and error (Peacock et al. 2014).

In addition, comparissons between farmed and non-farmed regions (i.e., areas where juvenile fish may or may not be exposed to salmon farms) and subsequent conclusions about the impacts of farms on wild fish have also been complicated by (or contested due to) additional non-farm variables (Price et al. 2010; Jones and Beamish 2012; and Price and Reynolds 2012).

The following two examples typify the debate, in both cases referring to large fluctuations in pink salmon populations observed in the early 2000s:

- Krkosek et al. (2007) concluded that, "*Recurrent louse infestations of wild juvenile pink salmon, all associated with salmon farms, have depressed wild pink salmon populations and placed them on a trajectory toward rapid local extinction. The louse-induced mortality of pink salmon is commonly over 80% and exceeds previous fishing mortality. If outbreaks continue, then local extinction is certain, and a 99% collapse in pink salmon population abundance is expected in four salmon generations.*"

- Marty et al. (2010) concluded that, "*We show that the number of pink salmon returning to spawn in the fall predicts the number of female sea lice on farm fish the next spring, which, in turn, accounts for 98% of the annual variability in the prevalence of sea lice on out-migrating wild juvenile salmon. However, productivity of wild salmon is not negatively associated with either farm lice numbers or farm fish production, and all published field and laboratory data support the conclusion that something other than sea lice caused the population decline in 2002*."

It is not the intent of this Seafood Watch assessment to reanalyze this long running debate, but rather to focus on more recent publications, their reflections upon it, and their additions to it.

Patanasatienkul et al. (2013) analyzed sea lice numbers on wild pink and chum salmon from 2003 to 2012 in the Broughton Archipelago – a densely farmed area at the southern end of the Johnstone Strait, and a focus for sea lice research. The prevalence of infected fish (i.e., the percentage of wild juvenile salmon with one or more sea lice) is shown in Figure 11, while data on lice abundance (average lice per fish for all fish) and intensity (average lice per infected fish) are plotted in Figure 12. Note that from 2003, regulatory measures were enacted to limit the number of sea lice on farmed salmon during the period of wild salmon outmigration.

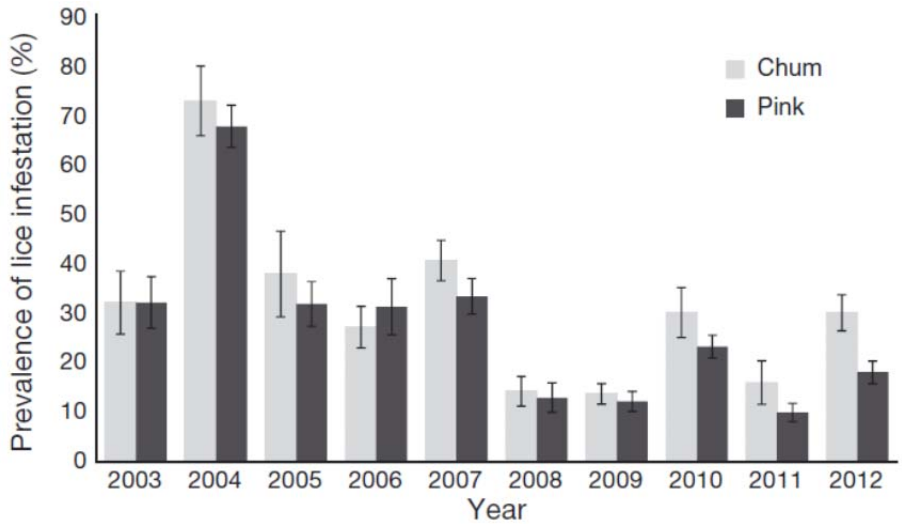

Figure 11: Yearly prevalence and 95% confidence intervals in wild chum and pink salmon sampled by beach seine in the Broughton Archipelago from 2003 to 2012. Graph from Patanasatienkul et al. (2013).

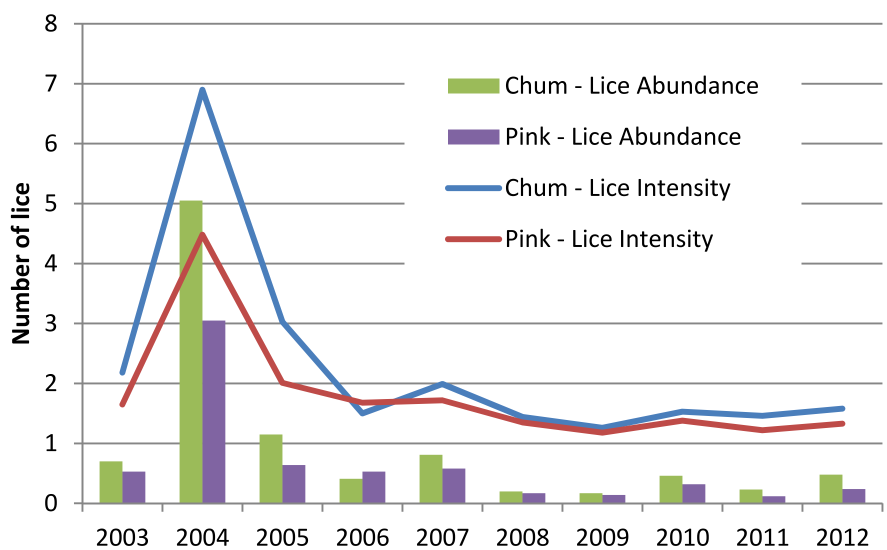

Figure 12: Abundance and intensity of sea lice on juvenile wild pink and chum salmon in the Broughton Archipelago from 2003 to 2012. Data from Patanasatienkul et al. (2013).

Figure 11 and 12 show that with the exception of 2004 (for which Patanasatienkul et al. do not have a strong explanation), approximately 10% to 30% of wild juvenile pink and chum salmon are infected with sea lice, and of those infected fish, the typical average number of lice is between 1 and 2. While the proportion of these lice that result from salmon farms exposure is unclear, the physiological impacts of these infections also remains uncertain. For example, due to the small size of some Pacific salmon species during out-migration, Brauner et al. (2012) demonstrated that infection with even a single louse will affect homeostasis in juvenile pink salmon and concluded that "*up to 10 percent of the juvenile pink salmon in the Broughton Archipelago may exhibit sublethal effects of salmon louse exposure*." However, they also state "*what this ultimately means in terms of fish survival remains unknown.*" As noted below, Saksida et al. (2012) reported that none of the fish (i.e., zero percent) sampled in 2008 had lethal infections of sea ice.

Many of the previous studies that demonstrated significant population-level impacts of sea lice on wild salmonids drew those conclusions from an analysis of data extending up to the middle of the last decade at the latest (i.e., the mid-2000s). For example, of the following key sea lice papers relating to BC, the latest data included and analyzed was from 2007: Krkosek et al. (2007), Ford and Myers (2008), Connors et al. (2010a,b), Krkosek et al. (2011), Frazer et al. (2012).

Using data subsequent to 2007, Morton et al. (2011) reported a 100-fold decrease in sea lice on juvenile wild fish in 2007 compared to previous epizootics[51]; Jones and Beamish (2011) reported a large drop between 2004 and 2008 and that the low numbers continued in 2009 and 2010; Marty et al. (2010) reported a large decrease from 2005 to 2008; Saksida et al. (2012) reported low lice numbers in 2007 and 2008 with 0% lethal infections in 2008 (based on the references of Jones et al.2008; Nendick et al. 2011; Sutherland et al. 2011).

It should be noted that despite this encouraging trend, Krkosek et al. (2011), Connors et al. (2010a, 2010b) highlighted the potential for additional as yet poorly studied impacts particularly with regard to increased vulnerability to predation of infected fish and the associated lice dynamics. Krkosek et al. (2011) concluded in relation to increased vulnerability to predation that *"the estimated mortality of wild juvenile salmon due to sea lice infestation is probably higher than previously thought."*

More recent papers highlight the apparently effective current industry management of sea lice on farmed salmon. Peacock et al. (2013) and (the same authors in) Rogers et al. (2013) conclude that precautionary management of parasites on Atlantic salmon farms in BC that suppresses parasite abundance to coincide with the timing of juvenile wild salmon migrations may reduce the risk of infection for wild Pacific salmon. They suggest a January or early February treatment strategy, generally across salmon farms in the Broughton Archipelago, may be an effective strategy to reduce sea louse exposure for migrating juvenile wild salmon.

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[51] Epizootic - an outbreak of disease affecting many animals of one kind at the same time (analogous to "epidemic" in humans).

Peacock et al. (2013) caution that despite the apparent success of parasite control on salmon farms in the study region, there remain concerns about the long-term sustainability of this approach because of the unknown ecological effects of parasiticides and the potential for parasite resistance to chemical treatments. In addition, Rogers et al. (2012) warn of potential climate change and increasing temperature effects, including increased lice population growth and reduced tissue retention times of the pesticide emamectin benzoate in fish.

Overall, while it is clear that the debate on sea lice will continue, the recent scientific literature allows some pragmatic conclusions to be reached. From a Seafood Watch perspective, a conclusion from Connors (Connors, 2013, personal communication) seems appropriate: "*In my scientific opinion, there is little legitimate scientific debate about the potential for sea lice from salmon farmed to negatively affect salmon populations. However, as the Peacock et al. (2013) paper highlights, these population-level effects can be controlled by management of lice on salmon farms.*"

3. Other factors to consider

As discussed above, there has been much speculation about the role pathogens and parasites from farmed salmon have played in wild salmon populations declines. For example, a period of pink salmon decline in the early 2000s occurred concurrent with increasing sea louse infestations on salmon farms (Peacock et al. 2014), and when considering the Fraser River sockeye decline from the early 1990s, shown in Figure 13, it is also easy to (at least hypothetically) correlate this with the rapid increase in salmon farm production over the same period.

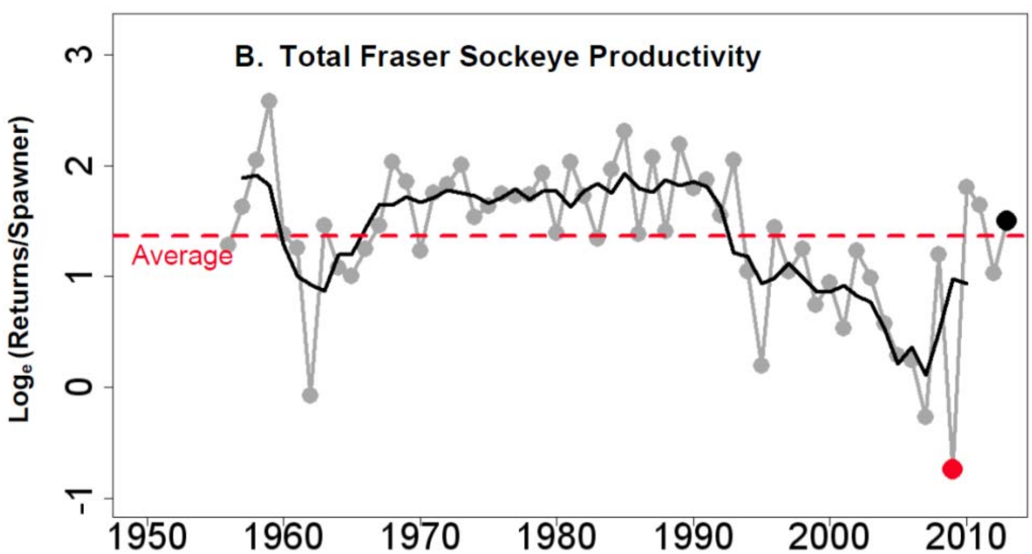

Figure 13: Total Fraser Sockeye productivity (log_e (returns/total spawner)) up to the 2013 return year. The light grey filled circles and line presents annual productivity and the black line presents the smoothed four year running average. Returns for 2009 (red filled circle) and 2010 are preliminary, for 2011 and 2012 are in season estimates only, and for 2013 (black filled circle) presents the 50% p-level forecast. Graph from DFO (2013a).

However, in contrast to these longer term apparent correlations, the very low Fraser River sockeye return in 2009 (which triggered the Cohen Commission) was followed by a near-record high return in 2010, and highlighted the natural fluctuations of wild fish populations in the Georgia Strait. Thompson et al. (2012) described the variations in these returns as an unprecedented opportunity to examine links between oceanic factors and the survival of Pacific salmon stocks. Thompson stated, "*The low returns in 2009 indicated poor early marine survival of juvenile sockeye salmon in 2007. The poor survival was likely due to low food levels arising from unfavorable wind and runoff conditions in the Strait of Georgia and the Queen Charlotte Sound–Hecate Strait region in the spring of 2007*." According to Beamish et al. (2012), the causes of the high mortality (in 2007) likely represented a unique extreme in the variability of the factors that normally affect the survival of juvenile Pacific salmon in the early marine period in the Strait of Georgia.

Extending this example further, with respect to the patterns of sockeye productivity in Figure 13, Preikshot et al. (2013) studied the ecosystem dynamics of the Georgia Strait from 1960 to 2009 and noted two periods of low regional productivity— the early 1960s to early 1970s and the early 1990s to late 2000s. In contrast, the period from the mid-1970s to late 1980s was characterized by relatively high production. A layman's correlation between this pattern and the productivity of Fraser sockeye in Figure 13 above is also clearly apparent.

Long-term monitoring of oceanographic and biological conditions in the Georgia Strait (also the greater Georgia Basin and the NE Pacific in general) now show it to be an enormously complex ecosystem with large stochastic (i.e., unpredictable) fluctuations of numerous key parameters and competing species (e.g., Araujo et al. 2013; Mackas et al. 2013; Irving and Crawford 2013). This stochastic variability overlays somewhat more predictable local and ocean-scale cycles with timeframes of days, months, years and decades. Importantly, these long-term data sets also distinguish the Georgia Strait region as a substantially different ecosystem from that of the open ocean to the west of Vancouver Island through which some subpopulations of wild salmon migrate instead of following the dominant route past the fish farms in the Georgia/Johnstone Straits (DFO 2012c, Irving and Crawford 2013).

Therefore, it is clear that if salmon farming, and specifically on-farm diseases and parasites, are having a population-level impact on wild salmonid populations in BC, it does so as part of a complex network of contributing factors, and identifying salmon farming's contribution (if any) to the large and stochastic variability in wild salmon populations is challenging.

The factors associated with the natural variability in wild salmon populations include sea surface temperatures, river flow rates, salinity, wind patterns, primary productivity and food availability, competition with other salmon species and, more broadly, climate change (Araujo et al. 2013; Mackas et al. 2013; Connors et al. 2012). For a further analysis of these aspects, see Appendix 3.

4. Drawing Conclusions

Given the complexity of the subject, clear conclusions remain challenging. While accepting the Cohen Commission's focus on Fraser River sockeye, its comprehensive study represents a useful starting point (it was a three-year investigation, a unique forum to study the effects of a multitude of stressors on Pacific salmon in BC, and it enabled public scrutiny of the multitude of stakeholders under oath). While sockeye was the focus, other wild salmon species were also considered in the commission's supporting technical reports.

The final report contains the following statements:

- I accept the evidence that Atlantic salmon farms may be a significant source of Leps [sea lice *L. salmonis*] infection for outmigrating smolts.
- I accept the evidence that Fraser River sockeye juveniles downstream of salmon farms have a greater Caligus lice load than upstream; however, the whole of the evidence before me presents different explanations for why that is so.
- I am satisfied that sea lice acting alone did not cause the decline of Fraser River sockeye, but sea lice acting in combination with factors such as other pathogens or increasing water temperature may have contributed to the decline.
- I accept the undisputed evidence that there is some risk posed to Fraser River sockeye from diseases on salmon farms, but I cannot make a determination as to the precise level of risk.
- I accept the evidence that management practices taken within net pens are intended to reduce the risk of disease as much as possible and to keep both farmed and wild fish healthy. However, I cannot determine on the evidence before me whether those measures ensure that the risk of serious harm from disease and pathogen transfer is a minimal one. Again, the evidence before me shows plausible mechanisms for harm and many knowledge gaps.

The report's conclusions also include the following statements:

- Although the data available to this Inquiry do not suggest that salmon farms are having a significant, negative impact on Fraser River sockeye, I am not prepared to conclude, based on that data, that there is a low risk to sockeye from salmon farms. It is simply too early to reach that conclusion.
- In short, there are insufficient data— almost no data—on cause-and-effect relationships, and insufficient data (in terms of a time series) to look for correlations between fish farm factors and sockeye productivity. At the same time, there is no evidence before me that diseases on fish farms are out of control or unusually high by industry standards. So, just as I cannot find the risk from salmon farms to be low, I cannot say the risk is high. Precaution would suggest assuming the risk is not insignificant.
- I therefore conclude that the potential harm posed to Fraser River sockeye salmon from salmon farms is serious or irreversible. Disease transfer occurs between wild and farmed fish, and I am satisfied that salmon farms along the sockeye migration route have the potential to introduce exotic diseases and to exacerbate endemic diseases that could have a negative impact on Fraser River sockeye.

It must be stressed that sockeye is a species which migrates at a larger smolt size than pink or chum salmon and is, therefore, potentially less vulnerable to sea lice impacts than the smaller species that have been the focus of the scientific research discussed previously (typically from regions in BC other than the Fraser River). Nevertheless, the Commission's conclusions highlight the complexity of the issues and the high concern, while stopping short of quantifying any significant impacts.

This Seafood Watch assessment agrees with the conclusions of the Cohen Commission, and also recognizes the potentially differing risks across different Pacific salmon species; it recognizes the potential for additional poorly studied pathogens or impacts, but it also recognizes the greatly reduced sea lice loads from farms over the last 7 years and the apparent (if not assuredly robust) ability of the industry to manage sea lice at present. It must also be noted that while ISAV was examined in some depth by the Cohen Commission, PRV was not, and the unknown potential impacts of introduced pathogens, despite no current evidence, remains a concern.

5. Final Disease Criterion Score

In the Seafood Watch criteria, a moderate score of 4 out of 10 is allocated when "*Amplification of pathogens or parasites on the farm results in increased infection in wild fish, shellfish or other populations in the farming locality or region.*" The large body of research on sea lice shows that this has been the case, and while infection levels have decreased, it continues to be the case with approximately 10%–30% of wild pink or chum salmon infected in 2012.

A very high concern (score of 0 out of 10) is allocated when these infections result in clinical diseases that "*lead to significant population declines in wild species.*" Many earlier peer reviewed scientific publications have clearly concluded this to be the case with respect to sea lice, and somewhat poorly studied concerns remain regarding complex interactions of sea lice and increased predation. The most recent research on the stochastic variability of many oceanic factors in BC, in addition to the apparently effective ongoing control of sea lice numbers on farms, demonstrate that "significant population declines in wild species" due to farm-origin sea lice cannot robustly be concluded at present and a higher score than 0 is justified.

A score of 2 out of 10 may be allocated for an intermediate situation (i.e., if a score between 0 and 4 is most appropriate) or when "*the farming system is open to the environment and suffers from high disease or pathogen related infection and/or mortality.*" While the system is open, and the majority of sites are likely to be infected with sea lice, the average on-farm annual mortality rates of approximately 2%, are not considered high. The significant numbers of infected juvenile wild salmon, even if not having a population-level impact, is an ongoing concern as are the potential sublethal and predation risks. The as yet unknown potential impacts of introduced viral pathogens such as PRV on Pacific salmon are also a concern, and despite the current lack of demonstrable impacts, any application of a precautionary principle in the face of this uncertainty would warrant a high concern.

Seafood Watch applies a precautionary principle in situations where there is significant uncertainty, therefore, the final score for the Disease Criterion is 2 out of 10 and reflects the ongoing high conservation concern. It is hoped that ongoing projects such as the Salmon Health Initiative will provide greater clarity on these issues.

Criterion 8: 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: Aquaculture operations use eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture.*

Source of stock parameters	Score	
C8 % of production from hatchery-raised broodstock or natural (passive) settlement	100	
C8 Source of stock Final Score	**10.00**	**GREEN**

Due to the industry-wide use of domesticated broodstocks, the BC salmon farming industry is considered to be independent of wild salmon fisheries for the supply of adult or juvenile fish. The score is 10 out of 10.

Criterion 9X: Wildlife and Predator Mortalities

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

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

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score	**-4.00**	**YELLOW**
Critical?	NO	

Harbor seals and sea lion mortalities have declined from a peak in the mid- to late-1990s of several hundred per year to less than ten for the first three quarters of 2013. The current numbers are not considered to significantly affect the population size of these species, and the final score (for this exceptional criterion) is a penalty of -4 out of -10.

Justification of Ranking

According to DFO[52]: "*Fisheries and Oceans Canada (DFO) is the agency responsible for the management, including conservation and protection, of marine mammals in Canada. Provisions in the Pacific Aquaculture Regulations allow for 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*."

Figure 14 shows mortality numbers of harbor seals, California sea lions and Stellar sea lions from 1990 to 2013, according to industry quarterly reported data published by DFO[53]. After a peak in mortalities in the mid- to late-1990s of over 600 harbor seals and sea lions per year and a recent upswing in 2010 and 2011 (71 harbor seals and 232 California sea lions of which approximately 94% of harbor seals and 98% of California sea lions were shot), results for 2012 and to September in 2013 show very low mortalities (less than ten for the first three quarters of 2013). This is due, at least in part, to new policies enacted by companies in late 2011 (Paula Galloway, Marine Harvest, personal communication). There are indications that high mortalities in 2010 and 2011 may have been largely the result of site-specific problems with DFO data showing that at just two sites (Mahatta East and Mahatta West), 120 California sea lions were shot in the first half of 2011.

[52] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/mar_mamm-eng.htm
[53] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/mar_mamm-eng.htm

In March 2013, a humpback whale was found dead at a salmon farm in BC. According to DFO, this incident is still being investigated, but appears to be an isolated incident[54].

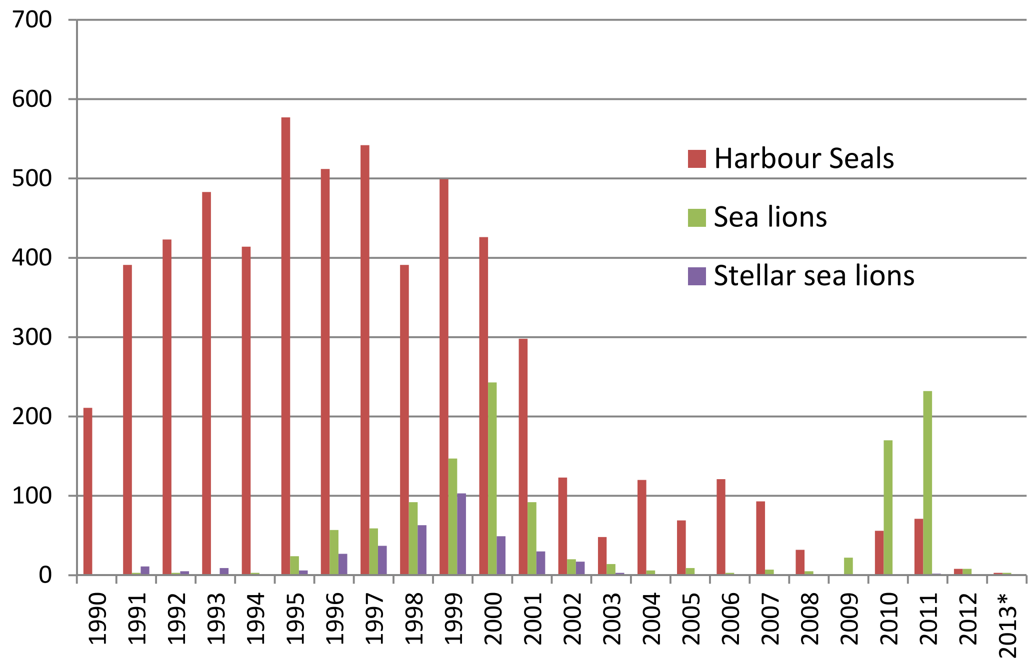

Figure 14: Industry-reported predator mortalities from shooting and drowning. Data source: DFO[55]. 2013 data total to September 2013.

The Stellar sea lion was designated by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as a Species of Special Concern in 2003, after which the seal control licenses were modified to remove them from the licenses. Subsequently, aquaculture facility operators must apply for special permission to lethally remove any marine mammal species other than harbor seals or California sea lions.

Having been depleted by over-hunting prior to the species being protected in 1970, the BC harbor seal population has increased considerably from approximately 10,000 in 1970 to about 105,000 in 2009 (DFO 2010). Stellar sea lion populations have been estimated to be between 20,000 and 28,000 in 2008 surveys (DFO 2008). California sea lions in BC waters are migrants from more southerly breeding populations; the abundance of the US stock of California sea lions, estimated to be 238,000, is considered to be approaching the carrying capacity of its environment (NOAA 2012)[56]. While distasteful from an anthropomorphic perspective, from an

[54] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/docs/mar_mamm/drowning-noyade/2013-Q1-T1-eng.html

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

[56] NOAA Fisheries Office of protected resources. http://www.nmfs.noaa.gov/pr/species/mammals/pinnipeds/californiasealion.htm

ecological perspective the apparently stable population gives confidence that the current low mortality numbers do not significantly impact the population size of these species.

In addition to marine mammals, incidental catches of fish within salmon net pens can be significant. An example from quarterly data reported by DFO[57] include catches of 5,400 herring in Q1, 2012, or 2.5 mt of herring, and 5,274 herring in Q2, including 2,355 Pacific cod in Q3. In Q1, 2011, there were 1,622 yellowtail rockfish caught, which is considered to be more than the annual quota for the recreational rockfish fishery (Kelly Roebuck, Living Ocean Society, personal communication). The catches also include small numbers of Pacific salmon.

Wildlife Mortality Criterion- Conclusions and Final Score

While significant mortalities of seals and sea lions have occurred in recent years, the numbers are not considered to significantly affect the population size of these species. The most appropriate scoring option in the Seafood Watch criteria is a low-moderate concern, defined as: "*Wildlife mortalities occur (beyond exceptional cases), but due to high population size and/or high productivity and/or low mortality numbers, they do not significantly impact the affected species population size."* Note this is an "exceptional" criterion and the scoring range is from 0 (no concern) to -10 (very high concern). The final score for this exceptional criterion is therefore a penalty of -4 out of -10.

[57] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/incidental-accidentel-eng.htm

Criterion 10X: Escape of Unintentionally Introduced Species

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

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

Escape of unintentionally introduced species parameters	Score	
C10Xa International or trans-waterbody live animal shipments score	0	
C10Xb Biosecurity of source/destination	6.0	
C10X Escape of unintentionally introduced species Final Score (deduction)	**-4.0**	**YELLOW**

BC has now become largely independent of international imports of eggs (none since 2009); however, the available evidence indicates that a newly identified European virus, piscine reovirus (PRV), was introduced into BC in approximately 2007. The presence of ISAV in BC continues to be debated as does its source and pathogenicity status if present. The ongoing risk of introducing further non-native species is also considered to be low while the import of eggs into BC remains low. The recent and potentially ongoing movements of PRV infected fish from freshwater hatcheries to marine grow-out sites continue to be a concern and, although these movements occurring within health zones, the potential impacts of PRV remain unknown in BC. The potential impacts of previously introduced pathogens such as PRV and ISA are assessed in the Disease Criterion below, but a penalty score of -4 (out of -10) is applied for the ongoing risk of introduction and spread of novel non-native species into BC.

Justification of Ranking

Salmon farming on a global basis (and aquaculture in general) has suffered from the introduction of pathogens during the international movements of live animals— primarily as eggs in the case of salmon[58]. While the impacts to production are well documented, the ecological impacts beyond the farm are less apparent yet understandably of a high concern to any wild salmon populations potentially vulnerable to the same diseases.

In BC, two viruses typify the current debate: ISA and PRV (piscine reovirus). There has been some considerable dispute regarding the presence or otherwise of ISA in BC, its endemic or introduced status and the potential impacts, if present (which may differ substantially between farmed and wild fish). For example, after considering a variety of testimonies, the conclusions of the Cohen Commission[59] stated, "*I find that the evidence does not allow me to conclude whether the infectious salmon anemia virus (ISAv) or an ISAv-like virus currently exists in Fraser River sockeye. I also do not have sufficient evidence to determine whether such an ISAv or ISAv-*

[58] The highest-profile case is probably the introduction of the Infectious Salmon Anemia (ISA) virus into Chile and the resulting collapse in production during 2008-2010 (for a review, see Alvial et al. 2012).
[59] www.cohencommission.ca

like virus, if present, is endemic to BC waters or has been introduced. The most that can be said at present is that a plausible mechanism has been identified, creating a risk that ISAv or an ISAv-like virus may have affected the health of Pacific salmon stocks for the past few decades, or that it may mutate in certain circumstances to a more virulent form."

With respect to the Fraser River sockeye, Cohen also concluded, "*Salmon farms along the sockeye migration route in the Discovery Islands*[60] *have the potential to introduce exotic diseases and to exacerbate endemic diseases, which can have a negative impact on Fraser River sockeye. Disease can cause significant population declines and, in some situations – for example, if a disease were to wipe out a vulnerable stock of Fraser River sockeye – such effects could be irreversible. I therefore conclude that the potential harm posed by salmon farms to Fraser River sockeye salmon is serious or irreversible."* While this is clearly a strongly conditional statement, and the Cohen report also clearly concludes that these potential impacts have not happened, it indicates the potential severity of the impacts should this chain of events occur.

More recently, concern has been expressed regarding the potential introduction of piscine reovirus (PRV) into BC; tests for PRV in BC were first established in 2010 and 75% of initial farmed salmon samples were positive for PCR (Gary Marty, personal communication, 2012). Piscine reovirus (PRV) has recently been described as "*a newly discovered fish reovirus of anadromous and marine fish ubiquitous among fish in Norwegian salmon farms*" (Kibenge et al. 2013), and although history of published scientific literature on the virus is limited to a few years, Finstad et al. (2012) concluded that PRV is almost ubiquitously present in Atlantic salmon marine farms. Kibenge et al. (2013) concluded that PRV present in BC is a Norwegian sub-genotype that diverged (i.e., was introduced to BC) from the Norwegian strain between 2006 and 2010 (further defined to 2007 ± 1)[61].

Transfers of fish into and within BC are reviewed by the Introductions and Transfers Committee, and Figure 15 plots salmon egg import data from 1985 to 2012 from DFO (2012a). This shows the last import of salmon eggs into Canada's Pacific region was in 2009 (from Iceland). The large salmon farming companies that dominate production globally are increasingly self-sufficient at the regional level in terms of their broodstock, egg and smolt production, and egg imports into BC from 2010 to 2012 were zero. It is not known if there will continue to be occasional imports of eggs into the region that would represent a threat of disease introduction as well as the introduction of non-native pathogens (or non-native strains of endemic pathogens) into BC.

[60] The Discovery Passage and the associated island are the main (but narrow) channel connecting the Georgia Strait to the Johnstone Strait.

[61] For information, Kibenge et al. (2013) concluded the Chilean PRV diverged from Norwegian sub-genotype around 2008 ± 1.

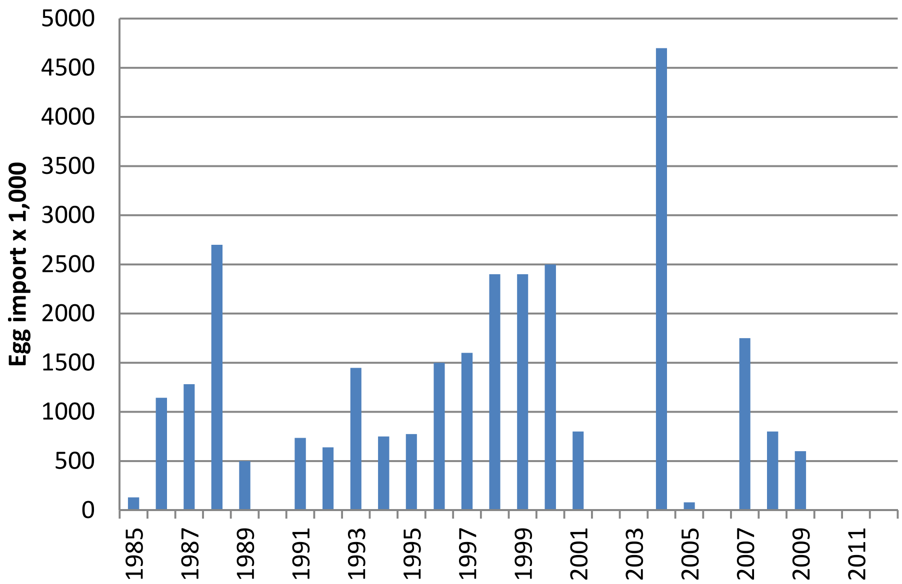

Figure 15. Salmon egg import data from 1985 to 2012. Source DFO.

It is clear that international movements of salmon eggs represent a risk of introducing pathogens into new areas where they have the potential to infect both farmed and wild fish. This Seafood Watch assessment is a snapshot of current production methods of salmon farming in BC and it seems clear that the introduction (or potential introduction) of ISA and PRV happened several years ago at the latest. Data in Figure 15 shows that there have not been any egg imports into BC since 2009 and, therefore, the risk of further introduction of pathogens is currently reduced to zero. Therefore, this criterion (which assesses the ongoing risk of introducing new pathogens associated with current practices), will discuss the current and ongoing potential for disease introduction, while the potential disease impacts of pathogens introduced previously (such as PRV) will be discussed more appropriately along with the existing endemic diseases in BC in the Disease Criterion (C7). The discussion in C7 will include the more complicated issues surrounding the connection of PRV with Heart and Skeletal Muscle Inflammation disease (HSMI), and the potential impacts of ISA to wild salmon populations in BC.

Although the farming system involves the movement of live salmon from freshwater hatcheries to seawater grow-out sites, movements within BC are restricted to health transfer zones, while transfers across zones or into BC require a separate license issued by the Introduction and Transfers Committee. Nevertheless, recent movements of PRV infected fish from hatcheries to grow-out sites have taken place in BC (Alexandra Morton, personal communication, 2013). According to Finstad (2012) and Marty (2013), PRV is probably widely distributed in BC, yet the ongoing movements of fish infected or potentially infected with a pathogen with as yet unknown impacts (even within health zones) in BC is a concern. In 2011 for example, DFO reported[62] 61 within-zone transfers and 60 outside/across-zone transfers, but does not distinguish between different farmed species.

[62] http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/intro-trans-eng.htm

Criterion 10X – Conclusions and Final Score

The scoring structure for this criterion combines the percentage of production reliant on international or trans-waterbody movements of live animals with the biosecurity of either the source or the destination of those shipments (whichever is higher). Note this is an "exceptional" criterion and the scoring range is from 0 (no concern) to -10 (very high concern).

Although current egg imports are zero, the 100% reliance on movements of fish from hatcheries in BC to ocean grow-out sites results in a score of zero out of 10 (i.e., the industry is fully reliant on the movement of potentially infected salmon).

Regarding the biosecurity of the source and the destination, it could be argued that the typical tank-based hatcheries are relatively biosecure and are allocated a score of 8 out of 10. However, with the concerns regarding movements of PRV infected fish and the uncertainty and evidence questioning the biosecurity, this score is reduced to 6 out of 10.

The scoring equation (see the Seafood Watch criteria) generates a penalty score for Criterion 10X of -4 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 (0-10)	Rank	Critical?
C1 Data	7.5	GREEN	
C2 Effluent	5.0	YELLOW	NO
C3 Habitat	6.1	YELLOW	NO
C4 Chemicals	2.0	RED	NO
C5 Feed	5.8	YELLOW	NO
C6 Escapes	4.0	YELLOW	NO
C7 Disease	2.0	RED	NO
C8 Source	10.0	GREEN	
C9X Wildlife mortalities	-4.0	YELLOW	NO
C10X Introduced species escape	-4.0	YELLOW	
Total	**34.4**		
Final score	**4.3**		

OVERALL RANKING

Final Score	4.3
Initial rank	YELLOW
Red criteria	2
Interim rank	RED
Critical Criteria?	NO
Final Rank	**AVOID/RED**

Acknowledgements

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

A large number of individuals and organizations provided input to this assessment, and due to the complexity and the widely varying opinions of stakeholders in BC, this report was reviewed by a large number of experts. I am grateful for all of the data, advice, papers, calls, discussions, meetings and review feedback, all of which was considered in detail in this assessment and made it more complete; however, the final recommendation, inevitably, cannot agree with all of them.

While some reviewers requested to remain anonymous, I am grateful to the following (listed alphabetically by surname):

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

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Reports in any way they find useful. For more information about Seafood Watch and Seafood Reports, please contact the Seafood Watch program at Monterey Bay Aquarium by calling 1-877-229-9990.

Disclaimer
Seafood Watch® strives to ensure all our Seafood Reports and the recommendations contained therein are accurate and reflect the most up-to-date evidence available at time of publication. All our reports are peer reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science or 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. We always welcome additional or updated data that can be used for the next revision. Seafood Watch and Seafood Reports are made possible through a grant from the David and Lucile Packard Foundation.

Guiding Principles

Seafood Watch™ defines sustainable seafood as originating from sources, whether fished[63] or farmed, that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

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

Seafood Watch will:

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

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

practices for some criteria may lead to more energy intensive production systems (e.g., promoting more energy-intensive closed recirculation systems)

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

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

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

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

Data Points And All Scoring Calculations

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

Criterion 1: Data quality and availability

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	*Yes*	7.5	7.5
Effluent	Yes	7.5	7.5
Locations/habitats	Yes	10	10
Predators and wildlife	Yes	7.5	7.5
Chemical use	Yes	7.5	7.5
Feed	Yes	7.5	7.5
Escapes, animal movements	Yes	5	5
Disease	Yes	5	5
Source of stock	Yes	10	10
Other – (e.g. GHG emissions)	No		n/a
Total			**67.5**

C1 Data Final Score	7.5	GREEN

Criterion 2: Effluents

Factor 2.1a - Biological waste production score

Protein content of feed (%)	39
eFCR	1.24
Fertilizer N input (kg N/ton fish)	0
Protein content of harvested fish (%)	16.9
N content factor (fixed)	*0.16*
N input per ton of fish produced (kg)	77.376
N in each ton of fish harvested (kg)	27.04
Waste N produced per ton of fish (kg)	**50.336**

Factor 2.1b - Production System discharge score

Basic production system score	0.8
Adjustment 1 (if applicable)	0
Adjustment 2 (if applicable)	0
Adjustment 3 (if applicable)	0

Discharge (Factor 2.1b) score	0.8

80 % of the waste produced by the fish is discharged from the farm

2.2 – Management of farm-level and cumulative impacts and appropriateness to the scale of the industry

Factor 2.2a - Regulatory or management effectiveness

Question	Scoring	Score
1 - Are effluent regulations or control measures present that are designed for, or are applicable to aquaculture?	Mostly	0.75
2 - Are the control measures applied according to site-specific conditions and/or do they lead to site-specific effluent, biomass or other discharge limits?	Partly	0.25
3 - Do the control measures address or relate to the cumulative impacts of multiple farms?	Partly	0.25
4 - Are the limits considered scientifically robust and set according to the ecological status of the receiving water body?	Partly	0.25
5 - Do the control measures cover or prescribe including peak biomass, harvest, sludge disposal, cleaning etc.?	Moderately	0.5
		2

Factor 2.2b - Enforcement level of effluent regulations or management

Question	Scoring	Score
1 - Are the enforcement organizations and/or resources identifiable and contactable, and appropriate to the scale of the industry?	Yes	1
2 - Does monitoring data or other available information demonstrate active enforcement of the control measures?	Mostly	0.75
3 - Does enforcement cover the entire production cycle (i.e. are peak discharges such as peak biomass, harvest, sludge disposal, cleaning included)?	Mostly	0.75
4 - Does enforcement demonstrably result in compliance with set limits?	Mostly	0.75
5 - Is there evidence of robust penalties for infringements?	Moderately	0.5
		3.75

F2.2 Score (2.2a*2.2b/2.5)	3

C2 Effluent Final Score	5.00	YELLOW
	Critical?	NO

Criterion 3: Habitat

3.1. Habitat conversion and function

F3.1 Score	7

3.2 Habitat and farm siting management effectiveness (appropriate to the scale of the industry)

Factor 3.2a - Regulatory or management effectiveness

Question	Scoring	Score
1 - Is the farm location, siting and/or licensing process based on ecological principles, including an EIAs requirement for new sites?	Partly	0.50
2 - Is the industry's total size and concentration based on its cumulative impacts and the maintenance of ecosystem function?	Partly	0.25
3 – Is the industry's ongoing and future expansion appropriate locations, and thereby preventing the future loss of ecosystem services?	Mostly	0.75
4 - Are high-value habitats being avoided for aquaculture siting? (i.e. avoidance of areas critical to vulnerable wild populations; effective zoning, or compliance with international agreements such as the Ramsar treaty)	Yes	1
5 - Do control measures include requirements for the restoration of important or critical habitats or ecosystem services?	Yes	1
		3.25

Factor 3.2b - Siting regulatory or management enforcement

Question	Scoring	Score
1 - Are enforcement organizations or individuals identifiable and contactable, and are they appropriate to the scale of the industry?	Yes	1
2 - Does the farm siting or permitting process function according to the zoning or other ecosystem-based management plans articulated in the control measures?	Moderately	0.5
3 - Does the farm siting or permitting process take account of other farms and their cumulative impacts?	Partly	0.25
4 - Is the enforcement process transparent - e.g. public availability of farm locations and sizes, EIA reports, zoning plans, etc.?	Mostly	0.75
5 - Is there evidence that the restrictions or limits defined in the control measures are being achieved?	Mostly	0.75
		3.25

F3.2 Score (2.2a*2.2b/2.5)	4.22

C3 Habitat Final Score	6.08	YELLOW
	Critical?	NO

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	Score	
C4 Chemical Use Score	**2.00**	
C4 Chemical Use Final Score	**2.00**	**RED**
Critical?	NO	

Criterion 5: Feed – Note – feed data below is from company 'a" for the purposes of demonstrating the calculations. See average final values in the text above

5.1. Wild Fish Use

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

Fishmeal inclusion level (%)	12
Fishmeal from byproducts (%)	15
% FM	10.2
Fish oil inclusion level (%)	12
Fish oil from byproducts (%)	0
% FO	12
Fishmeal yield (%)	22.5
Fish oil yield (%)	5
eFCR	1.24
FIFO fishmeal	0.56
FIFO fish oil	2.98
Greater of the 2 FIFO scores	2.14
FIFO Score	**4.65**

Factor 5.1b - Sustainability of the Source of Wild Fish (SSWF)

SSWF	-6
SSWF Factor	-1.284

F5.1 Wild Fish Use Score	**3.37**

5.2. Net protein Gain or Loss

Protein INPUTS	
Protein content of feed	39

eFCR	1.24
Feed protein from NON-EDIBLE sources (%)	76
Feed protein from EDIBLE CROP sources (%)	7
Protein OUTPUTS	
Protein content of whole harvested fish (%)	16.9
Edible yield of harvested fish (%)	54.8
Non-edible byproducts from harvested fish used for other food production	100
Protein IN	11.5
Protein OUT	16.9
Net protein gain or loss (%)	+47.7
Critical?	NO
F5.2 Net protein Score	**10.00**

5.3. Feed Footprint

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

Inclusion level of aquatic feed ingredients (%)	24
eFCR	1.24
Average Primary Productivity (C) required for aquatic feed ingredients (ton C/ton fish)	*69.7*
Average ocean productivity for continental shelf areas (ton C/ha)	*2.68*
Ocean area appropriated (ha/ton fish)	7.74

5.3b Land area appropriated by feed ingredients per ton of production

Inclusion level of crop feed ingredients (%)	31
Inclusion level of land animal products (%)	40
Conversion ratio of crop ingredients to land animal products	*2.88*
eFCR	1.24
Average yield of major feed ingredient crops (t/ha)	*2.64*
Land area appropriated (ha per ton of fish)	0.69

Value (Ocean + Land Area)	**8.43**

F5.3 Feed Footprint Score	**7.00**

C5 Feed Final Score	**5.80**	**YELLOW**
	Critical?	**NO**

Criterion 6: Escapes

6.1a. Escape Risk

Escape Risk	**2**

Recapture & Mortality Score (RMS)	
Estimated % recapture rate or direct mortality at the escape site	13
Recapture & Mortality Score	0.13
Factor 6.1a Escape Risk Score	**3.04**

6.1b. Invasiveness

Part B – Non-Native species

Score	**2.0**

Part C – Native and Non-native species

Question	Score
Do escapees compete with wild native populations for food or habitat?	To some extent
Do escapees act as additional predation pressure on wild native populations?	To some extent
Do escapees compete with wild native populations for breeding partners or disturb breeding behavior of the same or other species?	No
Do escapees modify habitats to the detriment of other species (e.g. by feeding, foraging, settlement or other)?	No
Do escapees have some other impact on other native species or habitats?	No
	4

F 6.1b Score	**6**

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

Criterion 7: Diseases

Pathogen and parasite parameters	Score	
C7 Biosecurity	2.00	
C7 Disease; pathogen and parasite Final Score	**2.00**	**RED**
Critical?	NO	

Criterion 8: Source of Stock

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

Criterion 9X: Wildlife and predator mortalities

Wildlife and predator mortality parameters	Score	
C9X Wildlife and Predator Final Score	**-4.00**	**YELLOW**
Critical?	NO	

Criterion 10X: Escape of unintentionally introduced species

Escape of unintentionally introduced species parameters	Score	
C10Xa International or trans-waterbody live animal shipments (%)	0.00	
C10Xb Biosecurity of source/destination	6.00	
C10X Escape of unintentionally introduced species Final Score	**-4.00**	**YELLOW**

Appendix 1: Main principles of responsible and prudent use of antibiotics in food animals— according to WHO (2011)

The responsible and prudent use of antibiotics in food animals is intended to minimize potential harm to human health— particularly the development of antibiotic resistance— while ensuring the safe and effective use of antibiotics in veterinary medicine. The main principles of responsible and prudent use of veterinary antibiotics in food animals include the following:

2. The need for antibiotics in food animals should be reduced by improving animal health through biosecurity measures (to prevent the introduction of harmful bacteria and the development of infections), disease prevention (including the introduction of effective vaccines, prebiotics and probiotics), and good hygiene and management practices.
3. Antibiotics should be administered to food animals only when prescribed by a veterinarian.
4. Antibiotics should be used only therapeutically, and use should be based on the results of resistance surveillance (microbial cultures and antibiotic susceptibility testing), as well as clinical experience.
5. Use of antibiotics as growth promoters should be eliminated.
6. Narrow-spectrum antibiotics should be the first choice when antibiotic therapy is justified.
7. Antibiotics identified as critically important for human medicine— particularly fluoroquinolones and third- and fourth-generation cephalosporins— should only be used in animals if their use is justified.
8. The use of antibiotics in food animals should be limited to their approved and intended uses, take into consideration on-farm sampling and testing of isolates from food animals during their production, where appropriate, and include adjustments to treatment when problems become evident.
9. International guidelines on prudent use of antibiotics, adapted to countries' circumstances, should be followed at the national level. Veterinarians' professional societies should establish guidelines on the appropriate usage of antibiotics for different classes of food animals, including indications of first, second and last-resort choices for treating different bacterial infections.
10. Economic incentives that facilitate the inappropriate prescription of antibiotics should be eliminated.

Appendix 2: Wild salmon conservation status

The table below shows that the status of many of the potentially affected wild salmon populations is “low” or “of concern” (DFO, 2012), and according to COSEWIC (2006) 3 sub-populations are endangered, and one threatened.

Species	Outlook Category			
	1	2	3	4
Sockeye	8	11	10	2
Chinook	7	14	4	0
Coho	2	5	8	1
Pink	0	4	1	1
Chum	2	6	3	0

Outlook categories: 1 = stock of concern, 2 = low, 3 = near target, 4 = abundant.

Overall DFO’s provisional 2013 outlook summary concludes:

•30 Outlook Units are likely to be at or above target abundance
•34 are expected to be of some conservation concern
•the remaining 25 have mixed outlook levels
•overall, the outlook for 2013 has declined slightly relative to the previous outlook

Appendix 3: Additional background on additional factors affecting wild salmon survival in BC

There has been much speculation about the role pathogens and parasites from farmed salmon have played in wild salmon populations declines (Connors 2011, referring specifically to Fraser sockeye). For example, Figure 16 shows that when the obvious decline in Fraser River sockeye productivity from the early 1990s is compared to the rapid increase in salmon farm production over the same period (Figure 17), a visual correlation is immediately apparent.

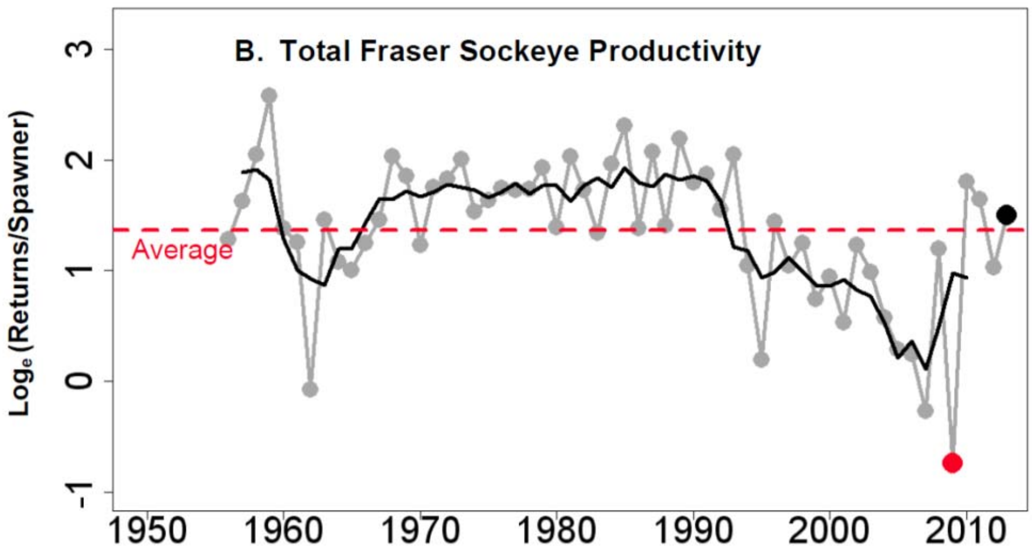

Figure 16: Total Fraser sockeye productivity (log$_e$ (returns/total spawner)) up to the 2013 return year. The light grey filled circles and line presents annual productivity and the black line presents the smoothed four year running average. Returns for 2009 (red filled circle) and 2010 are preliminary, for 2011 and 2012 are in season estimates only, and for 2013 (black filled circle) presents the 50% p-level forecast. Graph from DFO (2013a).

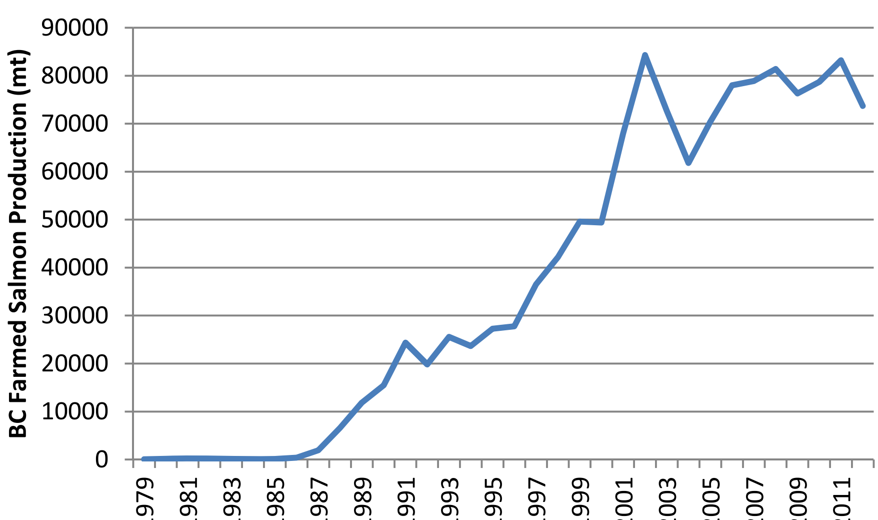

Figure 17: Approximate annual production of farmed salmon (all species) in BC. Data provided by the BC Ministry of Agriculture.

However, the previous sections of this Seafood Watch report show that if salmon farming, and specifically disease, is having a population-level impact on wild salmonid populations in BC, it does so as part of a complex network of contributing factors. Identifying salmon farming's contribution (if any) to the large and stochastic variability in wild salmon populations is challenging. A variety of other factors are explored below in order to put the potential role of salmon farming into context in this region. These other factors are in no way intended to imply any direct impact in opposition to that of salmon farming, but simply illustrate the need to include them in any debate.

The very low Fraser River sockeye return in 2009 followed by a near-record high return in 2010 highlighted the natural fluctuations of wild fish populations in the Georgia Strait and demanded the natural variability of the Strait and the greater Georgia basin be considered in this and any other assessment of the impacts of salmon farming. Thompson et al. (2012) described these returns as an unprecedented opportunity to examine links between oceanic factors and the survival of Pacific salmon stocks. Thompson stated: "*The low returns in 2009 indicated poor early marine survival of juvenile sockeye salmon in 2007. The poor survival was likely due to low food levels arising from unfavorable wind and runoff conditions in the Strait of Georgia and the Queen Charlotte Sound–Hecate Strait region in the spring of 2007*." According to Beamish et al. (2012), the causes of the high mortality (in 2007) likely represented a unique extreme in the variability of the factors that normally affect the survival of juvenile Pacific salmon in the early marine period in the Strait of Georgia.

While these aspects were studied in some depth during the Cohen Commission with respect to Fraser River sockeye, not surprisingly other species also show dramatic fluctuations in response to ocean conditions. For example, Preikshot (2013) noted that Pacific herring and other species of Pacific salmon in the Strait of Georgia had exceptionally poor survival and growth in the spring of 2007, when most sockeye salmon returning in 2009 entered the ocean as juveniles. According to Preikshot (2013), it was likely that extremely anomalous ocean conditions in the Strait of Georgia in 2007 affected the growth and survival of Pacific herring, coho salmon, Chinook salmon and chum salmon. The high return of sockeye in 2010 and, therefore, survival of fish entering the ocean in 2008 has even been associated with iron fertilization and phytoplankton blooms caused by the eruption of the Kasatochi volcano (Olgun et al. 2013), although this has been challenged by McKinnel (2013).

While the 2007/2008 conditions were closely studied with respect to the 2009/2010 Fraser sockeye returns, these anomalies (while perhaps extreme examples) are clearly part of longer term trends and responses to the effects of longer term ocean-scale cycles. For example, Preikshot et al. (2013) studied the ecosystem dynamics of the Georgia Strait from 1960 to 2009 and noted two periods of low production— the early 1960s to early 1970s and the early 1990s to late 2000s. In contrast, the period from the mid-1970s to late-1980s was characterized by relatively high production. A layman's correlation between this pattern and the productivity of Fraser sockeye, in Figure 16 above, is clearly apparent and again indicates the potential difficulty of attributing any role in this decline to salmon farming, which has increased predictably in volume and had relatively stable production characteristics by comparison over the same period.

There are indications that these factors apply over much larger area; Sharma et al. (2013) found evidence that survival of Chinook salmon stocks from the north California coast to Southeast Alaska (mostly now supported by large-scale hatchery releases) is affected by environmental conditions at ocean basin, regional, and local scales. They noted that juvenile salmon typically leave the freshwater environment to enter an ocean that is either in or near a state of transition from winter to spring conditions, the timing of which is also changing. Allen and Wolfe (2013) analyzed the timing of the spring plankton bloom showing it to have been later in the early 70s, earlier in the early 1990s, and later again in recent years. They also state that since the early 1990s there have been a few very early blooms leading to a large interannual spread in bloom times.

DFO (2012c) describes the Strait of Georgia as a semi-enclosed marine basin between Vancouver Island and the mainland, and as perhaps the most human-dominated marine ecosystem in Canada. They state, "*It is also experiencing important environmental changes, such as a warming of all depths (1970-2006) and declines in the concentration of oxygen in deep waters. Summer temperatures in the Fraser River have increased and its summer flow decreased (1942-2006), resulting in increased pre-spawning mortality of migrating sockeye salmon. The biomass of large cold-water copepods has been low during the 2000s compared with the 1980s and 1990s, and the peak of zooplankton biomass has been shifting to earlier in the year.*"

Clearly, this has implications for the feeding success of juvenile salmon in the region. DFO (2009) describes the importance of zooplankton production to the survival rate of fish species (and seabirds, etc.) and notes how observations of zooplankton anomalies provide a useful index of health and survival of juveniles along the BC coast. Figure 18 below shows principle component (PC) analysis of zooplankton anomalies between 1979 and 2008, demonstrating warm unproductive years in red, and cooler more productive years in blue. Obviously, it would also be possible to make a similar visual correlation between the regime shift in the early 1990s in this figure and the productivity of Fraser sockeye in Figure 16 above (it is important to note that this data is from the west of Vancouver Island, not the Georgia Strait).

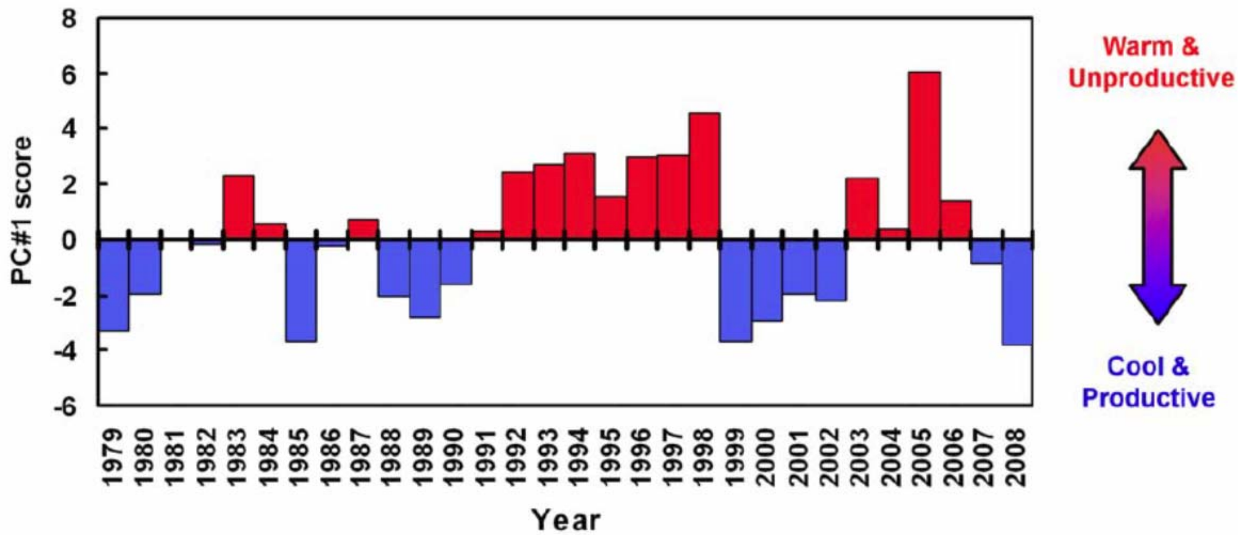

Figure 18: Time series of scores of the marine survival index in coastal waters off Vancouver Island. Graph from DFO (2009).

Araujo et al. (2013) concluded the zooplankton biomass anomaly, calanoid copepod biomass, and herring biomass were the best indicators of early marine survival of coho salmon. Li et al. (2013) concluded that these large changes in the zooplankton community may have had a substantial impact on higher trophic levels and the ecosystem as a whole.

With respect to the recent warm unproductive year in 2005 and cold productive year in 2008, it is interesting to note that catch-per-unit-effort of juvenile salmon in 2005 off the west coast of Vancouver Island was generally the lowest on record for most species, suggesting poor marine survival for the smolts that migrated to sea that year (DFO 2009). In contrast, the June-July 2008 catch-per-unit-effort of juvenile Chinook, sockeye and chum salmon off the west coast of Vancouver Island was the highest on record since 1998 by nearly a factor of ten, and the third highest for juvenile coho salmon (DFO 2009). This suggests that early marine survival in this area was consistently high for all the species of salmon in 2008. Thus, DFO (2009) predicted adult returns to be high in 2009 for coho salmon, in 2010-2011 for Chinook and Sockeye salmon, and in 2011 for chum salmon.

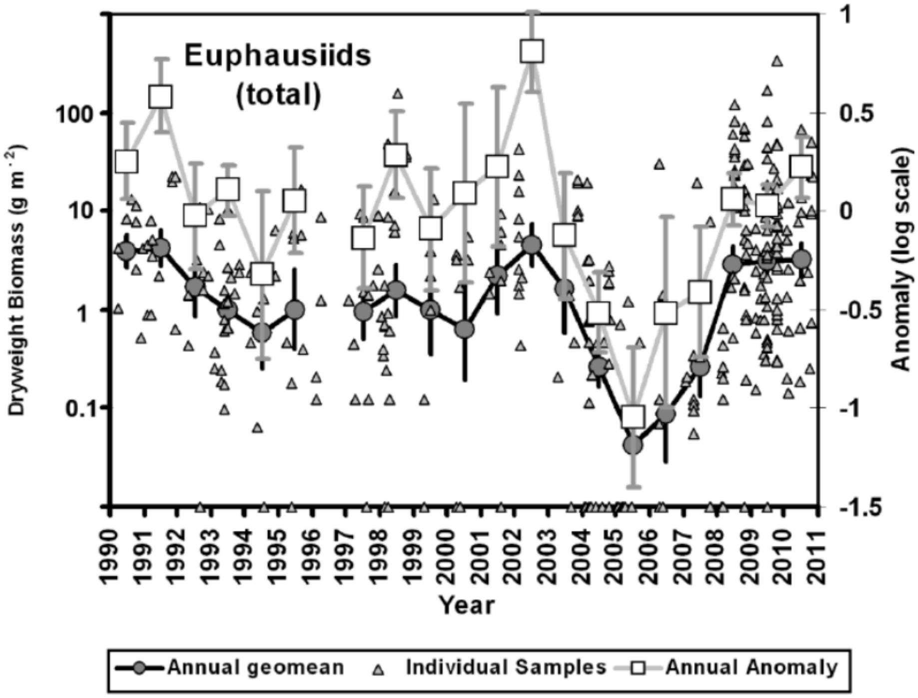

Figure 19: 1990-2010 zooplankton series from the Strait of Georgia showing results for euphausiids. Squares indicate log-scale anomalies relative to average seasonal cycle. Grey circles indicate geomean dry weight biomass; small triangles are biomass in individual samples. Graph from (Mackas, Galbraith et al. 2013).

The logarithmic axis in Figure 19 shows large variations in euphausiid numbers indicating strong interannual variability (Mackas et al. 2013) of about an order of magnitude within most zooplankton categories, and nearly two orders of magnitude for euphausiids and large copepods. Tanasichuk and Luedke (2002) concluded euphausiid availability, as a food source for young coho and sockeye salmon, was more important in determining subsequent returns of adult salmon than the number of smolts themselves. Again, this highlights the importance of factors other than salmon farming in the variability of wild salmon populations. According to Mackas et al. (2013), the dominant factor in zooplankton abundance is a low-frequency decadal fluctuation shared by most zooplankton taxa: declining from 1990 to 1995, increasing to a maximum ~1999–2002, declining to a second minimum in 2005–2007, and then recovering to near-average levels by 2010. This zooplankton signal correlates positively with the North Pacific Gyre Oscillation (NPGO) climate index, negatively with temperature anomalies throughout the water column, and positively (but less consistently) with survival anomalies of Strait of Georgia salmon and herring.

While this association between food availability and wild salmon abundance is not surprising, there continue to be examples that highlight the complexity of these relationships. For example, Price et al. (2013) investigated zooplankton density, diet composition, and foraging selectivity of juvenile Fraser sockeye Salmon during the 2009 and 2010 migrations. The fish appeared to have an adequate prey resource pool during their early marine migration, and in the 2 years of our study we observed similar feeding success throughout the migration period.

Importantly, we found no evidence of food limitations that might indicate that juveniles suffered food deprivation

Within the Georgia Strait, other dramatic variations are apparent. For example, Figure 20 shows a period of high anomalies in the freshwater discharge from the Fraser River between 1990 and 2007, and Figure 19 also shows large changes in euphausiid plankton biomass between 1990 and 2010 (Mackas et al. 2013). With respect to the highly variable returns in Fraser sockeye between 2009 and 2010, it is interesting to note the large variation in river flow anomaly in Figure 22 between 2007 and 2008 (when the 2009 and 2010 returning fish would have been juveniles migrating out to sea) and also the transition from a warm period up to 2006 to cooler in 2008.

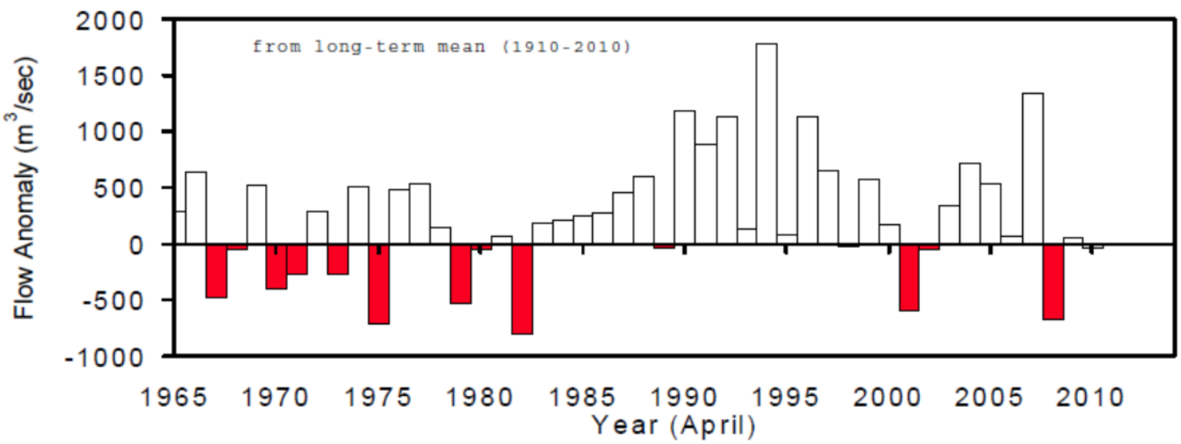

Figure 20: Fraser River flow anomaly from 1965 to 2010 compared to long term (1910 to 2010) average April flow rates. Graph from Irving and Crawford (2012).

It is essential to also note that with respect to many of these variables (i.e., temperature, water flows, salinity, primary productivity, oxygen levels, zooplankton species composition, timing of plankton blooms, salinity, juvenile fish survival and so on) the regions between Vancouver Island and the mainland (i.e., the area containing the majority of the farms) must be considered a separate ecosystem from offshore waters to the west of Vancouver Island (Irving and Crawford 2013). The temperature variations in Figure 20 off the west coast of Vancouver Island, and their associations with high or low productivity may be different from those in the Georgia Strait and the extended region of importance to wild salmon populations (and salmon farms) between the Island and the mainland.

In reality, these variables are part of longer term shifts in ocean cycles, including the North Pacific Ocean Gyre, the Pacific Decadal Oscillation, El Niño and La Niña (Irving and Crawford 2013; Mackas et al. 2013) and climate factors such as the Aleutian Low Pressure Index (Beamish et al. 2010). The interaction of shorter and longer term cycles leads to the high stochastic variability is key species such as Pacific salmon. For example, recent maximum returns for all Sockeye indicator stocks occurred in the early 1990s in association with the powerful 1989 La Niña event 2-3 years earlier. Similarly, a major La Niña event in 2008 was followed in 2010-11 by record to near-record returns of Vancouver Island, Fraser River and Columbia River indicator stocks (note the temperature regime shifts in Figure 20 above) (Irving and Crawford 2013).

An additional layer of complexity also appears to be added by climate change; the Strait of Georgia has experienced considerable warming over the last 50 years as shown in Figure 21 from Irving and Crawford (2012). It is likely (as Rodgers et al. (2013) propose in relation to sea lice) that increasing temperatures will change disease dynamics both in the wild and on salmon farms. These changes are not restricted to the Georgia Strait; Beamish et al. (2010) reported a synchronous and significant decrease in marine survival of coho salmon in the Strait of Georgia, Puget Sound, and off the coast from California to Washington after 1989, and trends in climate indices implies that climate/ocean changes can have profound impacts on the population dynamics of coho salmon.

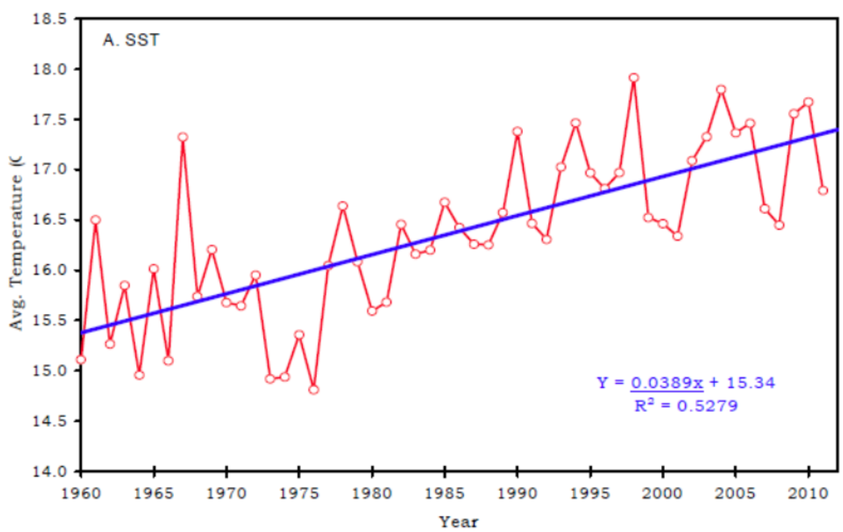

Figure 21. Summer sea surface temperatures (June-August) in the Strait of Georgia from 1960 to 2011. Graph from Crawford and Irving (2012).

In addition to these physical and oceanographic variables, there are also substantial interactions between different salmon species and other fish species in BC.; Irving and Crawford (2012) note a negative interaction with juvenile pink salmon abundance and juvenile Harrison River sockeye salmon, and Connors et al. (2012) suggest the long-term decline in Fraser River sockeye is primarily explained by competition with pink salmon, which can be amplified by exposure to farmed salmon early in sockeye marine life, and by a compensatory interaction between coastal ocean temperature and farmed salmon exposure. Even the minor role of salmon farms in Connors et al.'s results (salmon farming alone did not account for any of the variation in wild sockeye populations in the models) can be questioned with respect to their use of salmon farm production volume as a linear proxy for "pathogen pressure." In reality, while salmon farm production has increased, some farm diseases have been controlled by vaccinations, some have remained stable, while parasites such as sea lice appear to have decreased.

Although primarily studying the long-term decline in Fraser River sockeye that culminated in the low 2009 return, one of the Cohen Commission's many conclusions was: *"I am […] satisfied that marine conditions in both the Strait of Georgia and Queen Charlotte Sound in 2007 were likely to be the primary factors responsible for the poor returns in 2009. Abnormally high freshwater discharge, warmer than- usual sea surface temperatures, strong winds, and lower-than-normal salinity may have resulted in abnormally low phytoplankton and nitrate concentrations that could have led to poor zooplankton (food for sockeye) production."*