Environmental sustainability assessment of farmed Atlantic salmon and Coho salmon from Chile produced in marine net pens

Species:	Atlantic salmon (*Salmo salar*), Coho salmon (*Oncorhynchus kisutch*)
Location:	Chile
Gear:	Marine net pens
Type:	Farmed
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Assessed using Seafood Watch Aquaculture Standard v4

About Seafood Watch®

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

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

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

Guiding Principles

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

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

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

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

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

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

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

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

Final Seafood Recommendation

Atlantic salmon and coho salmon

Salmo salar and *Oncorhynchus kisutch*

Chile

Marine net pens

Criterion	Atlantic Salmon			Coho Salmon		
	Region X	Region XI	Region XII	Region X	Region XI	Region XII
C1 Data	6.59	6.59	6.59	6.59	6.59	6.59
C2 Effluent	4.00	4.00	2.00	4.00	4.00	2.00
C3 Habitat	6.93	6.93	6.93	6.93	6.93	6.93
C4 Chemicals	Critical	Critical	6	6	6	8
C5 Feed	3.41	3.41	3.41	3.41	3.41	3.41
C6 Escapes	4	4	4	1	1	1
C7 Disease	4	4	4	4	4	4
C8X Source of stock	0	0	0	0	0	0
C9X Wildlife mortalities	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00
C10X Introductions	-0.2	-0.2	-0.2	0	0	0
Total	24.73	24.73	28.73	27.93	27.93	27.93
Final score (0-10)	**3.53**	**3.53**	**4.10**	**3.99**	**3.99**	**3.99**

OVERALL RATING	Atlantic Salmon			Coho Salmon		
	Region X	Region XI	Region XII	Region X	Region XI	Region XII
Final Score	3.53	3.53	4.10	3.99	3.99	3.99
Initial rating	Y	Y	Y	Y	Y	Y
Red criteria	1	1	1	1	1	2
Interim rating	Y	Y	Y	Y	Y	Y
Critical Criteria?	1	1	0	1	1	1
Final Rating	**Red**	**Red**	**Yellow**	**Red**	**Red**	**Red**

Scoring note – scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of -10 reflects a very significant impact. Two or more Red criteria or one Critical criterion (illustrated with black background and white text) result in a Red final rating.

For **Atlantic salmon** farmed in net pens in Chile:

- In Region X and XI, the final numerical score is 3.53 out of 10, but with one critical criterion (Criterion 4 – Chemical Use), the final rating is red and a recommendation of Avoid.
- In Region XII, the final numerical score is 4.10 out of 10 and with one red criterion (Criterion 2 – Effluent), the final rating is yellow and a recommendation of Good Alternative.

For **coho salmon** farmed in net pens in Chile:

- In Regions X and XI, the final numerical score is 3.99 out of 10, and with one critical criterion (Criterion 6 – Escapes), the final rating is red and a recommendation of Avoid.
- In Region XII, the final numerical score is also 3.99 out of 10 but with one Critical criterion (Criterion 6 – Escapes), and one red criterion (Criterion 2 – Effluent) the final rating is red and a recommendation of Avoid.

Executive Summary

Chile is currently the world's second largest farmed salmon producer with harvests of 787,131 metric tons (mt) of Atlantic salmon and 204,740 mt of coho salmon in 2020. The industry is predominantly located in Chile's Region X (Los Lagos) and Region XI (Aysén del General Carlos Ibáñez del Campo), and is expanding further south into Region XII (Magallanes y la Antártica Chilena). Atlantic salmon are produced in all three regions, while coho are produced in Regions X and XI, with only minor harvests in two recent years in Region XII. Farmed salmon is Chile's second largest export product (after copper) and in 2018, 27% of exported salmon (and trout) was destined for the US market. US import figures show 192,385 mt of Atlantic salmon (all categories) was imported from Chile in 2020, and 142 mt of coho salmon.

The assessment involves criteria covering impacts associated with effluent, habitats, wildlife mortalities, chemical use, feed production, escapes, introduction of secondary species (other than the farmed species), disease, the source stock, and general data availability[1]. As noted below, the data availability in Chile is improving, with some types of data available at the site level and many datasets now differentiated by species and by production region. Each region of Chile has complex environmental and industry variables, but the improved availability of data now allows this Seafood Watch assessment to consider Atlantic and coho salmon separately for many criteria in each of the three primary production regions (Regions X, XI and XII). For coho salmon produced in Region XII, there were small harvests of 771 mt and 3,099 mt in 2019 and 2020 respectively, but the sole producing company has not restocked the sites and is uncertain if any further production will occur. The coho assessment for Region XII was conducted for reference should production resume (using the data from the 2019 and 2020 cycles).

Data collection and availability, particularly from the government, has improved in Chile but the access and availability from outside Chile continues to lag behind other major salmon producing countries, particularly for site-specific information. Many impact areas are active ongoing areas of data collection and study, and published peer-reviewed papers are increasing in addition to many multistakeholder workshops, but the environmental impacts across the three southernmost regions of Chile continue to be challenging to define robustly. Data from sources such as the seafood industry media and the Global Salmon Initiative (GSI) are also useful, but with regard to the latter, the limited number of companies means it must be used with caution as an indicator of a Chile's average performance. There is generally a greater focus on Atlantic salmon in the data and studies in Chile compared to coho, but there are sufficient similarities in the key data that both species in all three regions have the same score for Criterion 1 – Data of 6.59 out of 10.

Some important gaps exist in understanding the carrying capacity of Chile's fjords and channels and the corresponding impact of nutrient discharge from salmon sites cumulatively. However,

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

with good research available on near-field site-level impacts, and good benthic monitoring data (in addition to information on the control measures currently in place to manage biomass at the area level), the Evidence-Based Assessment method was used. The available evidence from Chile (and elsewhere) shows substantial impacts in the water column from salmon farm effluents are unlikely. Time series and 2020 site-level benthic monitoring data from Sernapesca's INFA reports both show high levels of aerobic (favorable) results in Region X, but poorer results in Regions XI and XII. Of particular concern is that less than half of INFA results across the 2012-2020 time series (mean of 49%) and in 2020 (47.3%) in Region XII were aerobic. The results for all regions are similar for both Atlantic salmon and coho. The long-term data shows these results are all improving over time, and the available research shows the impacts are likely to be limited primarily to the immediate farm area, but currently more than half the sites in Region XII must undertake subsequent repeated sampling that demonstrates a return to aerobic conditions before the site can be used again. There is also an ongoing potential for as-yet poorly researched cumulative impacts at the waterbody scale, particularly as the industry expands into new areas in Region XII that may not have sufficient water circulation.

For Regions X and XI, the occurrence of anerobic INFA results is considered frequent (i.e., greater than 10% of all results) but the impacts are considered temporary and primarily confined to the immediate farm area. There is some uncertainty in the potential for cumulative impacts at the waterbody scale, and the final score for Criterion 2 – Effluent is 4 out of 10. For Region XII, the proportion of anaerobic results is consistently much higher; with more than half of all results consistently anaerobic, the effluent impact can be considered persistent. These poor results demonstrate that the industry is expanding into an area for which there is insufficient understanding of the carrying capacity at the local and likely waterbody scale. The final score for Criterion 2 – Effluent in Region XII is 2 out of 10 for Region XII.

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

Effluent). However, the siting of floating net pen arrays does not result in the functional conversion of affected habitats, and the literature indicates that the realization of any or all of these potential impacts does not significantly impact the functionality of the ecosystems or the services provided by them. Further, the removal of farm infrastructure would quickly restore all baseline biophysical processes. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts.

The regulatory system for siting and impact assessment (at least for new or expanding sites) in Chile appears to be effective, but (noting that seabed impacts from particulate wastes are addressed in Criterion 2 – Effluent) it is unclear how the range of potential impacts associated with the infrastructure of the net pen systems are managed, including from a cumulative perspective. The ongoing expansion of the industry into largely pristine habitats in Region XII is a particular focus of interest. The scores for Factor 3.1 (8 out of 10) and 3.2 (4.8 out of 10) combine to result in a final Criterion 3 – Habitat score of 6.93 out of 10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations). This score applies to all regions and to both farmed salmon species.

The open nature of the net pen production system provides no barrier to infection from environmental pathogens and parasites that may subsequently require treatment by chemicals including antimicrobials and pesticides. Total Chilean antimicrobial use on salmon farms declined from 2015 to 2018 but has since increased through 2020. The average country-level use reported by Sernapesca of 350 g/mt hides considerable variability by species and production region both in total and relative terms; for example, Atlantic salmon production accounts for substantially more than coho salmon, and Regions X and XI account for more than Region XII. The relative use of Atlantic salmon in Regions X, XI and XII in 2020 was calculated to be 588.2 g/mt, 543.9 g/mt, and 99.5 g/mt respectively, with an approximate treatment frequency of 3.1 treatments per site per year in Region X, 2.9 in Region XI, and 0.5 in Region XII. The relative use of coho salmon in Regions X, XI, and XII in 2020 was calculated to be 29.3 g/mt, 27.1 g/mt, and 5.0 g/mt respectively, with a treatment frequency per site per year of 1.0 in Regions X and XI, and 0.2 for the small amount of coho production in Region XII.

Almost all antimicrobial use (96.8% by weight in 2020) is currently of florfenicol, although oxytetracyline has until recently also been important. The direct ecological impacts of antimicrobials to the receiving environments remain unclear, but of high general concern is the potential development of antimicrobial resistance (in the treated bacterial pathogen as well as in the surrounding non-target bacterial communities) and the possible passage of mobile resistance genes to human pathogens. Although only used in veterinary applications, florfenicol is listed by the World Health Organization as highly important for human medicine due to the concern regarding the contribution to resistance in a variety of bacterial populations to other antimicrobials (via mobile resistance genes, e.g., the “floR” gene for florfenicol). Determining the drivers and scale of these processes are challenging and this is an active area of research in Chile. It is important to note a contrasting paradigm that suggests resistance genes initially enter aquatic environments primarily from the human and terrestrial sources.

Some recent studies indicate phenotypic resistance (technically the loss of susceptibility) in the primary target of antimicrobials in Chile (the bacterial pathogen *P. salmonis)* is not developing or is uncommon, and there is no evidence of clinical failures in production due to resistance. However, the government's resistance surveillance program shows approximately 50% of the isolates of *P. salmonis* from Atlantic salmon farms tested in 2020 show reduced susceptibility to florfenicol (and approximately 17% to oxytetracycline) in laboratory in-vitro trials. Values were low for other pathogens with the exception of *Flavobacterium psychrophilum* which showed 67% of isolates had reduced susceptibility to oxytetracycline. The research on the mechanisms underlying the acquisition and dissemination of acquired antimicrobial resistance by varied bacterial populations continues to evolve, and there is no conclusive link to antimicrobial use in aquaculture. Yet, there is inevitably a high concern that the widespread, repetitive, and prolonged use of antimicrobials in Chilean salmon farms (particularly Atlantic salmon farms) has resulted in bacterial populations evolving and adapting to the two most commonly used drugs.

Pesticide use for Atlantic salmon in Chile is also high and increasing, reflecting the ongoing struggle to control parasitic sea lice. Nearly 20 mt active ingredient of pesticide was used in 2019, plus over 3,200 mt of hydrogen peroxide, with pesticide use predominantly occurring in Regions X and XI due to the low sea lice numbers to date in Region XII. The impact of these pharmaceuticals on the marine environment remains largely uncertain, particularly with regard to repetitive treatments at a single site or from coordinated treatments in a single waterbody. Widespread resistance has previously developed in Chile and is likely to recur with the repeated use of a limited number of available treatments. With a minimal presence of sea lice on coho salmon, pesticide use for coho is considered here to be zero.

Overall, there is no specific evidence indicating that antimicrobial use in Chilean salmon farms has led to the development of clinical resistance (i.e., the loss of efficacy of treatments) for the primary treated pathogens. It must also be noted that bacterial resistance genes in marine environments may have originated from human and terrestrial sources; however, the ongoing repetitive (and currently increasing) use of hundreds of metric tons of a single antimicrobial with multiple treatments per site per year for Atlantic salmon is a high concern. Florfenicol is noted for its "floR" mobile resistance gene and the potential contribution to the pool of resistant genes in the environment. This is considered a critical conservation concern for Criterion 4 – Chemical Use for Atlantic salmon in Regions X and XI where the use of florfenicol is concentrated. Pesticide use for Atlantic salmon in these two regions is also high. For Atlantic salmon in Region XII, where antimicrobial and pesticide use (and therefore contribution to the concern for resistance persistence and development) are currently lower, the final score is 6 out of 10. For coho salmon, the frequency of florfenicol use is approximately once per site per year in Regions X and XI and (with no pesticide use) the final score for Criterion 4 – Chemical use is 6 out of 10. For coho salmon in Region XII (if production were to continue) with low antimicrobial and pesticide use, the final score is 8 out of 10. It is noted here that while chemical use in Region XII is currently minor, it has increased as production has increased in the region. This assessment is based on current practices, but it is noted that while fish health and chemical use are considered within the ACS management system, there are no robust measures that would prevent the increases in antimicrobial or pesticide use seen in Regions X and XI as production increased in the past. Maintaining low reliance on chemotherapeutants in Region XII is imperative and monitoring of the industry's chemical use will be ongoing.

In the absence of specific feed composition information from Chilean feed mills, categorical feed composition data from salmon farming company reports was supported with specific ingredients from reference feeds in the academic literature. While not specifically accurate, the key aspects relating to this assessment were considered to be sufficiently robust. The same feeds are considered to be used for Atlantic and coho salmon in Chile, and while performance indicators such as the Feed Conversion Ratio may vary by region, there is currently insufficient regional data to assess them separately. Using total fishmeal and fish oil inclusions of 15% and 10% respectively (and typical proportions sourced from fish trimmings and byproducts) and an eFCR of 1.3, from first principles, 1.98 mt of wild fish must be caught to produce the fish oil needed to grow 1.0 mt of farmed salmon in Chile. This value was higher than the three-year average of eight companies reporting through GSI (1.61), but these eight companies cannot be considered to represent all of Chilean production; the difference is likely due to variations in feed conversion ratios, yields and inclusion rates which can be improved with greater data availability. Information on the sustainability of source fisheries obtained for three major feed companies from the Ocean Disclosure Project showed a moderate overall sustainability and resulted in a Wild Fish Use score of 2.82 out of 10. There is a substantial net loss of 63.8% of feed protein (score 3 out of 10) and a moderate feed ingredient footprint of 18.94 kg CO2-eq. per kg of harvested protein (score of 5 out of 10). Overall, the three factors combine to result in a final feed score of 3.41 out of 10.

Large escape events of farmed salmon continue to occur in Chile. 410,000 escapes were reported in 2020, and although large losses only affect a small proportion of farm sites each year, they continue to highlight the vulnerability of the net pen production system. Over the last decade, 4.6 million escaped fish have been reported, and undetected or unreported trickle losses may also be substantial. Recapture efforts are apparent and considered to account for approximately 14% of escapes on average (noting some, e.g., by local fishermen, may not be reported), but large numbers of salmon still enter the environment every year, and the production system remains vulnerable in all regions.

Mature Atlantic salmon are occasionally caught by anglers in rivers in Chile, but after decades of repeated escapes, the available evidence indicates this species is highly unlikely to establish viable populations in Chile. In contrast, the evidence of the establishment and increasing range of coho salmon is now clear in the far south of Chile. Recent research at the southern tip of Chile (in Region XII) has added new records of established populations of coho in the Beagle Chanel and in the Cape Horn Biosphere Reserve. In the IFOP's annual research fishing, an average of 8.4% of all fish caught from 2016 to 2019 (wild and farmed fish of any species) were coho salmon, and from a regional perspective, the proportions of coho increased in more southern regions (4.2% of all fish caught in Region X were coho salmon, with 12.8% in Region XI and 27.4% in Region XII). IFOP has used genetic profiling to assign rainbow trout caught in the wild as wild spawned or as direct farm escapes, but these techniques are still in development for coho salmon. It is therefore not yet known if these captures of coho and their apparent establishments and/or range expansion are due to previous ranching efforts (where coho and other salmonid species were deliberately introduced into Chilean rivers) or, as some recent authors have suggested, due to more recent aquaculture escapes. In Regions X and XI, despite the common occurrence of mature coho salmon returning to rivers in Region X in the 1980s, it does not appear that spawning has been successful. It is currently unclear what the impacts of coho would be in addition to those of the other non-native salmonids already widely established in Chile (rainbow, brown and brook trout, and Chinook salmon), but southern Chile has unique ecosystems with high degrees of endemism, and due to the demonstrated piscivorous nature of coho salmon, there is a high potential for impacts to native species, some of which are endangered.

The final score for Criterion 6 – Escapes combines the escape risk (Factor 6.1) with the risk of competitive and genetic interactions (Factor 6.2). For both species, the vulnerability of net pen systems to escape, with a small adjustment for recaptures, results in a Factor 6.1 score of 3 out of 10. For Atlantic salmon, which are considered to be highly unlikely to establish in Chile, the score for Factor 6.2 is 6 out of 10, and the final score for Criterion 6 – Escapes is 4 out of 10. For coho salmon, given their well-established migratory abilities, it is not clear how much (if any) aquaculture escapes in any of the three regions contribute to the apparent ongoing establishment and/or range expansion of coho in Region XII, but the potential impacts in Chile's unique ecosystems are a high concern; therefore, the score for Factor 6.2 in all three regions is 0 out of 10. For coho, the vulnerable containment system combined with the increasing evidence of ecological establishment and range expansion (with uncertain impacts to non-native species, some of which are endangered) results in a final score for Criterion 6 - Escapes of 1 out of 10 for coho in Region XII. This is considered a critical conservation concern.

Disease-related losses and increased production costs have been a defining characteristic of the development of salmon farming in Chile, but with improving control, the mortality due to disease is relatively low. While coho have a higher average monthly mortality than Atlantic salmon (1.24% for coho versus 0.96% for Atlantic salmon), coho are not significantly infected by parasitic sea lice. The IFOP monitoring of wild-caught fish for the presence of pathogens of concern to salmon farming (nine viral and nine bacterial pathogens, most of which are not salmonid-specific) shows a low presence in the wild. Similarly, the detection of external and internal parasites on wild fish was low (88.9% of the wild fish caught in IFOP sampling had no detectable parasites, and of the remaining 11.1%, two-thirds were infected with internal parasites, and only one-third had external parasites such as the sea lice that dominates farmed Atlantic salmon production). While encouraging, these data do not provide information on any other potential pathogens of concern to wild fish or any indications of subsequent mortality, nor do they account for the challenges of detecting diseases (including capturing diseased fish) in the wild. Unlike other major salmon farming regions (in the North Atlantic and North Pacific), there are no native salmonid populations of concern in Chile, but salmon farms still represent a chronic reservoir of known and probably unknown infectious pathogens and parasites which may be transmitted to wild fish (including species endemic to Chile). Parasitic sea lice in Region XII appear to have originated in Atlantic Argentina and moved to the Chilean Pacific with movements of wild fish through the Straits of Magellan (as opposed to being introduced from salmon farms in Regions X and XI), but the recent establishment of parasitic sea lice at high prevalence on a small number of farms in the southernmost Region XII, where it was previously undetected, is an additional concern as production increases.

Without a robust understanding of how on-farm diseases impact or do not impact wild fish, the Risk-Based Assessment method is used. Ultimately, despite the widespread employment of biosecurity protocols, Chilean salmon farms are challenged with disease and the openness of the net pen production system directly connects farmed salmon of both species to wild populations. Although the disease, parasite, and mortality profiles of Atlantic salmon and coho differ, the overall risks are considered similar and the final score for Criterion 7 – Disease is 4 out of 10 for both Atlantic and coho salmon.

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

The presence of cultivated salmon in net pens at high density is attractive to opportunistic coastal marine mammals, seabirds, and fish. The data availability for marine mammal and bird mortalities on salmon farms in Chile is limited and has been shown to be of questionable validity, particularly considering the remote areas in which the industry operates. As such, without a robust understanding of the impact to wildlife resulting from farm interactions, the Risk-Based Assessment method was used. Intentional mortality of marine mammals is prohibited (except in cases where human life is endangered), but animals such as Southern sea lions and birds are considered to regularly interact with farms. There are records of accidental cases of mortalities of sea lions, dolphins, humpback whales, and recently a single sei whale, and while there are no indications from other published studies that deliberate or accidental mortalities occur in quantities sufficient to affect the population status of relevant species, the data are limited. The aquaculture vessel fleet in Chile (which includes vessels servicing both the salmon and shellfish industries) is large and has a significant potential for interactions with blue whales. While the potential disturbance is addressed in Criterion 3 – Habitat, the risk of mortality to cetaceans from collisions with aquaculture vessels appears low. Overall, regulations and management practices for non-harmful exclusion and control are in place, but accidental mortalities (such as those resulting from entanglement) cannot be prevented, and mortality numbers are unknown. There is no evidence with which to distinguish Atlantic and coho salmon in this regard, and the final score for Criterion 9X – Wildlife Mortalities is -4 out of -10 for both species.

As Chile becomes self-sufficient in salmon egg production, the importation of eggs has declined to approximately 400,000 in 2020 (from a peak of 275 million in 2008); nevertheless, any movements carry a risk of introducing secondary species such as pathogens. The single permitted source of live egg movements to Chile is in Iceland, and the biosecurity is high (although never perfect). As such, there is only a small risk of unintentionally introducing secondary species during live animal shipments of Atlantic salmon to and within Chile, and the final score for Criterion 10X – Introduction of Secondary Species is a minor deduction of -0.2 out of -10. For coho, the apparent lack of egg imports or movements across ecologically distinct waterbodies results in a final deduction of 0 out of -10.

Overall, for **Atlantic salmon** farmed in net pens in Chile:

- In Region X and XI, the final numerical score is 3.53 out of 10, but with one critical criterion (Criterion 4 – Chemical Use), the final rating is red and a recommendation of Avoid.
- In Region XII, the final numerical score is 4.10 out of 10 and with one red criterion (Criterion 2 – Effluent), the final rating is yellow and a recommendation of Good Alternative.

Overall, for **coho salmon** farmed in net pens in Chile:

- In Regions X and XI, the final numerical score is 3.99 out of 10, and with one critical criterion (Criterion 6 – Escapes), the final rating is red and a recommendation of Avoid.
- In Region XII, the final numerical score is also 3.99 out of 10 but with one Critical criterion (Criterion 6 – Escapes), and one red criterion (Criterion 2 – Effluent) the final rating is red and a recommendation of Avoid.

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Introduction

Scope of the analysis and ensuing recommendation

Species: Atlantic salmon (*Salmo salar*), Coho salmon (*Oncorhynchus kisutch*)

Geographic coverage: Chile: Region X – Los Lagos; Region XI – Aysen; Region XII – Magallanes

Production method: Marine net pens

Species Overview

Atlantic salmon are native to the North Atlantic Ocean with high numbers of discrete genetic sub-populations through Western Europe in the NE Atlantic and the North America landmass in the NW Atlantic. The species has been introduced into Chile along with a number of other non-native salmonid species in historic attempts to establish salmon fisheries (Schröder & Garcia de Leaniz, 2011). It is an anadromous species; birth and early life stages occur in freshwater rivers and streams, followed by a migration downstream and over long oceanic distances where the bulk of feeding and growth take place. After one or more years in the ocean, they return upriver to their original spawning ground to complete the cycle.

Coho salmon are native to the North Pacific basin. They are found from northern Japan, across the Bering Sea to Alaska, and south to California. With a similar life history to Atlantic salmon, coho salmon usually mature during their third year of life. Coho salmon are non-native in Chile, although several historic attempts have been made to establish them for sport fishing in the 1920s and 30s and then for ocean ranching in the 1970s.

Production System

All farmed salmon in Chile are produced in floating net pens in coastal and fjordic inshore environments, typical to the industry worldwide. The hatchery phase is conducted primarily in tanks in indoor flow-through or recirculation systems on land. There are approximately 450 salmonid sites in Chile, but not all are active at the same time; according to Sernapesca[2], in 2020 there were a maximum of 367 active sites and approximately 70% were producing Atlantic salmon, 21% coho, and 9% rainbow trout. The sites (typically called “concessions”) are managed in production neighborhoods or *barrios* (the formal name is A*grupación de Concesiones para la Salmonicultura* – ACS), and marine production sites for salmon are located in Chile’s southernmost Regions X (Los Lagos), XI (Aysén del General Carlos Ibáñez del Campo) and XII (Magallanes y la Antártica Chilena) (Figure 1).

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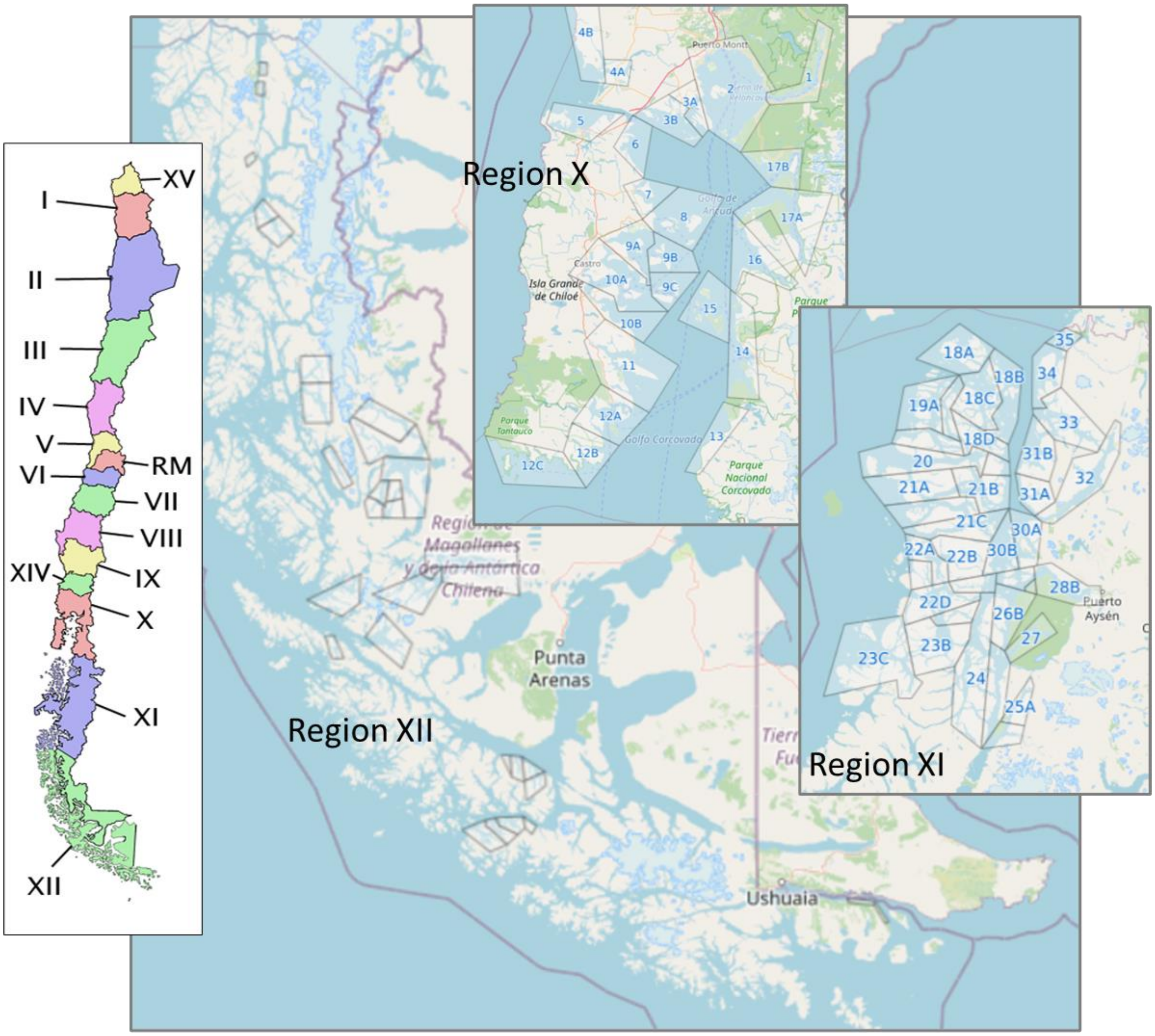
[2] http://www.sernapesca.cl/sites/default/files/informe_sanitario_salmonicultura_en_centros_marinos_2020v2.pdf

Figure 1: Map of aquaculture neighborhoods (ACS) in Region X (Los Lagos), Region XI (Aysen), and Region XII (Magallanes). The scale of the Region XII map is larger, and the ACSs are not numbered. Maps were created from SalmonChile/Intesal's map tool[3]. Inset of all Chilean regions copied from Wikipedia.com.



Production Statistics and Trends

Global production of farmed salmon was approximately 2.65 million metric tons (mt) in 2020, of which approximately 2.42 million mt was Atlantic salmon and 0.25 million mt was coho (Kontali data in Mowi, (2021)). In Chile, according to Sernapesca's annual statistics, the total harvest of seven farmed finfish species from all regions in 2020 was 1,079,626 mt, heavily dominated by Atlantic salmon (787,131 mt) and coho salmon (204,740 mt) (Sernapesca, 2021). These figures show Chile is an important global producer of Atlantic salmon, and the dominant producer of coho salmon.

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[3] http://mapas.intesal.cl/publico/

Figure 2 shows increasing annual production of both species since 2005, but with marked reductions in Atlantic salmon from 2009-2011 due to Infectious Salmon Anemia (ISA) and 2015-2016 due to algal blooms (Sernapesca, 2020). There have been no reported Chinook salmon (*O. tshawytscha*) harvests from aquaculture since 2009. The production of Atlantic salmon increased by over 85,000 mt from 2019 to 2020, while coho declined by 650 mt.

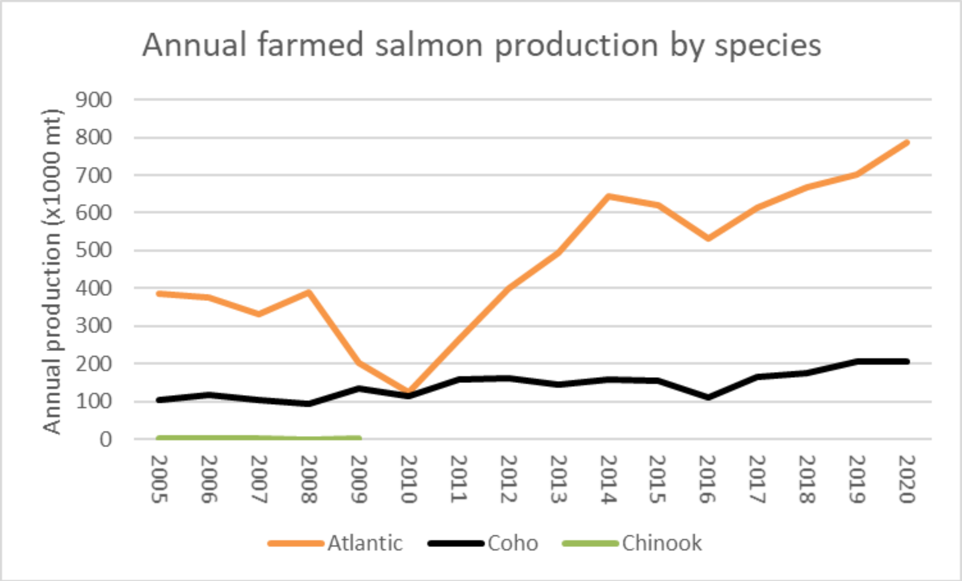

Figure 2: Annual salmon production in Chile. Data from Sernapesca (2020).

The total biomass of farmed salmonids varies from approximately 500,000 to 600,000 mt each year, with a maximum of 610,000 mt in September 2020 (Sernapesca) data. Monthly harvests of Atlantic salmon are consistent through the year, whereas coho salmon has a marked seasonal harvest cycle (Figure 3).

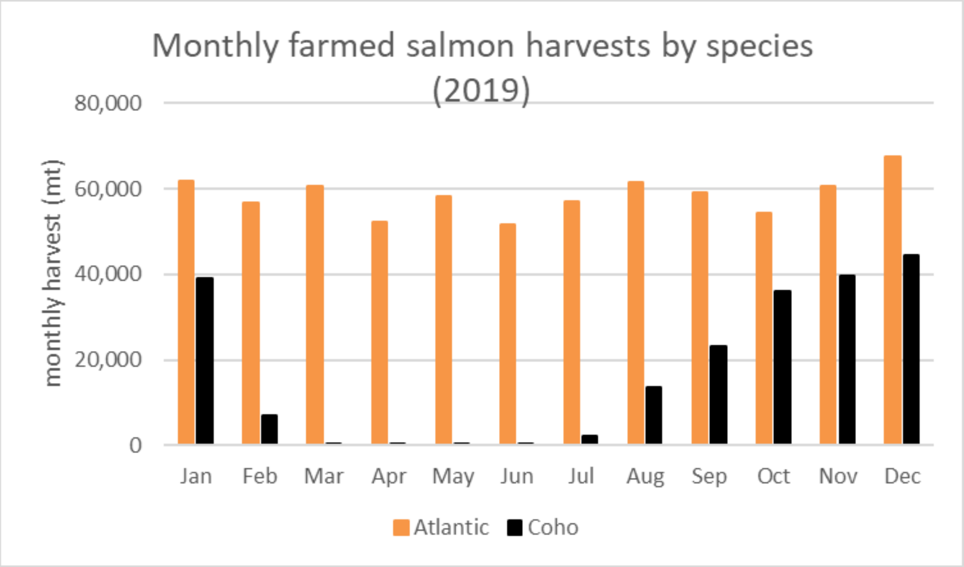

Figure 3: Monthly harvests of Atlantic and coho salmon in 2019. Data from Sernapesca.

While salmon farming was initially concentrated in Region X (Los Lagos – see map in Figure 1), only 33.0% of Atlantic salmon production in 2020 occurred there (Figure 4), compared to 47.8% in Region XI (Aysén) (Sernapesca, 2021). In contrast, 73.2% of coho production in 2020 was in Region X and 25.3% in Region XI. The Magallanes region (Region XII) produced 19.1% of the 2020 total of Atlantic salmon and only 1.5% of coho (Sernapesca, 2021). The harvest of coho salmon from Region XII was zero in 2018, with an initial harvest in 2019 of 771 mt increasing to 3,099 mt in 2020. The company producing the coho in Region XII has not restocked the sites, and it is currently uncertain if there will be further production of coho there (P. Cajtak, pers. comm. 2021).

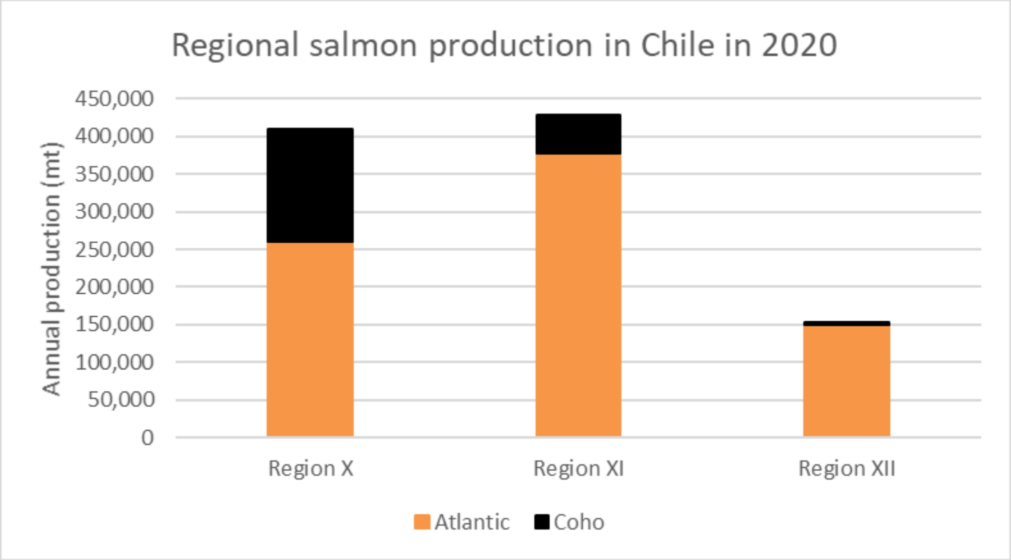

Figure 4: Regional salmon production in Chile in 2020. Data from Sernapesca (2021).

Production is increasing in all regions, but 65% of the increase from 2019 to 2020 was due to the expansion of Atlantic salmon in southernmost Region XII (Magallanes y la Antártica Chilena). Figure 5 shows quarterly harvests and the number of active sites (including trout) in Region XII from Sernapesca's regional bulletins[4],[5]. The number of sites has increased moderately from 2018 to 2021 (39 to 52 sites) as companies bring previously granted licenses into production in remote areas with complex logistics (equipment, labor, smolts, feed, harvesting and processing, etc.) However, production appears to be increasing more rapidly and annual harvests (including trout) more than doubled from 2018 to 2020. A simple linear regression of the quarterly harvests shows a steeper increase, nearly doubling each year (x0.94) over the same three years (Figure 5).

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[4] http://www.sernapesca.cl/boletines-regionales

[5] The harvest of rainbow trout from Region XII in 2020 was 26,882 mt compared to 150,498 mt of Atlantic salmon

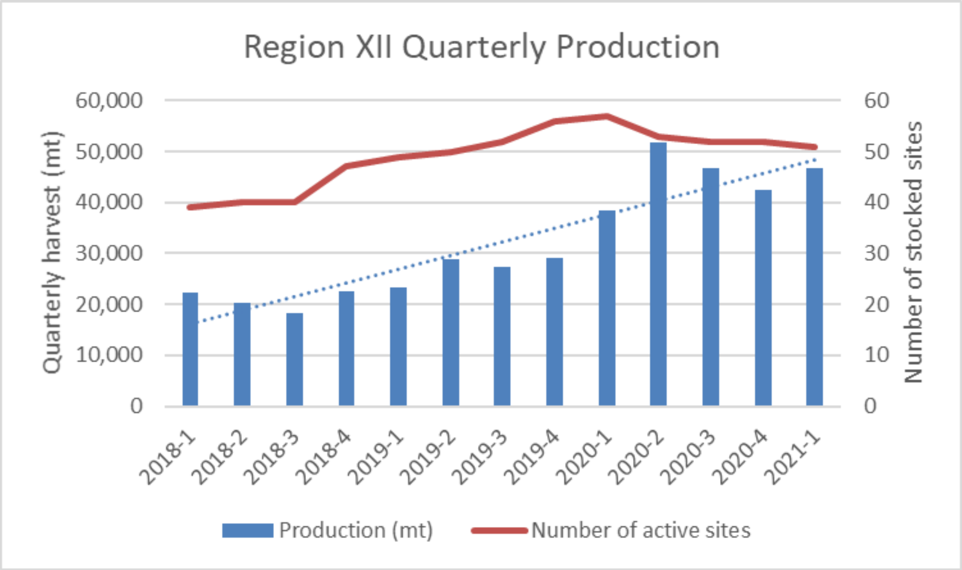

Figure 5: Quarterly farmed salmonid production (mt – including rainbow trout) in Region XII from 2018 to the first quarter of 2021 (blue bars, primary y-axis), and the number of active sites (red line, secondary y-axis, including rainbow trout sites). The dotted blue line shows a simple linear regression fitted by Excel. Data from Sernapesca quarterly bulletins.

Regarding the expansion of the industry in Region XII, Vila et al. (2016) identified High Conservation Value Areas in the Magallanes region, and the results of this process were subsequently used by the Chilean government to assist in aquaculture zoning. By comparing Figure 6 from Vila et al. (2016) with Figure 7 showing Sernapesca's map of areas in which the industry is being allowed to expand, it can be seen that all the current salmon production areas are in locations considered to be "Appropriate Areas for Aquaculture". Currently, production in Region XII is concentrated in three of the areas, labelled in Figure 7 as 3, 6, and 8.

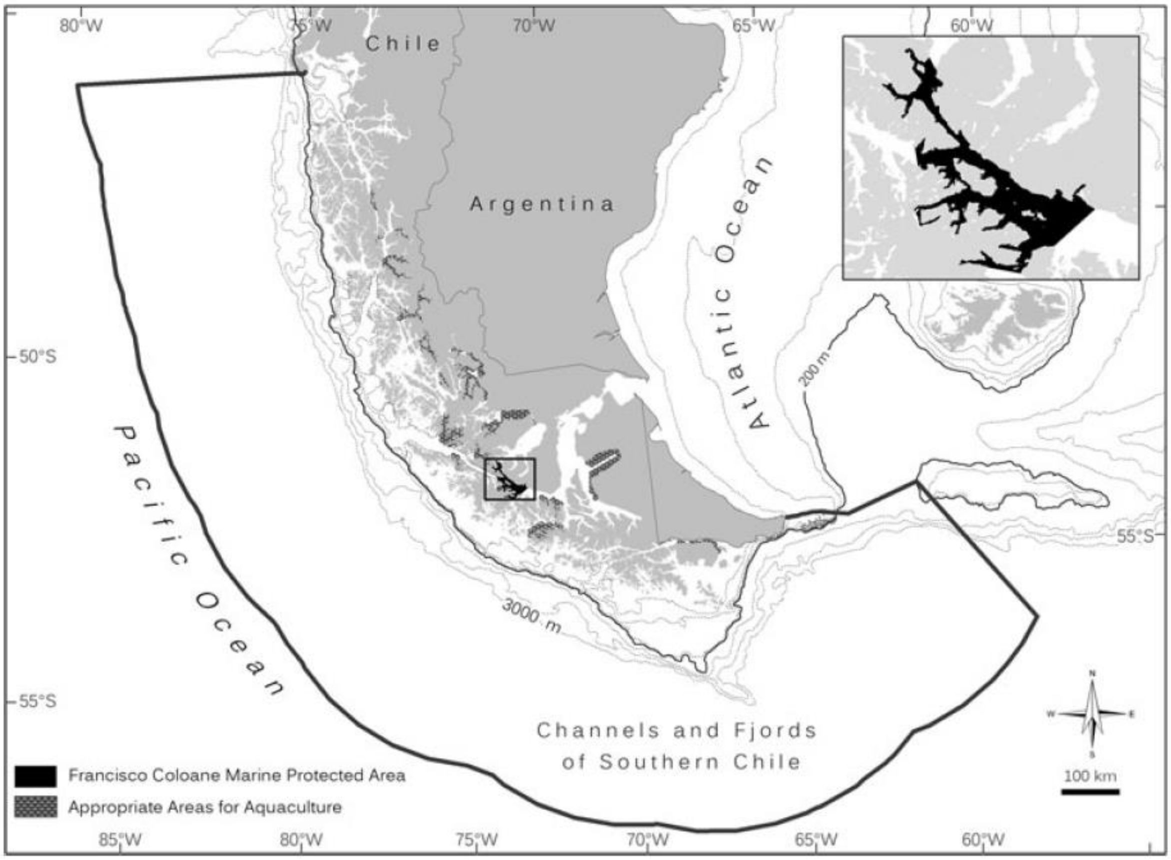

Figure 6: Areas appropriate for Aquaculture in Region XII – image copied from Vila et al. (2016).

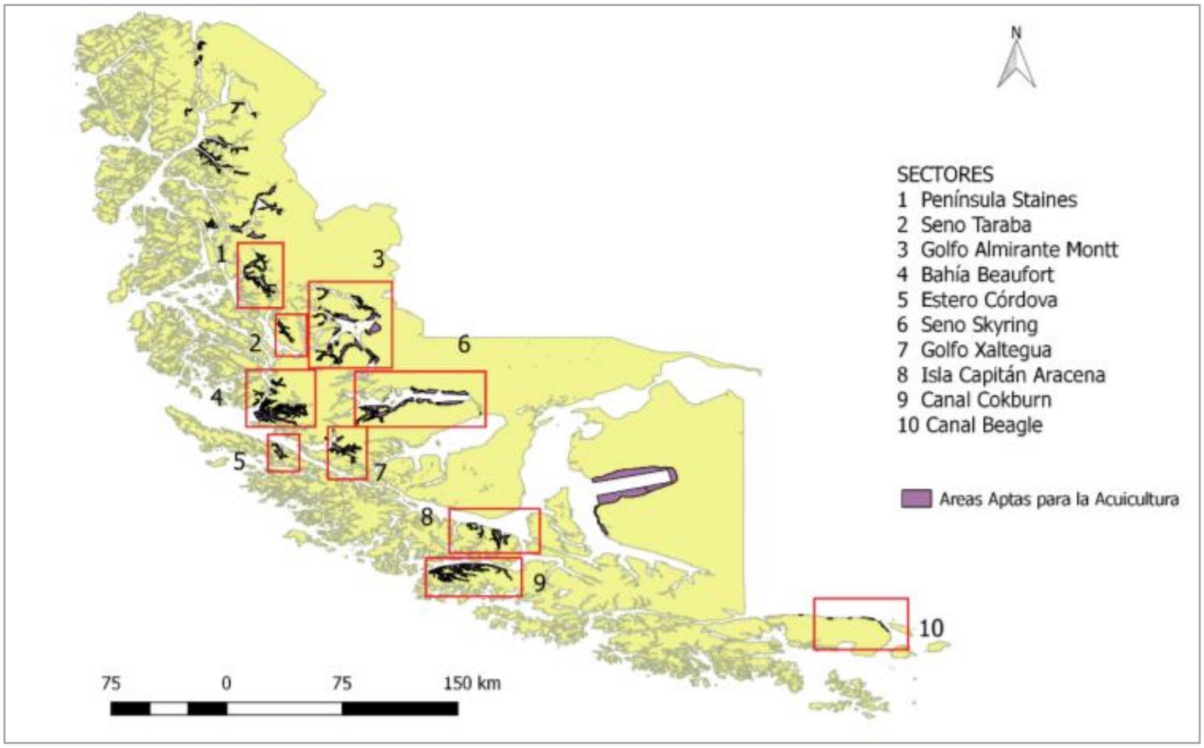

Figure 7: Map of Region XII with ten production sectors (red boxes) and Appropriate Areas for Aquaculture (black and purple). Image copied from Sernapesca.

In total, there are 1,357 finfish aquaculture concessions (sites) defined by Sernapesca (Table 1, of which 37% are in Region X, 53% in Region XI and 9.8% in Region XII. Not all these concessions are for salmon, and not all are in active production (or have ever been in production); for example, as noted above there were 367 active salmon sites in Chile in 2020 with approximately 50 active sites in Region XII.

Table 1: Number of aquaculture concessions (sites) in each of Chile's three southernmost regions. Data from Sernapesca.

Region	Number	Percent of total (%)
Region X	501	36.9
Region XI	723	53.3
Region XII	133	9.8
Total	1,357	100

Currently approximately 111 Atlantic salmon sites and 137 coho sites in Chile are certified to the Aquaculture Stewardship Council (ASC) Salmon Standard (as of July 21, 2021). 247 salmon farm sites (species not specified) are listed as being certified to the Global Aquaculture Alliance's Best Aquaculture Practices Salmonid Standard (as of July 20, 2021) (note some sites are certified to both schemes).

Import and Export Sources and Statistics

Salmon is Chile's second largest export product, after copper; in 2018, 27% of exported salmon (and trout) was destined for the US market (170,058 mt), followed by 23% to Japan (142,921 mt) and 14% to Brazil (87,082 mt) (SalmonChile website[6], accessed July 21, 2021). According to the US National Marine Fisheries Service[7], 192,385 mt of Atlantic salmon (all categories) was imported from Chile in 2020, and 142 mt of coho salmon.

Common and Market Names

Scientific Name	*Salmo salar*	*Oncorhynchus kisutch*
Common Name	Atlantic salmon	Coho salmon, Silver salmon
Spanish	Salmón del Atlántico	Salmón coho, Salmon del pacífico, Salmon plateado
French	Saumon de l'Atlantique	Saumon coho
Japanese	Taiseiyō sake	Ginzake

Product forms

Salmon from Chile is available in all common fish presentations, particularly fillets, whole, and smoked.

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[6] https://www.salmonchile.cl/en/exports/

[7] https://www.fisheries.noaa.gov/national/sustainable-fisheries/foreign-fishery-trade-data

Criterion 1: Data quality and availability

Impact, unit of sustainability and principle

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

Criterion 1 Summary

Atlantic and Coho salmon; Regions X, XI and XII.

C1 Data Category	**Data Quality**
Production	7.5
Management	7.5
Effluent	7.5
Habitat	5.0
Chemical Use	7.5
Feed	5.0
Escapes	5.0
Disease	5.0
Source of stock	10.0
Wildlife mortalities	5.0
Introduction of secondary species	7.5
C1 Data Final Score (0-10)	**6.59**
	Yellow

Brief Summary

Data collection and availability, particularly from the government, has improved in Chile but the access and availability from outside Chile continues to lag behind other major salmon producing countries, particularly for site-specific information. Many impact areas are active ongoing areas of data collection and study, and published peer-reviewed papers are increasing in addition to many multistakeholder workshops, but the environmental impacts across the three southernmost regions of Chile continue to be challenging to define robustly. Data from sources such as the seafood industry media and the Global Salmon Initiative (GSI) are also useful, but with regard to the latter, the limited number of companies means it must be used with caution as an indicator of a Chile's average performance. There is generally a greater focus on Atlantic salmon in the data and studies in Chile compared to coho, but there are sufficient similarities in the key data that both species in all three regions have the same score for Criterion 1 – Data of 6.59 out of 10.

Justification of Rating

In 2007, Buschmann et al. noted, “Chile is now one of the world’s largest aquaculture producing countries but has published only an estimated 2% of the world’s aquaculture environment studies.” Since then, there has been a large increase in publicly available data from the industry through government institutions (particularly Sernapesca), from the companies themselves, and from significant academic research in the region. Nevertheless, some gaps in understanding remain as described below.

Industry and Production Statistics

Annual and monthly production figures are available from the Chilean government’s *Subsecretaria de Pesca y Acuicultura*[8] (undersecretary of fisheries and aquaculture) known as Subpesca and the *Servicio Nacional de Pesca y Acuicultura*[9] (national fisheries service) known as Sernapesca, particularly the Statistical Yearbook of Fisheries and Aquaculture (*Anuario Estadístico de Pesca y Acuicultura*). Subpesca has a mapped database of Chile with salmon farm site locations with basic company ownership and surface area details[10], as does Intesal[11], (the technical arm of the industry body SalmonChile) for each production neighborhood or *barrio*. Site-level biomass or other production data must be reported for all sites (to Subpesca) but are not publicly available as is the case in other salmon producing regions (e.g., Norway’s Directorate of Fisheries mapped database[12] or Scotland’s Aquaculture database[13]). Export/import figures are available from Sernapaesca, SalmonChile[14], and the US National Marine Fisheries Service[15]. The data sources vary somewhat in their figures but provide a good overview of the industry. The data score for the Industry and Production Statistics is 7.5 out of 10.

Management and Regulations

Some company-level management practices and information are available from some annual reports and websites, and also partly from the industry’s trade body SalmonChile and their technical organization Intesal[16], but national management and regulatory information in Chile is available in detail on Sernapesca’s and/or Subpesca’s websites (in Spanish). A summary of key regulations with links is available from Intesal[17]. With frequent additions, revisions, and amendments, this is typically challenging to interpret and understand, but good information is generally available. The data score for Management and Regulations is 7.5 out of 10.

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[8] Subpesca: http://www.subpesca.cl/institucional/602/w3-channel.html

[9] Sernapesca: http://www.sernapesca.cl/index.php.

[10] http://mapas.subpesca.cl/ideviewer/

[11] http://mapas.intesal.cl/publico/

[12] https://kart.fiskeridir.no/

[13] http://aquaculture.scotland.gov.uk/default.aspx

[14] https://www.salmonchile.cl/

[15] https://www.fisheries.noaa.gov/national/sustainable-fisheries/foreign-fishery-trade-data

[16] https://www.intesal.cl/es/index.php

[17] https://www.intesal.cl/es/regulacion.php

Effluent

Soluble effluent monitoring is not a regulatory requirement in Chile, so there are no farm-level data available, but benthic monitoring results for each site are available from Sernapesca (prior to 2019[18], and from 2020[19]). With a change in reporting characteristics, there are no data available from 2019, but a comprehensive report is now published twice per year from 2020. The site-level data (which allowed a comparison of Atlantic salmon and coho salmon sites) no longer appear to be publicly available. There is also a growing body of literature specific to Chile which provides further information (e.g., Iriarte et al., 2013; Rebolledo et al., 2011; Mayr et al., 2014, Elizondo-Patrone et al., 2015; Quiñones et al., 2019), in addition to numerous studies or reviews of similar impacts in other countries (e.g., Grefsrud et al., 2021a,b and Tett et al., 2018) There is a substantial volume of information available from Sernapesca in terms of information on regulations, management, farm registration and environmental monitoring requirements, site locations, and the grouping of concessions. There is still a limited understanding of potential cumulative effluent impacts of salmon farming in Chile, particularly as the industry continues to move into pristine habitats in Region XII in the far south of Chilean Patagonia, but the limitations are increasingly defined such that the overall understanding of effluent impact is largely understood. As such, the data score for effluent is 7.5 out of 10.

Habitat

The location and size of every salmon farm concession in Chile is available in the mapped database of Subpesca[20], and with readily available satellite images (also available as a layer in the Subpesca mapped database or other public sources such as Google Earth) a simple overview of salmon farm locations and habitats can be obtained. However, there are few specific data on the impacts of the infrastructure or their operation (other than the discharge of nutrient wastes addressed in Criterion 2 – Effluent). The review of McKindsey (2011) provides a useful list of potential impacts associated with the infrastructure, and other academic studies provide additional information on the attraction or repulsion of wildlife, hydrodynamics and other operational activities such as the use of submerged lights and increased boat traffic. In general, these potential impacts have been poorly studied and are difficult to quantify. The regulatory system for site licensing in Chile includes an environmental impact assessment (EIA) process through the *Sistema de Evaluación de Impacto Ambiental* (SEIA)[21] but only for sites constructed after the law was established in 1994. Their "Ruling for Environmental Certification" reports (*Resolución de Calificacion Ambiente*, RCA) are available online at the SEIA database. With a limited understanding of potential impacts of the infrastructure, the data score for the habitat impacts of the floating net pen farming system is 5 out of 10.

Chemical Use

While detailed antimicrobial use data is collected by SEPA through the Aquaculture Inspection Information System (SIFA - Sistema de Información para la Fiscalización de Acuicultura[22]) only

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[18] Prior to 2019: http://www.sernapesca.cl/informacion-utilidad/informes-trimestrales-resa

[19] 2020 onwards: http://www.sernapesca.cl/informes/resultados-gestion

[20] https://mapas.subpesca.cl/ideviewer/

[21] https://www.sea.gob.cl/

[22] http://sifa.sernapesca.cl/acuicultura_sernapesca/inicio

aggregated data for the use of each antimicrobial type (by region, species and freshwater/marine use) are available from Sernapesca's annual report (*Informe Sobre Uso De Antimicrobianos En La Salmonicultura*), and from the first annual report of the Chilean Salmon Antimicrobial Reduction Program (CSARP). Similar data from other countries allow a reflection on the scale of antimicrobial use in Chile. Sernapesca's "antimicrobial-free" certification program (Programa para la Optimización del Uso de Antimicrobianos - Certificación PROA-Salmón) provides a list of farm sites that have been certified under this program. The subject of antimicrobial resistance is enormously complex and has a large and rapidly evolving body of literature. The Aquaculture Research Division of Chile's Fisheries Development Institute (*Instituto de Fomento Pesquero*, IFOP) has established an antimicrobial resistance surveillance program which produces an annual report e.g., IFOP, 2020a), yet it remains challenging to draw robust conclusions about the likely impacts in Chile.

Sernapesca also collects detailed data on pesticide use through SIFA, but none are publicly available, and there is no central source for pesticide use data in Chile. SalmonChile publishes data for its members, but aggregates species (including coho for which pesticides are not considered to be used). A second dataset is available for eight Chilean companies reporting through the GSI from 2013 to 2019, and these data are separated by species. A third dataset published by industry media (Intrafish) breaks down pesticide use in 2019 by type. Collectively these give a good impression of pesticide use in Chile. Similar to antimicrobials, there is a large body of literature on the development of pesticide resistance, and a similar surveillance program and annual report from IFOP (e.g., IFOP, 2020b) but again limited data on specific impacts. Overall, there is sufficient data to build a robust picture of chemical use in Chile, but caution is always needed due to the use of different types of antimicrobial or pesticides that have greatly differing dose rates. The data on impacts remains limited, and the data score for Chemical Use is 7.5 out of 10.

Feed

Detailed information could not be obtained from feed companies for this assessment, and there do not appear to be any feed data available from either SalmonChile or Intesal. Categorical feed formulation information (both from a global perspective, and specific to Chile) was obtained from the Mowi industry handbook[23] and a company annual report, and these data were supplemented by specific ingredients in each category from the salmon reference diets of Mørkøre et al. (2020) and Aas et al. (2019). As such a best-fit feed composition was created that is considered to adequately represent the Chilean feeds for the purposes of this assessment. Without specific data for source fisheries supplying fishmeal and oil to Chilean salmon feeds, the global data for three major feed companies (Biomar, Ewos-Cargill, and Skretting) reporting through the Ocean Disclosure Project were used[24]. Performance results (e.g., FFER) could be checked against data from eight Chilean companies reporting through the GSI. The Global Feed Lifecycle Initiative (GFLI) database was used for the feed footprint calculations. The data score for Feed is 5 out of 10.

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

[24] https://oceandisclosureproject.org/

Escapes

Sernapesca provides basic data on reported escape events and total numbers of escapes aggregated by region, from 2010 to 2020[25]. The data are not separated by species. GSI provides basic data on reported escape numbers for eight member companies, and SalmonChile provides escape data by company, but there is considerable discrepancy between these datasets. Data on recaptures are not published but can be estimated from industry media reports of (typically only large) escape events. Academic articles continue to highlight the global potential for undetected and/or unreported escapes (e.g., Skilbrei et al., 2015). The topic of escapes is an active area of research by groups such as INCAR[26], and various academic articles provide a basic level of understanding on the fate and impact of escaping Atlantic salmon in Chile, and recent research highlights the growing concern regarding coho (Górski et al., 2017; Chalde et al., 2019; Nardi et al., 2019; Maldonado-Márquez et al., 2020). Substantial gaps remain in understanding the scale and impact of salmon escapees in Chile, and the data score for Escapes is 5 out of 10.

Disease

Sernapesca provides substantial data on disease in Chile through an annual fish health report (*Informe Sanitario de Salmonicultura en Centros Marinos*), in addition to their management through the grouping of sites (*Agrupación de Concesiones*, ACS), and the prevention and surveillance programs for high-risk diseases (*Programas de Prevención, Vigilancia y Control de la Enfermedades de Alto Riesgo*). Fish health regulatory information (*Reglamento Sanitario para la Acuicultura*, RESA), and mortality data by species and region, categorized by disease type, are also available from Sernapesca. There is also a comprehensive body of literature on the pathogens and parasites of concern to salmon production (including, for example, the recent outbreaks of parasitic sea lice in Region XII where it had previously been undetected - Arrigada et al., 2019). The Program for Sanitary Management in Aquaculture (*Programa para la Gestión Sanitaria en Acuicultura*, PGSA) has been a comprehensive research project, and has published some studies on the transfer of pathogens between farmed and wild fish and vice-versa (e.g., Quintanilla et al., 2021; Soto-Dávila et al., 2020). Research in other regions (e.g., the Strategic Salmon Health Initiative in British Columbia) highlights the potential presence of previously unknown pathogens on salmon farms (Mordecai et al., 2019, 2020) but there is still little direct information on the potential impacts (if any) of pathogen and parasite transmission to wild fish in Chile. The data score for Disease is 5 out of 10.

Source of stock

With the ubiquitous use of domesticated broodstocks and a volume of literature detailing selective breeding strategies and programs, the source of stock is well established for both Atlantic and coho salmon. The data score for Source of Stock is 10 out of 10.

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[25] http://www.sernapesca.cl/informacion-utilidad/escape-de-peces-de-la-salmonicultura

[26] https://centroincar.cl/

Wildlife mortalities

Regulations confirming marine mammal mortalities must be reported to Sernapesca are available, but the data are not publicly reported. In their study of marine mammal entanglements, Espinosa-Miranda et al. (2020) obtained the data from Sernapesca but questioned its validity. GSI provides basic data on accidental and intentional mortalities for their member companies between 2013 and 2019. Academic studies on key species such as whales, dolphins, and sea lions provide useful information on the interactions with salmon farms (e.g., Sepulveda et al., 2015; Espinosa-Miranda et al., 2020), but these authors typically emphasize that many impacts are uncertain. The data score for Wildlife Mortalities is 5 out of 10.

Introduction of secondary species

The number of egg imports by species and year is available from Sernapesca "*Estadística de Importación de Ovas por origen*[27]". Regulations on live fish movements and authorizations in Chile are also available from Sernapesca's website, and the fish health certificate from the only approved egg importer (Icelandic company Benchmark Genetics Iceland) and additional details are available on the company's website. Nevertheless, information on the movements of smolts between hatcheries and growout sites is not available. The data score for Introduction of Secondary Species is 7.5 out of 10.

Conclusions and Final Score

Data collection and availability, particularly from the government, has improved in Chile but the access and availability from outside Chile continues to lag behind other major salmon producing countries, particularly for site-specific information. Many impact areas are active ongoing areas of data collection and study, and published peer-reviewed papers are increasing in addition to many multistakeholder workshops, but the environmental impacts across the three southernmost regions of Chile continue to be challenging to define robustly. Data from sources such as the seafood industry media and the Global Salmon Initiative (GSI) are also useful, but with regard to the latter, the limited number of companies means it must be used with caution as an indicator of a Chile's average performance. There is generally a greater focus on Atlantic salmon in the data and studies in Chile compared to coho, but there were sufficient similarities in the key data that both species have the same score for Criterion 1 – Data of 6.59 out of 10.

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[27] http://www.sernapesca.cl/index.php?option=com_content&task=view&id=73&Itemid=185

Criterion 2: Effluent

Impact, unit of sustainability and principle

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

Criterion 2 Summary

Atlantic and Coho salmon; Regions X, XI

Effluent Evidence-Based Assessment

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

Atlantic and Coho salmon; Region XII

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0-10)	**2**	Red

Brief Summary

Some important gaps exist in understanding the carrying capacity of Chile's fjords and channels and the corresponding impact of nutrient discharge from salmon sites cumulatively. However, with good research available on near-field site-level impacts, and good benthic monitoring data (in addition to information on the control measures currently in place to manage biomass at the area level), the Evidence-Based Assessment method was used. The available evidence from Chile (and elsewhere) shows substantial impacts in the water column from salmon farm effluents are unlikely. Time series and 2020 site-level benthic monitoring data from Sernapesca's INFA reports both show high levels of aerobic (favorable) results in Region X, but poorer results in Regions XI and XII. Of particular concern is that less than half of INFA results across the 2012-2020 time series (mean of 49%) and in 2020 (47.3%) in Region XII were aerobic. The results for all regions are similar for both Atlantic salmon and coho. The long-term data shows these results are all improving over time, and the available research shows the impacts are likely to be limited primarily to the immediate farm area, but currently more than half the sites in Region XII must undertake subsequent repeated sampling that demonstrates a return to aerobic conditions before the site can be used again. There is also an ongoing potential for as-yet poorly researched cumulative impacts at the waterbody scale, particularly as the industry expands into new areas in Region XII that may not have sufficient water circulation.

For Regions X and XI, the occurrence of anerobic INFA results is considered frequent (i.e., greater than 10% of all results) but the impacts are considered temporary and primarily confined to the immediate farm area. There is some uncertainty in the potential for cumulative impacts at the waterbody scale, and the final score for Criterion 2 – Effluent is 4 out of 10. For Region XII, the proportion of anaerobic results is consistently much higher; with more than half of all results consistently anaerobic, the effluent impact can be considered persistent. These poor results demonstrate that the industry is expanding into an area for which there is insufficient understanding of the carrying capacity at the local and likely waterbody scale. The final score for Criterion 2 – Effluent in Region XII is 2 out of 10 for Region XII.

Justification of Rating

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

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

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

There is a substantial body of literature on the fate and impact of nutrient wastes from net pen fish farms, including salmon farms, and key recent reviews such as Price et al. (2015) provide a useful summary. Price et al. (2015) conclude modern operating conditions have minimized impacts of individual fish farms on marine water quality; effects on dissolved oxygen and turbidity have been largely eliminated through better management, and near-field nutrient enrichment of the water column is usually not detectable beyond 100 m of the farm (when formulated feeds are used, feed waste is minimized, and farms are properly sited in deep waters with flushing currents). However, when sited nearshore, extra caution should be taken to manage farm location, size, biomass, feeding protocols, orientation with respect to prevailing currents, and water depth to minimize near- and far-field impacts, and Price et al.

(2015) caution that regardless of location, other environmental risks may still face this industry; for example, significant questions remain about the additive (i.e., cumulative) impacts of discharge from multiple, proximal farms, potentially leading to increased primary production and eutrophication.

Soluble nutrients in the water column

The total nutrient discharges from the salmon farms in Chile appear large; for example, in Chile's Region XI alone, Niklitschek et al. (2013) estimated the nutrient discharges from salmon farms were equivalent to 12,300 mt of nitrogen (N) and 1,600 mt of phosphorous (P) in 2010. However, many studies in Chile and elsewhere indicate that the increases in nutrient concentration in the water column near salmon farms can generally be considered minor in comparison to natural fluxes in coastal environments, and therefore unlikely to cause significant cumulative impacts (e.g., Buschmann et al., 2006, 2007; Niklitschek et al., 2013; Husa et al., 2014; Tett et al., 2018; Jansen et al., 2018; Grefsrud et al., 2021a; Pérez-Santos et al. 2021).

According to Niklitschek et al. (2013), despite the fact that the Patagonian fjords are relatively poor in nutrients, the enormous volumes of N and P released from fish farms have not provided evidence of measurable nutrient enrichments and/or detectable changes in pelagic ecosystems in the waters around salmon farms. Pérez-Santos et al. (2021) noted the annual ventilation cycle mediated by the exchange of oceanic water masses into Patagonian fjords provided ecosystem services by reducing anthropogenic impacts resulting from economic activities such as salmon farming. In Norway, Grefsrud et al. (2019) note that even in the densest farming areas, the in-situ measurements of phytoplankton show "Very good" to "Good" environmental condition at all monitoring stations, and they state with high confidence (due to the combination of their modelling results and physical monitoring data) that there is a low risk of environmental effects as a result of increased nutrient supply from aquaculture.

Nevertheless, Niklitschek et al. (2013) also emphasize the importance of less well-studied impacts of salmon farm effluent, including changes to the natural nutrient ratios in salmon farming areas (e.g., Iriarte et al., 2010, 2013; Rebolledo et al., 2011), and the effects on the microbial communities, food webs, and algal bloom events (e.g., Navarro et al., 2008 and Elizondo-Patrone et al., 2015). In a Chilean study of the responses in bacterial community structure to waste nutrients from aquaculture, Olsen et al. (2017) reported that the nutrient loading from salmon farms did indeed have a significant effect on the bacterial community structure of the Comau Fjord, but since the diversity of the community was maintained, it appears to be a healthy response to increased primary production. As such, Olsen et al. (2017) suggested other environmental impacts, such as increased sedimentation of organic matter and subsequent anoxia in the bottom sediments, may be more appropriate for determining the limits for sustainability.

While some uncertainty and a potential for localized impacts in some areas remains (for example, Grefsrud et al., 2021a,b) highlighted the uncertainty with regard to potential variability between sites and small geographic areas, and the large variation in phytoplankton biomass and species composition during any one year and between years), this Seafood Watch assessment follows the suggestion of Olsen et al. (2017) and considers soluble nutrient loading from salmon farms to be generally less impactful than the benthic impacts of particulate effluents.

Particulate effluents on the seabed

Feces and uneaten feed 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; Keeley et al., 2013, 2015). Keeley et al. (2013) describe the major pathways of bio-deposition from a typical net pen salmon farming system, showing 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 re-suspended 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.

The general effects on benthic fauna have been well-studied, and typically, the local flux of solid waste generated by fish farms much exceeds natural inputs to the seabed, and the degree of effect depends on the scale of flux, the hydrodynamics and bathymetry of the site, and the type of sediment such that the highest impacts are likely to be seen in areas that have low current speeds, soft sediment, and a high flux of carbon to the seabed (Tett et al., 2018).

Benthic communities in Chilean fjords are very rich and diverse and of high ecological value (Quiroga et al., 2013). They have been shown to possess a unique benthic fauna, comprising endemic cold-water corals, anemones, and other species (Buschmann et al., 2006), and fjords are considered one of the most biogeochemically active areas in the biosphere due to their land-ocean exchange of energy and matter (Elizondo-Patrone et al., 2015, and references therein). Regarding specific studies in Chile, Soto and Norambuena (2004), although now somewhat dated, found 2- to 5-fold higher mean concentrations of nutrients (nitrogen, phosphorus, carbon, and particulate organic matter) and a nearly 50% lower species richness below net pens compared to control sites. Kowalewski (2011) documented a catastrophic decline in local benthic productivity triggered by salmon farms, and Aranda et al. (2010) studied mats of filamentous bacteria (indicative of excessive nutrient loading) covering the substrate below the pens and within the near field area, from 10 to 60 m away (their sampling was done in 2006-2007). Niklitschek et al. (2013) also note conflicting studies that have shown increased species richness around farm sites in Chile (Soto and Jara, 2007), attributed to an edge effect that may be explained by increased productivity due to nutrient inputs and/or by enhanced protection (refuge) from small-scale fisheries that operate in the area.

Like the changes in bacterial community structure in the water column (Olsen et al., 2017), Hornick and Buschmann (2018) indicate that sediment bacterial communities influenced by salmon aquaculture presented localized changes in taxonomic diversity, composition, and function due to the increased organic loading.

The impacts of settling particulate wastes from salmon farms in Chile are managed by environmental reports known as INFAs (*Informes Sanitarios y Ambientales Acuicultura*) within the sanitary regulations (*Reglamento Sanitario para la Acuicultura*, RESA), and as of 2020, Sernapesca publishes a comprehensive analysis twice per year[28]. The specific monitoring requirements and methodologies for the INFA are laid out in Resolution N°3612 (2009). For salmon farms, monitoring must take place every cycle, two months before the harvest starts, and samples must be taken at 30 m intervals around the perimeter of the net pen modules (within 10 m from the edge of any predator nets). Samples can be collected by the farming companies but must be analyzed at independently certified laboratories, and the INFA reports must be signed by a professional accredited with a Certificate of Professional Title.

The primary characteristic assessed is the aerobic or anaerobic status of the site, but there are several potential parameters with which this is determined in practice, which in turn are dictated by the production volumes, seabed types (hard or soft), and the depth (greater or less than 60 m). The greatest number of parameters are required for soft substrates in depths of less than 60 m, and include sediment grain size, total organic matter, benthic macrofauna, pH, temperature, redox, dissolved oxygen, salinity, and sulfide. For sites with hard substrates and depths of less than 60 m, a visual survey is required in addition to monitoring for dissolved oxygen, temperature, and salinity. For sites with greater than 60 m depth, the requirements are limited to dissolved oxygen, temperature, and salinity. Sernapesca's data from 2012 to 2019 show the presence of bacterial mats is the dominant factor used to determine the aerobic status of sites, accounting for 39%, 55% and 34% of the INFA classifications in Regions X, XI and XII respectively. Benthic oxygen levels and redox make up the majority of the remaining determinations in each region.

Figure 8 shows the country-level INFA status for all Chilean salmon sites (i.e., all regions) from 2012 to 2019. The average over this period is 76% aerobic and 24% anaerobic; that is, on average, 76% of sites had aerobic conditions underneath the net pen arrays, indicating that the nutrient enrichment had not overloaded the benthic habitats.

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[28] http://www.sernapesca.cl/informes/resultados-gestion

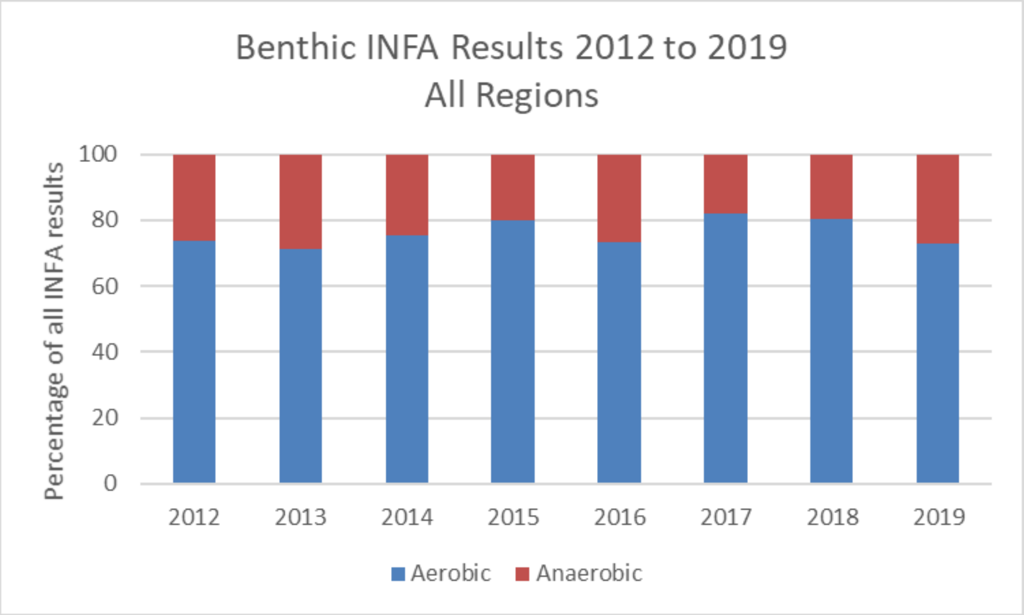

Figure 8: Annual average percent of Chilean salmon farms achieving "Aerobic" status in INFA assessments. Data from Sernapesca.

With regard to species, Sernapesca published separate site-level data from 2016 to 2018 for Atlantic salmon and coho, which shows similar results. The percentage of aerobic coho sites was 4.7% higher level than Atlantic salmon sites. As such, the two species are considered similar and analyzed collectively in this criterion.

In contrast, the INFA results vary considerably by region. Figure 9 shows the annual percentage of aerobic INFA results is consistently high in Region X and progressively lower in Regions XI and XII. In 2020, the percentage of all INFA results that were aerobic in Regions X, XI and XII was 84.0%, 59.6% and 47.3% respectively. The average values over the 2012 to 2020 time period show 87% and 69.5% of INFA results in were aerobic in Regions X and XII respectively, but less than half (49%) were aerobic in Region XII. The simple trendlines in Figure 9 show that despite poor results in 2020, the percentage of aerobic sites is increasing over time, particularly in Regions X and XII. Nevertheless, more than half the sites in Region XII must have subsequent repeat sampling that demonstrates a return to aerobic conditions before the site can be used again.

The reason for these regional differences is not clear; while north-south variations in key parameters such as temperature are apparent, other variables include complex large scale hydrodynamic processes associated with the Humboldt current and upwelling which can be characterized by the intrusion of water with higher salinity (>34.0 ppt) and lower oxygen (<1 mL O_2 L^{-1}) (Manriquez et al., 2009). In a seafood media report[29], Sernapesca noted some sites in Region XII are located in deep areas with poor water circulation such as the Puerto Natales

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[29] https://www.salmonexpert.cl/article/incrementan-fiscalizacin-a-entidades-que-realizan-infas-en-centros-de-salmn/

sector, which causes the dissolved oxygen content of deep waters to decrease to below-standard values.

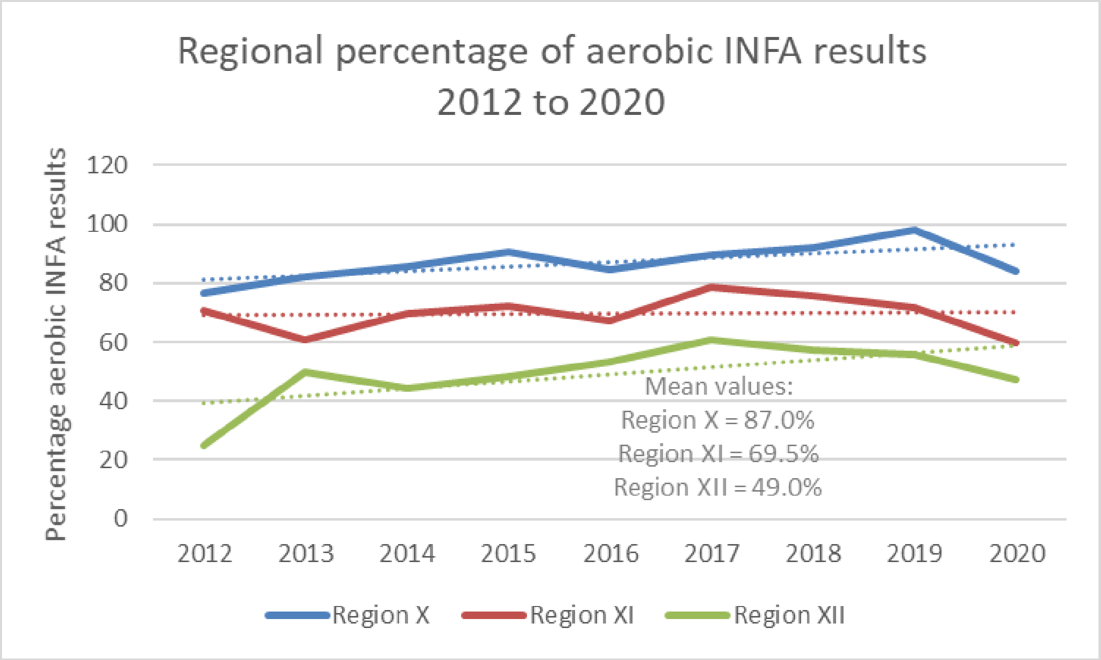

Figure 9: Percentage of all INFA results by region that were aerobic from 2012 to 2020. Dotted lines for each region show simple trendlines fitted by Excel. Data from Sernapesca.

Anaerobic sites must be shown to have returned to aerobic status (with more comprehensive sampling) before fish can be restocked at a site (after a compulsory three-month fallow period, or longer if necessary). Anaerobic INFA reports, particularly when repetitive, lead to reduced biomass permissions and affect the stocking of the ACS as a whole.

While a return to aerobic status does not imply a full recovery, benthic impacts of this nature are considered to be relatively rapidly reversed with cessation of production or fallowing (Keeley et al., 2015). The INFA data from Sernapesca show that recovery times between an anaerobic sample and subsequent aerobic sample varies between approximately 2 and 18 months (noting that due to fallowing periods and other production cycle strategies, subsequent sampling may be done until sometime after the site has returned to aerobic status).

Potential cumulative impacts

Husa et al. (2014) noted (in a Norwegian study) that the cumulative effect of numerous impacted areas around multiple farm sites must be taken into consideration when evaluating the total impact from aquaculture on ecosystem functioning. The primary tool employed to manage cumulative impacts and the scale of production is the division of the farming regions into groups of farm sites (each site called a concession) sharing a similar waterbody or area - *Agrupación de Concesiones*, or ACS. Each ACS is legally defined and has a management plan (a map of ACSs is available in Figure 1 in the Introduction, or Figure 16 in Criterion 4 – Chemical Use).

Biomass limits and stocking densities are set according to a classification calculation of the ACS based on the INFA results of the farms (aerobic or anaerobic), the mortality numbers of fish, and the production relative to projections (all from the previous production cycle). For example, if between 75.1% and 100% of the INFA results for sites in the ACS are aerobic after the last production cycle, then 100% of the planned stocking can be repeated. This reduces sequentially with increasing numbers of anaerobic INFA results, such that only 25% of the fish can be stocked in the next cycle if less than 25% of the INFA results are aerobic. Similarly, mortalities above 15.1% have a reduction in stocking of 10% which increases to a reduction of 60% if mortality is greater than 26%. These factors are weighted and used to give a final score for the ACS which determines the stocking density (which ranges from 11 to 17 kg/m^3 for Atlantic salmon) and the corresponding number of fish stocked. Based on growth projections, this will correspond to a predicted peak biomass before harvesting begins. One limitation of the ACS system's relevance to nutrient-related impacts is that it is unclear if the boundaries were set according to relevant hydrographic characteristics of the waterbodies, or if they were primarily defined according to practical production requirements of the industry (including biosecurity concerns; Alvial, 2017).

Further limitations in our understanding of cumulative impacts and the carrying capacity of Chilean waterbodies are highlighted by the review of Quiñones et al. (2019), who noted the understanding of the potential far-field effects of nutrients discharged from individual sites is limited, but more importantly, there are no sound estimates of carrying capacity at the scale of Chile's fjords and channels. Recent carrying capacity studies (e.g., Rojas et al., 2017) highlighted the complexities of the system by showing the primary productivity dynamics varying between the northern and southern areas of the inner sea of Chiloe, and also between seasons within an area.

Quiñones et al. (2019) identified the following key knowledge gaps and research needs in relation to effluent wastes (including uneaten feed) and cumulative impacts:

- The far-field effects of salmon farming on nutrient flow and nutrient mass balance in the benthic and pelagic food webs (from microorganisms to wild predators) and ecosystem functioning (e.g., biogeochemical cycles), considering natural and anthropogenic sources.
- The impact of salmon production on benthos over a longer timescale.
- The cumulative impacts of multiple farms in conjunction with other human activities.

In addition to the broad absence of adequate carrying capacity models, there is a need to develop and/or refine models for estimating productive carrying capacity specifically in key Patagonian ecosystems, and these models require crucial information from the research gaps regarding the impacts of organic wastes described above (Quiñones et al., 2019). With many of the studies referenced above (or reviewed by Quiñones et al., 2019) taking place prior to the expansion of the industry into the southernmost Region XII, these limitations are exacerbated in this area.

The potential impacts in Region XII are a particular area of focus, and as noted in the introduction, Vila et al. (2016) proposed Appropriate Areas for Aquaculture in Region XII based on the identification of High Conservation Value Areas using 39 conservation features (Figure 6). They also expressed caution that the proposed areas are located in remote places where fine-scale data are lacking, and the lack of apparent potential conflict with their conservation targets may reflect this. Importantly, they also concluded that the potential impacts of salmon farming on conservation targets outside High Conservation Value Areas may be important and should be minimized.

As also noted in the Introduction (e.g., Figure 5), 65% of the increase in total Chilean production from 2019 to 2020 was due to the expansion of Atlantic salmon in Region XII. The number of active sites in Region XII has increased 25% from 2018 to 2021 (39 active sites in the first quarter of 2018 to 51 sites in 2021) as companies bring previously granted licenses into production in remote areas with complex logistics (equipment, labor, smolts, feed, harvesting and processing, etc.). However, production appears to be increasing more rapidly, and annual harvests in Region XII (including trout) more than doubled from 2018 to 2020 (noting the simple linear regression in Figure 5 shows a steeper increase, with production nearly doubling each year (x0.94) over the same three years). The industry is therefore expanding in regions where the potential impacts of effluent at the site and waterbody scale are not fully understood.

Conclusions and Final Score

Some important gaps exist in understanding the carrying capacity of Chile's fjords and channels and the corresponding impact of nutrient discharge from salmon sites cumulatively. However, with good research available on near-field site-level impacts, and good benthic monitoring data (in addition to information on the control measures currently in place to manage biomass at the area level), the Evidence-Based Assessment method was used. The available evidence from Chile (and elsewhere) shows substantial impacts in the water column from salmon farm effluents are unlikely. Time series and 2020 site-level benthic monitoring data from Sernapesca's INFA reports both show high levels of aerobic (favorable) results in Region X, but poorer results in Regions XI and XII. Of particular concern is that less than half of INFA results across the 2012-2020 time series (mean of 49%) and in 2020 (47.3%) in Region XII were aerobic. The results for all regions are similar for both Atlantic salmon and coho. The long-term data shows these results are all improving over time, and the available research shows the impacts are likely to be limited primarily to the immediate farm area, but currently more than half the sites in Region XII must undertake subsequent repeated sampling that demonstrates a return to aerobic conditions before the site can be used again. There is also an ongoing potential for as-yet poorly researched cumulative impacts at the waterbody scale, particularly as the industry expands into new areas in Region XII that may not have sufficient water circulation.

For Regions X and XI, the occurrence of anerobic INFA results is considered frequent (i.e., greater than 10% of all results) but the impacts are considered temporary and primarily confined to the immediate farm area. There is some uncertainty in the potential for cumulative impacts at the waterbody scale, and the final score for Criterion 2 – Effluent is 4 out of 10. For

Region XII, the proportion of anaerobic results is consistently much higher; with more than half of all results consistently anaerobic, the effluent impact can be considered persistent. These poor results demonstrate that the industry is expanding into an area for which there is insufficient understanding of the carrying capacity at the local and likely waterbody scale. The final score for Criterion 2 – Effluent in Region XII is 2 out of 10 for Region XII.

Criterion 3: Habitat

Impact, unit of sustainability and principle

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

Criterion 3 Summary

Atlantic and Coho salmon; Regions X, XI and XII.

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

Brief Summary

Salmon farm net pens and their supporting infrastructures contribute much physical structure to nearshore habitats and are known to modify the physical environment at the farm location by modifying light penetration, currents, and wave action, as well as providing surfaces for the development of rich biotic assemblages that may further increase the complexity of the habitat. An average salmon farm comprises approximately 50,000 m^2 of submerged artificial substrates that can be colonized by a large suite of hard-bottom associated species that may not otherwise find suitable habitat in a given area (e.g., sandy or muddy bottoms or in the water column). These additional species may have a variety of direct and cascading effects on the surrounding ecosystem, including inadvertently supporting the persistence and distribution of non-native species, and/or pathogens and parasites. Salmon farms also attract a variety of wild animals as fish aggregation devices or artificial reefs, or repel other wild animals through disturbance such as noise, lights or increased boat traffic. Due to the relatively large size of the aquaculture vessel fleet, there is the potential for an as-yet unquantified disturbance of cetaceans including seasonal interactions with blue whales. Changes in behavior of wild fish around fish farms and even of their flesh quality due to the consumption of waste feed have been reported. A key aspect of these potential impacts is their circumstantial variability, their limited study, and the challenge of their quantification, particularly in the context of the confounding impacts of soluble and particulate effluent wastes (assessed in Criterion 2 - Effluent). However, the siting of floating net pen arrays does not result in the functional conversion of affected habitats, and the literature indicates that the realization of any or all of these potential impacts does not significantly impact the functionality of the ecosystems or the services provided by them. Further, the removal of farm infrastructure would quickly restore all baseline biophysical processes. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts.

The regulatory system for siting and impact assessment (at least for new or expanding sites) in Chile appears to be effective, but (noting that seabed impacts from particulate wastes are addressed in Criterion 2 – Effluent) it is unclear how the range of potential impacts associated with the infrastructure of the net pen systems are managed, including from a cumulative perspective. The ongoing expansion of the industry into largely pristine habitats in Region XII is a particular focus of interest. The scores for Factor 3.1 (8 out of 10) and 3.2 (4.8 out of 10) combine to result in a final Criterion 3 – Habitat score of 6.93 out of 10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations). This score applies to all regions and to both farmed salmon species.

Justification of Rating

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

Factor 3.1. Habitat conversion and function

Southern Chile contains one of the major fjord regions of the world and being within the Valdivian Rainforest Eco-Region and the transition zone of the West Wind Drift Current, it is classified amongst those with the highest conservation priority worldwide due to its threats and high degree of endemism (Iriarte et al., 2010). Although the benthic communities in Chilean fjords have only recently been studied, there is clear demonstration that they are very rich and diverse, and of high ecological value (Quiroga et al., 2013). They have been shown to possess a unique benthic fauna, comprising endemic cold-water corals, anemones, and other species (Buschmann et al., 2006), and fjords are considered one of the most biogeochemically active areas in the biosphere due to their land-ocean exchange of energy and matter (Elizondo-Patrone et al., 2015, and references therein). These ecosystems provide important services to humans which, according to Iriarte et al. (2010), have not been adequately measured and valued, and as a consequence, their ecosystem services are commonly ignored in public policy design and in the evaluation of development projects.

The location, size, and company information of every salmon farm concession is available in the mapped database of Subpesca[30]. Options for the database map layering allow the concessions to be overlaid on satellite images (examples shown in Figures 10 and 11), from which it is apparent that the floating net pen containment system does not result in any gross functional conversion of surface habitats compared to (for example) the construction of ponds, but that is not to say there are no habitat impacts.

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[30] https://mapas.subpesca.cl/ideviewer/

Figure 10: Location of salmon farm concessions (yellow polygons) in the Islas Verdes area of Region XII in Chile (note this area was selected at random, and not all concessions are in production at any one time). The dotted square is enlarged in Figure 11 below. Screenshot from Subpesca's Map Viewer database.

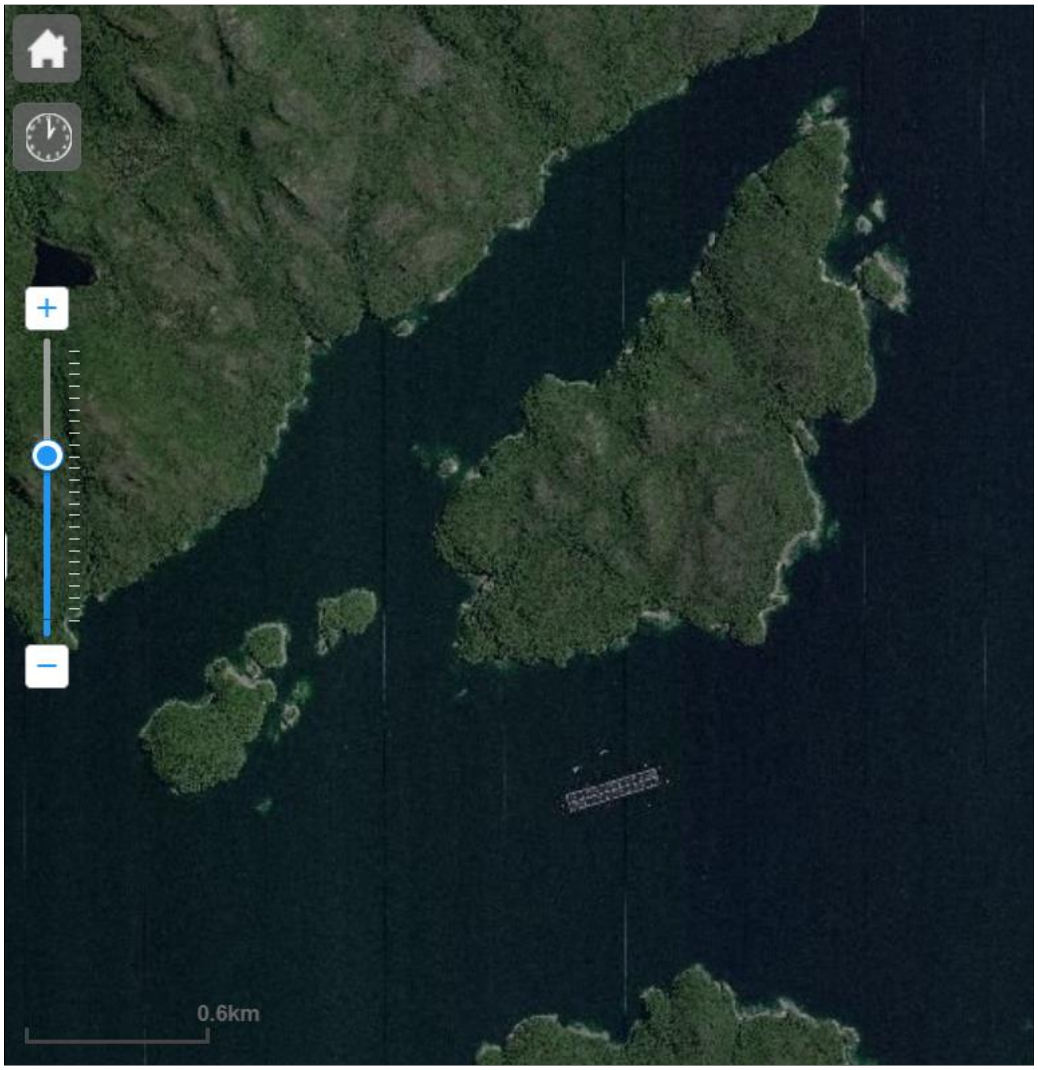

Figure 11: Closer image of the white square in Figure 10, showing one of the two concessions in the area had net pens in position. Screenshot from Subpesca's Map Viewer database.

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

The mooring structure encompasses a larger area than the net pens themselves, and Figure 12 shows a typical mooring pattern of anchor lines at a (Norwegian) site randomly selected from Norway's Directorate of Fisheries database. The positioning of the anchors (notably at approximately 1 km from southeast end of the net pen array in this example) shows the extent of the physical structures.

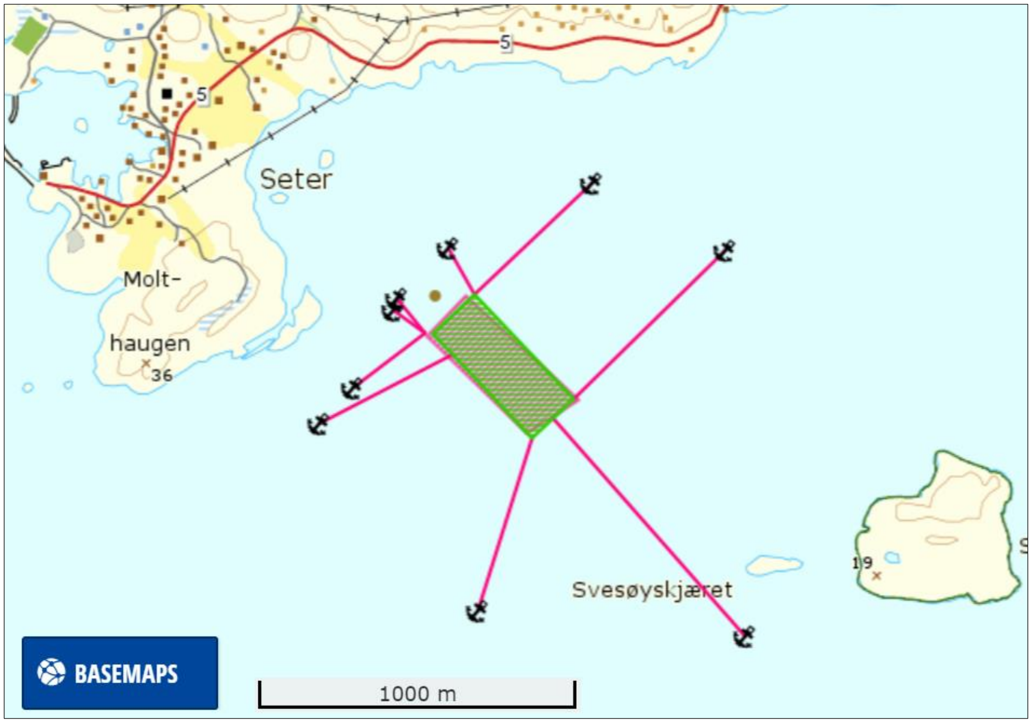

Figure 12: Illustration of the anchoring array of a Norwegian salmon farm (selected at random). Image copied from the Directorate of Fisheries' mapped database (https://kart.fiskeridir.no/)

McKindsey (2011) provided a detailed review of "Aquaculture-related physical alterations of habitat structure as ecosystem stressors[31]", and for net pen finfish aquaculture the report is summarized as follows:

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

McKindsey (2011) noted an overriding issue in all discussions of these potential stressors is the fact that most proposed effects due to the addition of structure related to fish cage aquaculture are confounded by the addition of large quantities of feed to the environment (and thereby the soluble and particulate fecal wastes discussed in Criterion 2 – Effluent), and any observable impacts may be due, at least in part, to this factor. McKindsey also noted that the effects related to the addition or modification of physical structure are not well studied, most effects have not been quantified, and the discussion of effects in the scientific literature is largely

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[31] This was a Canadian study, but the findings are considered here to be directly relevant to farmed salmon net pen systems elsewhere.

based on extrapolations from other systems. Noting the publication date of 2011, McKindsey also noted that major recent reviews on aquaculture-environment interactions (at that time) did not discuss the implications of these structures or did so only in a very limited way.

A search for relevant literature since 2011 adds additional potential impacts; for example, the Canadian Department of Fisheries and Ocean (DFO - in a 2017 information webpage on the Alteration of Habitats[32]) also notes the use of underwater lights may influence the behavior of wild fish by attracting them to—or causing them to avoid—farm sites, but also notes the lights do not penetrate more than a few meters beyond marine nets, suggesting that their use has minimal effect on the surrounding environment. Floerl et al. (2016) note a large number of fish (and mussel) farms in North America, Europe and New Zealand support extensive populations of biofouling invasive species, and the in-situ cleaning of fouled net pens may inadvertently support the persistence and distribution of such species within aquaculture regions by the localized dispersal of non-indigenous propagules and fragments, or by the use of farm structures as stepping stones for range expansion (Bloecher and Floerl, 2020). In Chile, Levipan et al. (2020) demonstrated that the commercially important pathogen *Piscirickettsia salmonis* (see Criterion 7 – Disease) can form biofilms on plastic surfaces thereby creating a potentially important environmental risk for its persistence and dissemination. In New Zealand, MPI (2013) also note the potential for impacts to benthic habitats due to shading, but in keeping with McKindsey (2011), they note that no studies exist that separate the effects of shading from that of benthic enrichment, presumably because they occur concurrently, and the latter is thought to be the dominant stressor.

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

Uglem et al. (2020) also note salmon farms attract large amounts of wild fish which consume uneaten feed pellets, and as specific examples, Otterå et al. (2014) and Skilbrei et al. (2016), note saithe (*Pollachius virens*) are by far the most numerous fish visitors to fish farms on the Norwegian coast and show evidence of establishing core residence areas close to fish farms such that the aquaculture industry is influencing the local saithe distribution. Again, Otterå et

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

al. (2014) conclude large-scale population effects are difficult to prove, but note it is possible that the dynamic relationship between the coastal and oceanic phases of saithe has been altered. A similar phenomenon, albeit with different species, is considered to be likely in Chile. Uglem et al. (2020) also note the modified diet of the wild fish aggregating at salmon farms (i.e., the consumption of salmon feed pellets) may reduce the flesh quality of the fish, influencing the local fisheries (although they noted the changes in flesh quality were small).

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

While mortalities of local wildlife species due to their interaction with farms is assessed in Criterion 9X – Wildlife Mortalities, it is worth noting here that the daily activities of farms can disturb sensitive species. For example, Viddi (2004) noted aquaculture operations might negatively affect the movement, distribution, and behavioral patterns of Chilean dolphins (*Cephalorhynchus eutropia*), a local species listed on the IUCN Red List as "Near Threatened" with a decreasing population trend[33]. Viddi et al. (2015) noted that the preference for coastal, shallow waters and river-influenced habitats by Chilean dolphins puts them in direct conflict with a growing aquaculture industry (and hydropower projects). Montecinos (2016) reports on a project established in 2016 to monitor and reduce any interaction between blue whale (*Balaenoptera musculus*) and salmon aquaculture in Chile. The partnership (the partners include the Environmental Ministry, Consejo Nacional de Producción Limpia, WWF Chile, Blue Whale Center, Universidad Austral de Chile, and several salmon farming companies) has led to the establishment of two new protected areas for marine mammals, including the 90,000 ha Tic-Toc marine protected area within the Corcovado Gulf, an area identified as a high-value conservation area by WWF[34] (pers. comm., Intesal 2017).

The Northern Chilean Patagonia (NCP) area is regarded as an important summer foraging and nursing ground for the endangered Eastern South Pacific blue whale population (which was severely depleted by the commercial whaling industry during the 20th century) and Hucke-Gaeteet al. (2013) reported that the level of ship traffic has increased considerably during the previous decade as a result of more cargo and supply shipping for the salmon farming industry, as well as public transportation, tour boats and fishing. Bedriñana Romano et al. (2021)

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[33] Heinrich, S. & Reeves, R. 2017. *Cephalorhynchus eutropia*. The IUCN Red List of Threatened Species 2017: e.T4160A50351955. https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T4160A50351955.en.

[34] https://wwf.panda.org/?216893/Blue-whale-conservation-gets-a-boost

modeled the predicted overlap between vessel traffic and blue whale habitat use in NCP. While the aquaculture industry's vessel fleet – used for staff commuting, transport of fish and other materials, and moving farm infrastructure – was one order of magnitude more numerous than that for other industries (artisanal fishery, industrial fishery, and transportation), the modeled probability of a vessel encountering a blue whale was third highest of the four industries, and similar to the industrial fishing and transportation fleets (Bedriñana Romano et al., 2021). The research did not identify what percentage of the aquaculture industry's fleet serviced the salmon industry (as compared to, for example, the shellfish farming industry), and many other vessels were excluded from the analysis (e.g., artisanal fishing vessels <15 m in length, cruise ships, military vessels, cargo and tanker vessels). Nevertheless, the scale of the salmon industry and the number of its vessels operating in the study area does present some concern for seasonal whale disturbance. Sernapesca has information sheets[35] for many aquatic Species of Conservation Status in Chile (*Especies Hidrobiológicas en Estado de Conservación en Chile*); for the Chilean dolphin and blue whale, they do not mention aquaculture as one of the "anthropic threats," but do note the risk of commercial fishing activities with gill nets for the Chilean dolphin. Similar information sheets for a variety of other marine mammals, turtles, otters, and fish also do not implicate salmon farming among their human threats.

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

Factor 3.2. Farm siting regulation and management

Factor 3.2a: Content of habitat management measures

Chile's System of Environmental Impact Assessment (*Sistema de Evaluación de Impacto Ambiental*, SEIA)[36] operates within the Ministry of the Environment (*Ministerio del Medio Ambiente*). Since 2001, all farm sites must be licensed, and evidence of their approval (their "Ruling for Environmental Certification" - *Resolución de Calificacion Ambiente*, RCA) is available online at the SEIA database[37]. Sites that were approved before 2001 are not required to submit to the SEIA unless they undergo "important changes" that require them to enter the SEIA evaluation under an RCA. In this case, "important changes" include an expansion of production

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[35] http://www.sernapesca.cl/informacion-utilidad/fichas-de-especies-protegidas-urcep

[36] https://www.sea.gob.cl/

[37] https://seia.sea.gob.cl/expe

(under Law 19300, and Resolution 290), which has occurred on many sites. The SEIA environmental impact assessment takes the form of a Preliminary Characterization of the Site (*Caracterización Preliminar de Sitio*, CPS), and examples are publicly available[38].

It is generally considered that the Chilean salmon industry initially expanded in a poorly organized manner without adequate consideration for the density of farms. For example, Salgado et al. (2015) described it as the fastest growing industry in Chile that developed with very limited regulation. The ongoing requirements of the SEIA are now considered to minimize the risk of locating a new or expanding site, including its mooring infrastructure, in sensitive locations, but the initial locations of many sites may not have received full environmental impact assessments, and were sited prior to the ACS system. As described in the Introduction (Production System), the ACS system divides the farming regions into groups of farm sites (each site called a concession) sharing a similar waterbody, and the ACS is the primary tool employed to manage cumulative impacts and the scale of production. Although each ACS is legally defined and has a management plan, the system is primarily focused on biosecurity and fish health, and there is no indication that the types of impact described in Factor 3.1 above are considered in the cumulative management of the ACS system. The establishment of ACS boundaries was not substantively based on hydrographic characteristics, and do not necessarily equate with distinct waterbodies such as discreet fjords, and Iriarte et al. (2010) note that the precise estimation of the carrying capacity of the fjord systems for aquaculture activities and the possible impacts of changes in the carrying capacity on ecosystems services is a major scientific challenge in this pristine region.

Given the concerns regarding the management of the industry's expansion in Regions X and XI, a particular concern is the ongoing expansion of the industry into the Magallanes region in the far south of Chile. In addition to the high conservation value of southern Chile as a whole, the sub-Antarctic Magellanic ecoregion (42–56°S) is considered to be unique and presents remarkably high levels of endemism, with 50% of the fish species being endemic to the biome (Armesto et al., 1998). While the industry here appears to be expanding into Approved Areas for Aquaculture (see the Introduction – Production Statistics and Trends) and new sites will require Environmental Impact Assessments, it is again unclear whether the potential impacts in Factor 3.1 are taken into account, particularly with regard to the unique habitats in these regions. The number of active sites is increasing (from 39 in 2018 to 52 in 2021) and production is increasing more rapidly. At present, the regulatory system appears to be managing the expansion appropriately, at least with regard to the defined "appropriate areas for aquaculture", but the potential for unforeseen challenges remains (for example, see Criterion 2 – Effluent above).

Overall, the management system in Chile is considered to require new farms to be sited according to ecological principles and/or environmental considerations (e.g., EIAs

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[38] For example, selected at random: https://infofirma.sea.gob.cl/DocumentosSEA/MostrarDocumento?docId=fe/d5/97859df7877e5011a573a3609b9e8878bd3f

are required for new sites), but there are considered to be limited consideration of potential cumulative habitat impacts associated with the combined infrastructures of the industry in all regions. With consideration of the uncertainties in carrying capacities and the scale of the impacts described in Factor 3.1, the score for Factor 3.2a is 3 out of 5 for all regions. Given the basic net pen system is the same for both Atlantic and coho salmon, the score applies to both species.

Factor 3.2b: Enforcement of habitat management measures

It is clear that there is substantial enforcement of the aquaculture regulations in Chile, and with regard to the environmental impact assessments through SEIA, the extensive documentation can be seen in the database for each application (noting that not all sites were the subject of EIAs). Enforcement of other site-level and ACS-level management can be seen through Sernapesca and readily available monitoring results such as the INFAs.

GSI provides data on environmental non-compliances and shows most of the eight companies represented have had one or more fines for non-compliance to environmental regulations. This is further indication that enforcement is active to some extent, although it is not known if these extend to non-compliances in relation to farm infrastructure and habitat impacts.

Overall, the enforcement organizations are identifiable and active in all regions, but with regard to the potential impacts outlined in Factor 3.1, the activities are perhaps limited in their effectiveness and/or have some gaps in transparency particularly with regard to any potential cumulative impacts. Nevertheless, the enforcement of the site licensing process is robust and the score for Factor 3.2b - Enforcement of habitat management measures, is therefore 4 out of 5 for all regions and both species of salmon.

Factor 3.2 Final Score

The final score for Factor 3.2 is a combination of Factors 3.2a and 3.2b. These factors combine to result in a final Factor 3.2 score of 4.8 out of 10 for all regions and both salmon species.

Conclusions and Final Score

Salmon farm net pens and their supporting infrastructures contribute much physical structure to nearshore habitats and are known to modify the physical environment at the farm location by modifying light penetration, currents, and wave action, as well as providing surfaces for the development of rich biotic assemblages that may further increase the complexity of the habitat. An average salmon farm comprises approximately 50,000 m^2 of submerged artificial substrates that can be colonized by a large suite of hard-bottom associated species that may not otherwise find suitable habitat in a given area (e.g., sandy or muddy bottoms, or in the water column). These additional species may have a variety of direct and cascading effects on the surrounding ecosystem, including inadvertently supporting the persistence and distribution of non-native species, and/or pathogens and parasites. Salmon farms also attract a variety of wild animals as fish aggregation devices or artificial reefs, or repel other wild animals through disturbance such as noise, lights or increased boat traffic. Due to the relatively large size of the aquaculture vessel fleet, there is the potential for an as-yet unquantified disturbance of cetaceans including seasonal interactions with blue whales. Changes in behavior of wild fish around fish farms and even of their flesh quality due to the consumption of waste feed have been reported. A key aspect of these potential impacts is their circumstantial variability, their limited study, and the challenge of their quantification, particularly in the context of the confounding impacts of soluble and particulate effluent wastes (assessed in Criterion 2 - Effluent). However, the siting of floating net pen arrays does not result in the functional conversion of affected habitats, and the literature indicates that the realization of any or all of these potential impacts does not significantly impact the functionality of the ecosystems or the services provided by them. Further, the removal of farm infrastructure would quickly restore all baseline biophysical processes. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts.

The regulatory system for siting and impact assessment (at least for new or expanding sites) in Chile appears to be effective, but (noting that seabed impacts from particulate wastes are addressed in Criterion 2 – Effluent) it is unclear how the range of potential impacts associated with the infrastructure of the net pen systems are managed, including from a cumulative perspective. The ongoing expansion of the industry into largely pristine habitats in Region XII is a particular focus of interest. The scores for Factor 3.1 (8 out of 10) and 3.2 (4.8 out of 10) combine to result in a final Criterion 3 – Habitat score of 6.93 out of 10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations). This score applies to all regions and to both farmed salmon species.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

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

Criterion 4 Summary

Atlantic salmon

Region	Score		Critical
Region X	Critical	Critical	Yes
Region XI	Critical	Critical	Yes
Region XII	6	Yellow	No

Coho salmon

Region	Score		Critical
Region X	6	Yellow	No
Region XI	6	Yellow	No
Region XII	8	Green	No

Brief Summary

The open nature of the net pen production system provides no barrier to infection from environmental pathogens and parasites that may subsequently require treatment by chemicals including antimicrobials and pesticides. Total Chilean antimicrobial use on salmon farms declined from 2015 to 2018 but has since increased through 2020. The average country-level use reported by Sernapesca of 350 g/mt hides considerable variability by species and production region both in total and relative terms; for example, Atlantic salmon production accounts for substantially more than coho salmon, and Regions X and XI account for more than Region XII. The relative use of Atlantic salmon in Regions X, XI and XII in 2020 was calculated to be 588.2 g/mt, 543.9 g/mt, and 99.5 g/mt respectively, with an approximate treatment frequency of 3.1 treatments per site per year in Region X, 2.9 in Region XI, and 0.5 in Region XII. The relative use of coho salmon in Regions X, XI, and XII in 2020 was calculated to be 29.3 g/mt, 27.1 g/mt, and 5.0 g/mt respectively, with a treatment frequency per site per year of 1.0 in Regions X and XI, and 0.2 for the small amount of coho production in Region XII.

Almost all antimicrobial use (96.8% by weight in 2020) is currently of florfenicol, although oxytetracyline has until recently also been important. The direct ecological impacts of antimicrobials to the receiving environments remain unclear, but of high general concern is the potential development of antimicrobial resistance (in the treated bacterial pathogen as well as in the surrounding non-target bacterial communities) and the possible passage of mobile resistance genes to human pathogens. Although only used in veterinary applications, florfenicol is listed by the World Health Organization as highly important for human medicine due to the concern regarding the contribution to resistance in a variety of bacterial populations to other antimicrobials (via mobile resistance genes, e.g., the "floR" gene for florfenicol). Determining the drivers and scale of these processes are challenging and this is an active area of research in Chile. It is important to note a contrasting paradigm that suggests resistance genes initially enter aquatic environments primarily from the human and terrestrial sources.

Some recent studies indicate phenotypic resistance (technically the loss of susceptibility) in the primary target of antimicrobials in Chile (the bacterial pathogen *P. salmonis)* is not developing or is uncommon, and there is no evidence of clinical failures in production due to resistance. However, the government's resistance surveillance program shows approximately 50% of the isolates of *P. salmonis* from Atlantic salmon farms tested in 2020 show reduced susceptibility to florfenicol (and approximately 17% to oxytetracycline) in laboratory in-vitro trials. Values were low for other pathogens with the exception of *Flavobacterium psychrophilum* which showed 67% of isolates had reduced susceptibility to oxytetracycline. The research on the mechanisms underlying the acquisition and dissemination of acquired antimicrobial resistance by varied bacterial populations continues to evolve, and there is no conclusive link to antimicrobial use in aquaculture. Yet, there is inevitably a high concern that the widespread, repetitive, and prolonged use of antimicrobials in Chilean salmon farms (particularly Atlantic salmon farms) has resulted in bacterial populations evolving and adapting to the two most commonly used drugs.

Pesticide use for Atlantic salmon in Chile is also high and increasing, reflecting the ongoing struggle to control parasitic sea lice. Nearly 20 mt active ingredient of pesticide was used in 2019, plus over 3,200 mt of hydrogen peroxide, with pesticide use predominantly occurring in Regions X and XI due to the low sea lice numbers to date in Region XII. The impact of these pharmaceuticals on the marine environment remains largely uncertain, particularly with regard to repetitive treatments at a single site or from coordinated treatments in a single waterbody. Widespread resistance has previously developed in Chile and is likely to recur with the repeated use of a limited number of available treatments. With a minimal presence of sea lice on coho salmon, pesticide use for coho is considered here to be zero.

Overall, there is no specific evidence indicating that antimicrobial use in Chilean salmon farms has led to the development of clinical resistance (i.e., the loss of efficacy of treatments) for the primary treated pathogens. It must also be noted that bacterial resistance genes in marine environments may have originated from human and terrestrial sources; however, the ongoing repetitive (and currently increasing) use of hundreds of metric tons of a single antimicrobial with multiple treatments per site per year for Atlantic salmon is a high concern. Florfenicol is noted for its "floR" mobile resistance gene and the potential contribution to the pool of resistant genes in the environment. This is considered a critical conservation concern for Criterion 4 – Chemical Use for Atlantic salmon in Regions X and XI where the use of florfenicol is concentrated. Pesticide use for Atlantic salmon in these two regions is also high. For Atlantic salmon in Region XII, where antimicrobial and pesticide use (and therefore contribution to the concern for resistance persistence and development) are currently lower, the final score is 6 out of 10. For coho salmon, the frequency of florfenicol use is approximately once per site per year in Regions X and XI and (with no pesticide use) the final score for Criterion 4 – Chemical use is 6 out of 10. For coho salmon in Region XII (if production were to continue) with low antimicrobial and pesticide use, the final score is 8 out of 10. It is noted here that while chemical use in Region XII is currently minor, it has increased as production has increased in the region. This assessment is based on current practices, but it is noted that while fish health and chemical use are considered within the ACS management system, there are no robust measures that would prevent the increases in antimicrobial or pesticide use seen in Regions X and XI as production increased in the past. Maintaining low reliance on chemotherapeutants in Region XII is imperative and monitoring of the industry's chemical use will be ongoing.

Justification of Rating

This Seafood Watch assessment focuses on antimicrobials and sea lice pesticides as the dominant veterinary chemicals applied to salmon farming. While other types of chemicals may be used in salmon aquaculture (e.g., antifoulants, anesthetics), the risk of impact to the ecosystems which receive them is acknowledged to be less than that for antimicrobials and pesticides.

Antimicrobials

Quantity of antimicrobials used

Sernapesca has published annual antimicrobial use in Chilean aquaculture every year since 2011 (it is legally required to do so) with data going back to 2005 in the report "*Informe Sobre Uso De Antimicrobianos En La Salmonicultura*". The data are broken down by species, antimicrobial type and quantity, and by the disease treated. In 2016, Sernapesca's report (for 2015) was also broken down by company, but this has not been repeated since and SalmonChile now provides these data. In addition, the first report of the Chilean Salmon Antibiotic Reduction Program[39] (CSARP) was published in 2020 (with data from 2017 to 2019) and provides additional information on antimicrobial use by species and by farming area in Chile (CSRAP, 2020). As described below, Sernapesca and CSARP use different reporting metrics, therefore, there are some differences in the reported figures for antimicrobial use from these two data sources.

Sernapesca reports the total antimicrobial use by the industry in each calendar year, and in combination with the total annual harvest data, and the proportion used per species (Figure 13) the simple relative use (in grams of active ingredient per mt of harvested salmon) per year can be calculated.

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[39] CSARP is an initiative between the Monterey Bay Aquarium Seafood Watch program and the Chilean salmon farming industry. CSARP maintains industry data privacy and only anonymous aggregated data were available through the CSARP report or on request for this Seafood Watch assessment.

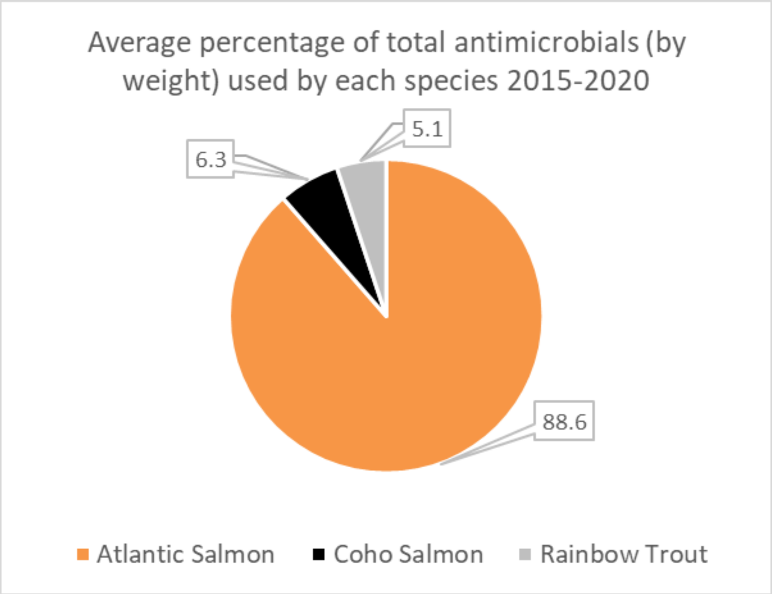

Figure 13: Proportion of antimicrobials used by each species as a percentage of the total use averaged from 2015 to 2020. Data from Sernapesca.

The total (mt) and relative antimicrobial use (g/mt) calculated for each species from Sernapesca data are plotted in Figure 14 and show that while both total antimicrobial use (in mt active ingredient per year) and relative use (in g/mt) declined for both Atlantic and coho salmon from 2015 to 2018, both indicators for Atlantic salmon increased again from 2018 to 2020 and also increased slightly for coho from 2019 to 2020.

The 2020 the total use of antimicrobials by Atlantic salmon was 349.5 mt (compared to 301.4 mt in 2019, and 445.8 in 2015) and relative use was 444.0 g/mt (compared to 429.3 g/mt in 2010, and 716.8 in 2015). The antimicrobial use for coho is much lower than for Atlantic salmon, with total use of 18.8 mt in 2020 and relative use of 91.9 g/mt (compared to 64.2 g/mt in 2019 and 397.7 g/mt in 2015). Note these relative use figures are averaged across all three production regions, and antimicrobial use will vary across them – see the regional analysis below.

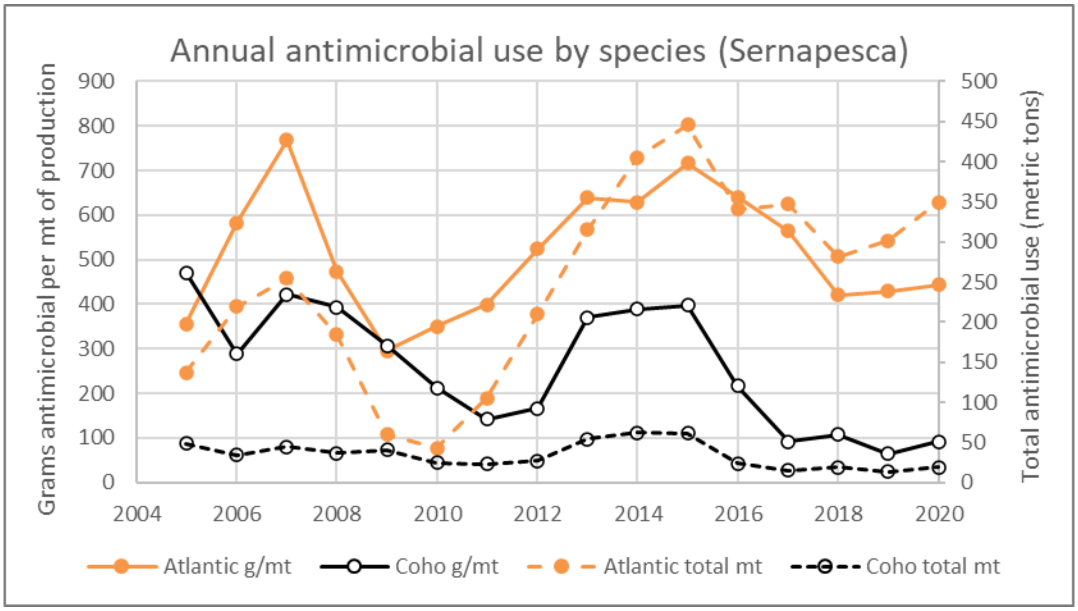

Figure 14: Solid orange line shows antimicrobial use in Atlantic salmon aquaculture in Chile in grams per ton of production (primary y-axis). Dashed orange line shows total antimicrobial use for Atlantic salmon in tons (secondary y-axis). Black lines show the same for coho salmon. Data from Sernapesca.

The CSARP primarily recognizes that production cycles commonly span two or even three calendar years (and therefore a single batch of harvested fish, particularly Atlantic salmon with the longer production cycle, may have been treated with antimicrobials in multiple previous years). CSARP reports total and relative antimicrobial use as 'closed cycle' values based on the cycle-specific antimicrobial use for all the production cycles that are harvested each calendar year. The total and relative CSARP values are therefore more closely aligned as they relate directly to completed production cycles but will differ in any one year from Sernapesca figures. Using these indicators, the three-year dataset from CSARP (plotted in Figure 15) shows that for Atlantic salmon, the total use has continued to decline to 263.5 mt in 2019 and the relative use has declined to 375.4 g/mt in 2019. For coho salmon, the total use declined to 7.9 mt in 2019 and relative use declined to 38.5 g/mt in 2019. These data confirm antimicrobial use in coho salmon production is substantially lower than Atlantic salmon, but the values are somewhat different from those generated by the annual Sernapesca data. Given the nature of the complete cycle indicators used by CSAPR, it is to be expected that there would a delay before these indicators show the annual increases shown in the Sernapesca data.

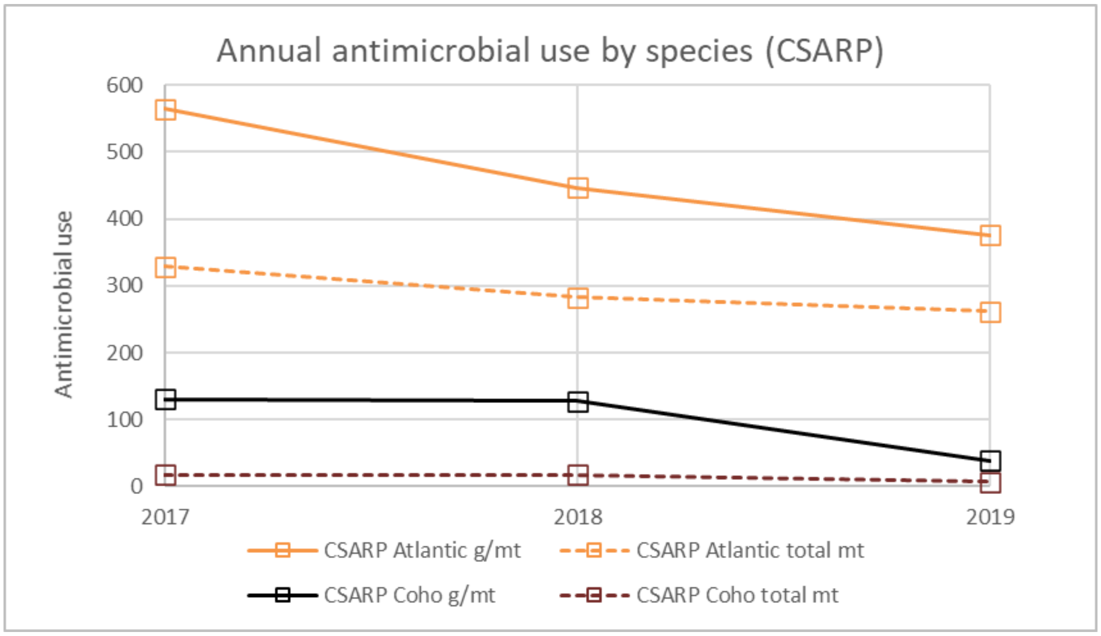

Figure 15: Solid orange line shows antimicrobial use in Atlantic salmon aquaculture in Chile in grams per ton of production. Dashed orange line shows total antimicrobial use for Atlantic salmon in mt. Black lines show the same for coho salmon. Data from CSARP.

In addition to the different Sernapesca and CSARP indicators, it is important to note that both the units of total mt and relative g/mt must be used with caution due to the different potencies of each antimicrobial[40] (and therefore the amount used in each "treatment") and changes in use of different antimicrobials over time.

At the country level, nearly all of antimicrobial use in Chile (97.6%) occurs during the marine stage of production, and 92.2% of that marine use is to treat the bacterial pathogen *Piscirickettsia salmonis,* the causative agent of piscirickettsiosis (Salmon Rickettsial Septicemia/syndrome, SRS) (Sernapesca, 2021b). Numerous vaccines for SRS are currently registered for use in Chile, but as the occurrence of SRS is influenced by multiple factors, there is little evidence of their widespread or uniform effectiveness under field conditions (Happold et al., 2020).

Company-specific data provided by Sernapesca in 2016 (for the 2015 production year) showed a wide range of average antimicrobial use by different companies, ranging from 114 g/mt to 1,170 g/mt (Sernapesca, 2015a), and a high variation likely continues today (also see the regional variability information below).

Regional antimicrobial use

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[40] For example, oxytetracycline has a much larger treatment dose does of approximately 55 to 82 mg/kg body weight of salmon for 10 days compared to approximately 10 mg/kg for 10 days for florfenicol (according to a simple search on www.drugs.com).

The total antimicrobial use by weight (in mt) is highly variable by region. Figure 16 from CSARP shows the 2017-2019 use in each ACS relative to the national average for all species combined. This initially highlights the lower use in Region XII.

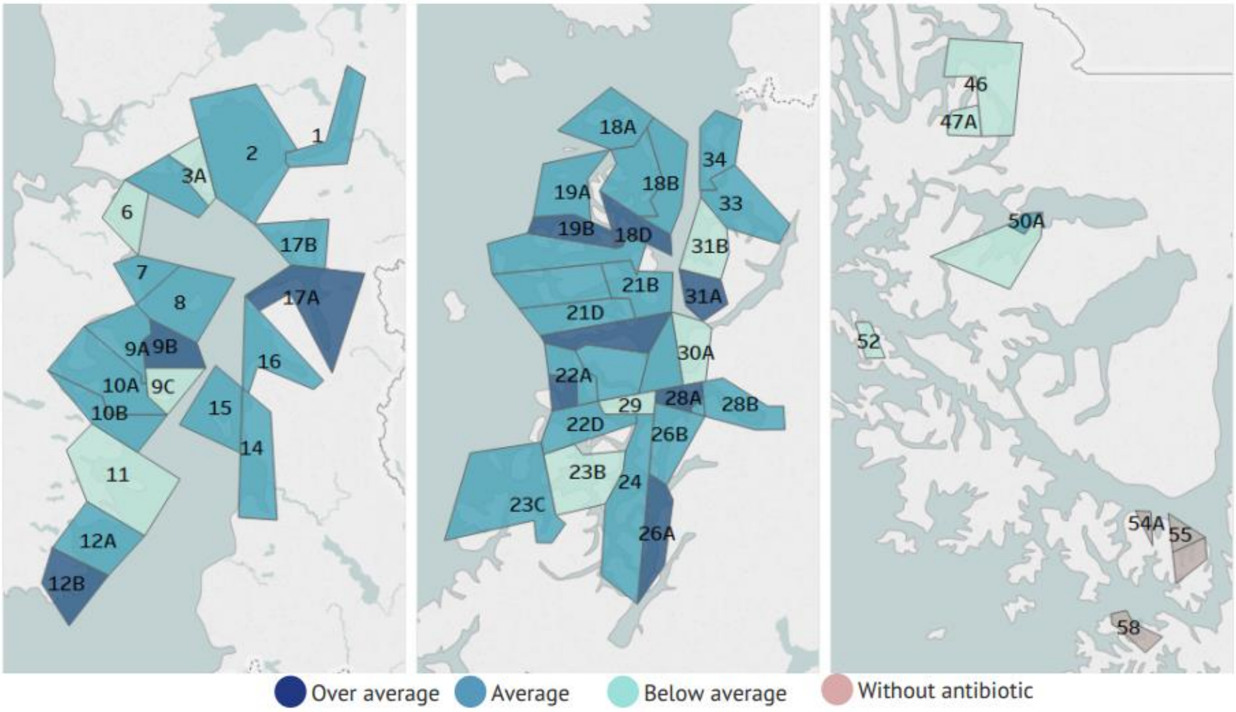

Figure 16: Antimicrobial use (combined for Atlantic and coho salmon) relative to the national average in each ACS neighborhood in Regions X, XI and XII using the same annual indicators as Sernapesca (2017-2019). Alphanumeric codes indicate each ACS. Image copied from CSARP (2020).

Using Sernapesca data, Figure 17 shows the regional antimicrobial use by weight (combined use of both Atlantic and coho salmon), for example showing over 200 mt of antimicrobials used in Region XI in 2020 compared to 15 mt in Region XII. The regional total use is correlated with regional production (see Figure 4), but it is also affected by the mix of species produced, and the bacterial disease characteristics of both the species and region. For example, In Region XII, antimicrobials were mostly prescribed for Bacterial Kidney Disease (BKD) (87%), Tenacibaculosis (5%), Atypical Furunculosis (5%) and Flavobacteriosis (3%), which differs substantially from Regions X and XII dominated by treatments for *P. salmonis* (data provided by Asociación Salmonicultres de Magallanes).

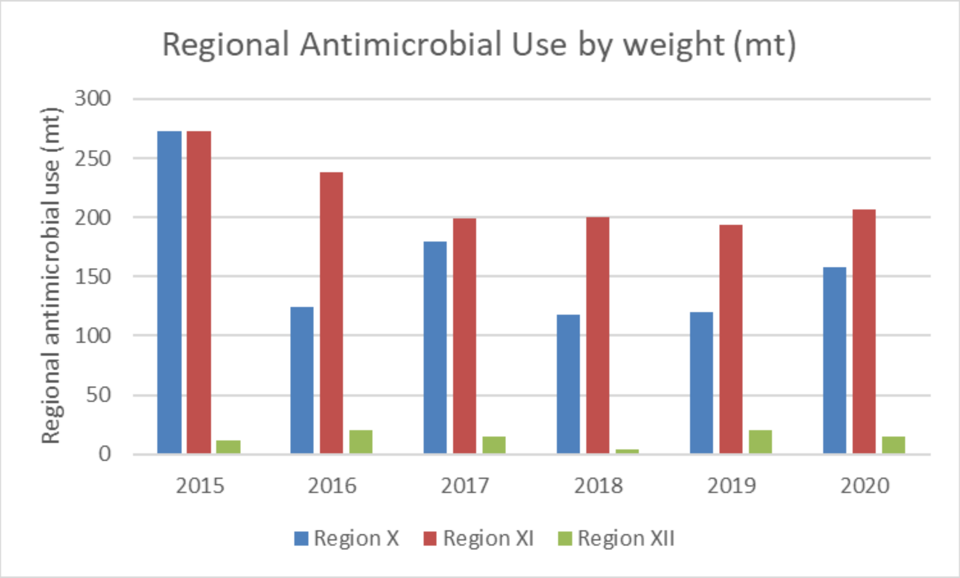

Figure 17: Regional antimicrobial use in Chile, combined for Atlantic and coho salmon, from 2017 to 2020. Data from Sernapesca (2021).

Sernapesca also provides figures for the proportion of the annual total used by each species (2015 to 2020 average shown in Figure 13); for example, in 2020, 92.7% of the total antimicrobial use in Chile was for Atlantic salmon, 4.6% for coho and 2.7% was for rainbow trout). By combining these species and regional antimicrobial use data with the harvest data for each species in each region, the relative antimicrobial use per species per region (in g/mt per region) can be approximated. Figure 18 shows these values for Atlantic salmon from 2015 to 2020, and Figure 19 for coho salmon; note the different scale of the y-axis between these two graphs for Atlantic and coho salmon.

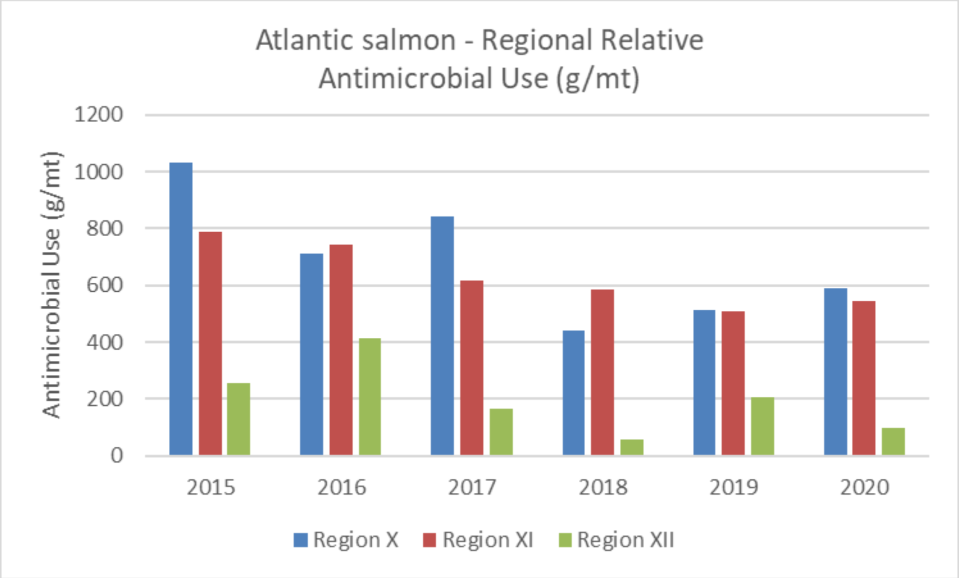

Figure 18: Regional relative antimicrobial use (in g/mt of production) for Atlantic salmon from 2015 to 2020. Values calculated from Sernapesca data.

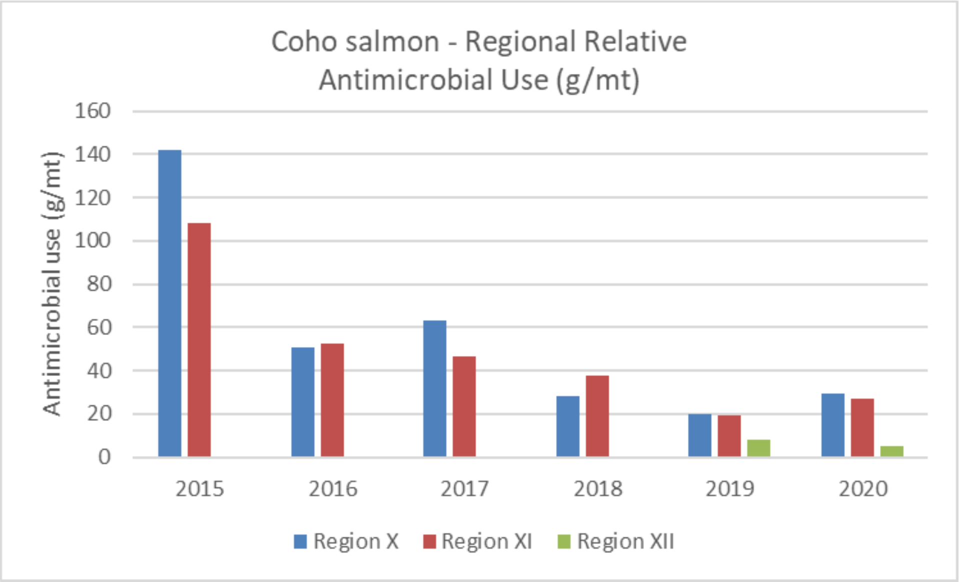

Figure 19: Regional relative antimicrobial use (in g/mt of production) for coho salmon from 2015 to 2020. Values calculated from Sernapesca data. Note there has only been short term production of coho in Region XII.

Figure 18 shows the relative use of antimicrobials for Atlantic salmon is substantially lower in Region XII; that is, for every 1 mt of Atlantic salmon produced in Region XII, there is less antimicrobial used compared to producing the same 1 mt of salmon in either Region X or XI. It can be seen that the 2020 country-level average relative antimicrobial use for Atlantic salmon of 440 g/mt (solid orange line in Figure 14) hides considerable regional variation, with 588 g/mt in Region X, 543 g/mt in Region XI and 99 g/mt in Region XII. These data (in Figure 18) also indicate antimicrobial use for Atlantic salmon in Region X in 2015 exceeded 1 kg per mt of production.

For coho salmon in Figure 19, the relative antimicrobial use is consistently and substantially lower than Atlantic salmon in all regions and all years. The relative use in 2020 was 29 g/mt in Region X, 27 g/mt in Region XI and 5 g/mt in Region XII (noting the short term and apparently discontinued production of coho in Region XII).

In 2016 Sernapesca initiated a program to recognize sites that had not used antimicrobials during production (antimicrobial-free), and in 2020, this evolved into the voluntary Program for the Optimization of Antimicrobials (*Programa Para La Optimización Del Uso De Antimicrobianos*), known as PROA Salmon[41]. Since 2016, 180 sites have been certified, 54% of which were in Region X, 18% in Region XI and 27% in Region XII. By species, 59% of the certified sites produced coho salmon and 31% Atlantic salmon (and 10% trout). In combination, 85% of the certified sites in Region XII produced coho and 8% Atlantic salmon, and in Region XI, 70% were coho sites and 27% Atlantic salmon. The number of new sites certified each year is shown in Figure 20.

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[41] http://www.sernapesca.cl/manuales-publicaciones/procedimiento-para-la-ceritificacion-de-peces-libres-de-uso-de

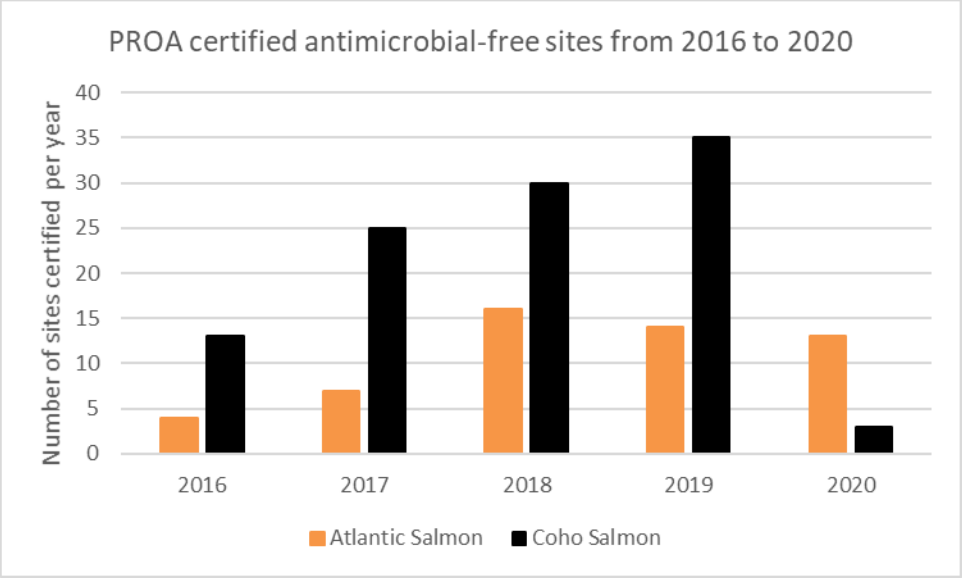

Figure 20: Number of sites certified as antimicrobial-free by the PROA each year from 2016 to 2020 by species. Data from Sernapesca.

These data reflect the discussion above with regard to the antimicrobial use between Atlantic salmon and coho salmon, and also likely reflect the evolution of the program since 2016. The low number of coho sites certified in 2020 may reflect an approaching practical limit on the number of potential sites that can achieve the antimicrobial-free status.

International comparison

Antimicrobial use in Chile has typically been very high in comparison to other salmon farming countries globally; in 2020, the average use was 0.17 g/mt in Norway[42], and in 2019 was 10.94 g/mt in Scotland[43] and 94.0 g/mt in British Columbia[44], compared to the Chilean use of 444.0 g/mt for Atlantic salmon and 91.9 g/mt for coho in 2020 (using Sernapesca data and comparable indicators). As discussed in Criterion 7 – Disease, this is primarily due to the intracellular bacterial pathogen *P. salmonis* which has high prevalence in Chile compared to other countries. While again emphasizing the need for caution in making direct comparisons (i.e., the type of antimicrobials used in Norway may be different to those in Chile, and Norway's primary disease challenges are viral and parasitic, not bacterial), in relative terms, the use of antimicrobials in g/mt for Atlantic salmon in Chile is 2,611 times higher than for the same species farmed in Norway.

Frequency of antimicrobial use

The CSARP reports frequency data for antimicrobial use in terms of the mean number of treatments administered to all production cycles completed in any one calendar year. The 2020 CSARP report provides data from 2017 to 2019 for all salmonid species aggregated and shows

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[42] Data from Sommerset et al. (2021)

[43] From a freedom of information request from the Scottish Environmental Protection Agency. Due to a data hack of SEPA, recent requests for updated data have not been addressed.

[44] From the Department of Fisheries and Oceans, Canada.

the average treatment frequency was 2.27 treatments per cycle in 2017, 2.31 in 2018, and 1.97 in 2019. The CSARP also provided species-specific frequency data for this assessment. These data (Figure 21) are averaged over all three regions and show the declines in antimicrobial use for salmon harvested over this three-year period. These data show Atlantic and coho salmon harvested in 2019 receiving 2.59 and 0.51 antimicrobial treatments per cycle respectively in 2019, compared to 3.59 and 0.9 for those fish harvested in 2017.

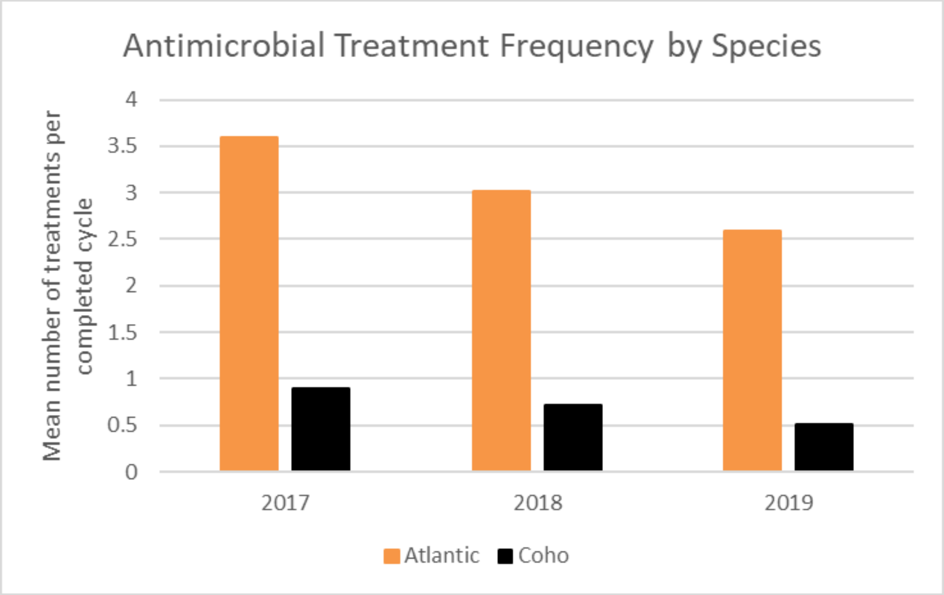

Figure 21: Antimicrobial treatment frequency, as the mean number of antimicrobial treatments administered to the fish harvested in completed production cycles each year. Data from CSARP (CSARP, pers. comm., 2021).

Similar to the country-level total and relative antimicrobial data discussed above, these average country-level frequency data hide substantial regional variations. By combining the CSARP frequency data for 2017 to 2019 with the regional Sernapesca data (proportions of total antimicrobial use, proportions used per species, and regional harvest data for each species up to 2020) and accepting small errors due to the different CSARP-Sernapesca reporting units[45], the treatment frequency for each species in each region can be approximated and also extrapolated to 2020. The treatment frequency values are calculated per year based on a marine production period of 16 months for Atlantic salmon, and 10 months for coho salmon. Figure 22 shows these approximate calculated treatment frequency values per year for Atlantic salmon, and Figure 23 for coho salmon (note the differing y-axis scales on these two graphs). For example, these figures show that the average 2019 Atlantic salmon frequency of 2.59 treatments per year in Figure 21 is actually the average of approximately 3.3 treatments in Regions X, 3.2 in Region XI, and 1.3 in Region XII. In 2020, Figure 22 shows the approximate treatments per year for Atlantic salmon were 3.1 in Region X, 2.9 in Region XI and 0.5 in Region XII

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[45] Due to these differences, it is considered that the calculated 2019 and 2020 values for Atlantic salmon will be a little low (i.e., the true frequency is slightly higher than shown) due to the delay in the CSARP data recognizing the increasing annual use in the Sernapesca data which increases from 2018 to 2020

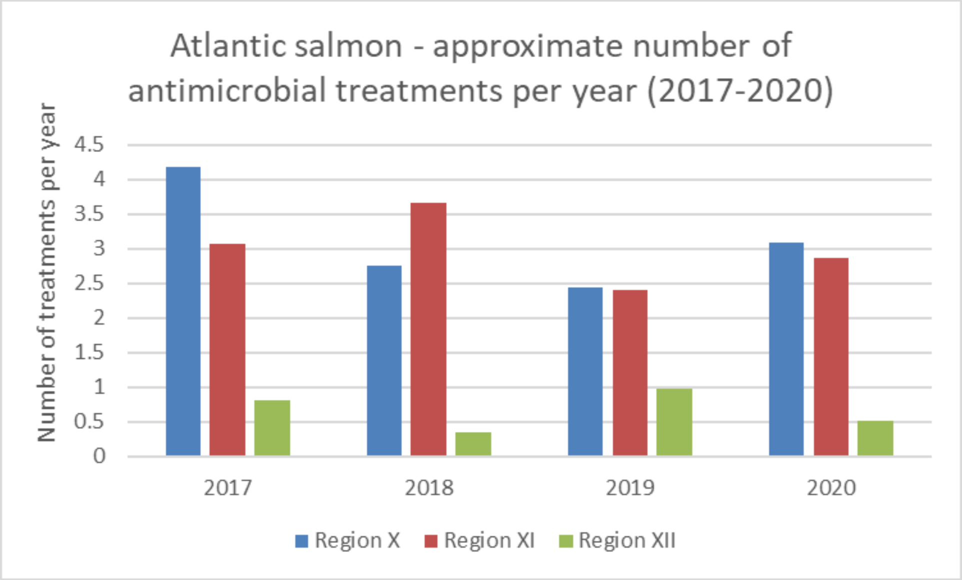

Figure 22: Approximate antimicrobial treatment frequency in number of treatments per year, for Atlantic salmon in each Region from 2017 to 2020. Calculated using data from Sernapesca and CSARP.

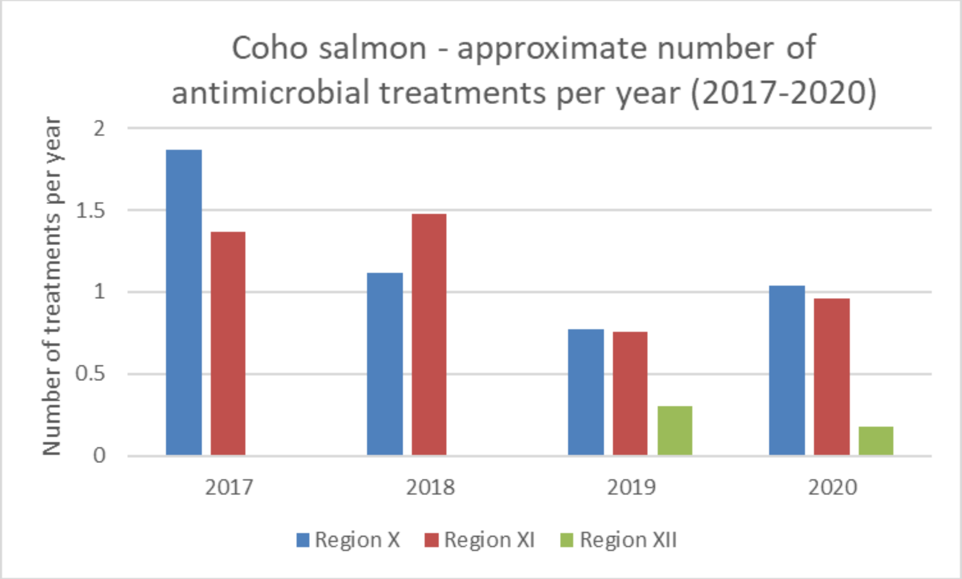

Figure 23: Approximate antimicrobial treatment frequency in number of treatments per year, for coho salmon in each Region from 2017 to 2020. Calculated using data from Sernapesca and CSARP.

Figures 22 and 23 again confirm the higher antimicrobial use in Atlantic salmon compared to coho salmon, with (for example) the 2020 frequency values for Atlantic salmon approximately three times those of coho salmon in each region. Atlantic salmon in Regions X and XI continue to have multiple antimicrobial treatments per year, while the frequency has been less than once per year over this 2017 to 2020 data period in Region XII. For coho salmon, the treatment frequency was close to once per year in Regions X and XI (1.03 and 0.95 respectively) but has been very low (0.3 and 0.2 treatments per year) for the first productions of coho in Region XII in 2019 and 2020 respectively.

Type of antimicrobial used

Sernapesca (2021) show 98.6% of antimicrobial use in 2020 in Chile in the marine growout phase was florfenicol, with minor amounts of oxytetracycline (0.8%), tiamulin (0.52%) and tilmicosin (0.02%). The proportional use of florfenicol has increased sharply in recent years; in 2012, florfenicol was 54% of treatments and oxytetracycline 43% (Sernapesca, 2013).

In the World Health Organization's list of Highly- and Critically Important Antimicrobials for Human Medicine (WHO, 2019), florfenicol is noted as highly important (even though it is used only in veterinary medicine) due to the potential for human pathogens to acquire resistance genes from florfenicol-treated non-human sources (e.g., livestock or fish). Oxytetracycline is also listed as highly important for human medicine. For veterinary applications, the World Organisation for Animal Health (OIE) has also prepared the List of Antimicrobial Agents of Veterinary Importance, within which both florfenicol and oxytetracycline are listed as "Veterinary Critically Important Antimicrobial Agents" (OIE, 2019). The OIE (2019) states: "The wide range of applications and the nature of the diseases treated make phenicols [and tetracyclines] extremely important for veterinary medicine. This class is of particular importance in treating some fish diseases, in which there are currently no or very few treatment alternatives." This emphasizes the need for responsible and prudent use (OIE, 2019).

Ecological impacts of antimicrobials

Antimicrobials in the environment can have direct ecological impacts (for example, changes in species composition and biogeochemical function) but very few recent studies have focused on benthic bacteria under marine salmon cages in Chile or on pelagic food webs around treated farms (Quiñones et al., 2019, and references therein). For aquaculture in general, Lulijwa et al. (2020) report antimicrobials may impose toxic effects in wild non-target species and can affect phytoplankton and zooplankton diversity via bacterial intoxication, and they have also been implicated in the disruption of zooplankton development and phytoplankton chlorophyll production. These changes, in turn, may result in alterations of food web dynamics with consequences throughout the ecosystem; however, a characteristic of this literature is that all potential impacts are poorly understood at different scales and locations (global, country, waterbody, site), and particularly the contributions that salmon farming's antimicrobial use makes in relation to other key users (i.e., terrestrial agriculture and human health) (Lulijwa et al. 2020). Quiñones et al. (2019) also emphasize there is an urgent need for more comprehensive ecosystem (beyond farm) studies on the impacts of antimicrobials.

Antimicrobial resistance

The use of antimicrobials in salmon farming links it to global concerns regarding the development of bacterial resistance to one or more antimicrobials, and to the passage of resistance genes from aquatic to terrestrial pathogens (Santos & Ramos, 2018; Lilijwa et al., 2020). The subject of antimicrobial susceptibility and resistance is extremely complex and the focus of a voluminous and rapidly growing body of literature; as such, understanding the complex potential impacts to food safety, occupational health, and (marine and non-marine) antimicrobial resistance continues to be challenging to fully comprehend (Lulijwa et al., 2020).

As noted above, the concern here is that the repeated use of antimicrobials in salmon farms may result in the proliferation and passage of resistance genes from aquatic to terrestrial pathogens; specifically, Cabello and Godfrey (2019) conclude that, "Resistance genes and mobile genetic elements containing them from these bacteria [collected from salmon farms] are transmissible bidirectionally by horizontal gene transmission to other bacteria, and some of them appear to have reached the resistome of human pathogens in the population bordering salmon aquaculture. It is important to note an alternative perspective, and in their response to Cabello and Godfrey (2019), Avendaño-Herrera (2020) consider the conclusion of Cabello and Godfrey to be highly debatable, stating it "goes against the more widely accepted paradigm that antimicrobial resistance genes enter aquatic environments from the human resistome (referencing Higuera-Llantén et al. 2018; Domínguez et al. 2019).

While clinical resistance in a practical context may be defined as the loss of treatment efficacy due to the developed resistance by the infective pathogen, the situation in fish is complicated by an often poor and inconsistent response to antimicrobial treatments due to other factors; these include the intracellular nature of the bacterium (Avendaño-Herrera, 2018) and practical aspects such as the timing, duration, and other management aspects of antimicrobial treatment practices such as reduced appetite for antimicrobials administered in feeds (Happold et al., 2020; San Martin., 2020).

The classification of bacterial populations into resistant, intermediate, and susceptible categories relies on standardizing laboratory in-vitro tests (see Contreras-Lynch et al., 2017; Yáñez et al., 2014) with treatment results in practice (both successful and failed treatments). In contrast to human medicine, the latter process is challenging in fish due to the variables that affect the success or failure of a treatment as described above, in addition to the bacterial susceptibility. Therefore, for fish, bacterial isolates are classified using in vitro analysis only into "wild type" isolates which are considered susceptible to the relevant antimicrobial, and "non-wild type" which have reduced susceptibility (Contreras-Lynch et al., 2017). Various academic articles continue to use the term "resistance" and when referenced here, the same term is used.

A robust understanding of the status of reduced antimicrobial susceptibility in Chile remains elusive. Lulijwa et al.'s (2020) review of antimicrobial use in aquaculture indicates antimicrobial residues accumulate in sediments and may drive change in microbial communities through selection for antimicrobial-resistant species and/or strains of species (and antimicrobial resistance genes may persist in the environment for several years after actual use of the drugs). With consideration of the dominant target of antimicrobial use in Chile *(P. salmonis)*, several studies in Chile have reported that this bacterium has developed resistance to antimicrobials (e.g., Quiñones et al., 2019, and references therein). Figueroa et al. (2019) noted some strains of *P. salmonis* had reduced susceptibility to florfenicol and oxytetracycline compared to a reference strain that had not been exposed to antimicrobials, but the same number of resistance genes were present, and the reduction was mediated at the protein level. Similarly, Quiñones et al., (2019) and Henriquez et al. (2016) also note that this bacterium does not appear to be developing phenotypic resistance to florfenicol, the dominant antimicrobial used repeatedly against it. In freshwater systems, Concha et al. (2019) reported a high level of multidrug resistance in bacterial samples from lake-based salmon farms in Chile, mostly showing resistance to florfenicol and oxytetracycline, but allocating any impact to aquaculture or the surrounding agriculture and urban centers is challenging.

The Aquaculture Research Division of Chile's Fisheries Development Institute (*Instituto de Fomento Pesquero*, IFOP) has established a resistance surveillance program; the "Surveillance of the resistance of pathogens to antimicrobials commonly used in national salmon farming"[46]. Initiated in 2016, the results are published in an annual report (e.g., IFOP, 2020a). As noted above, it is important to note that despite the name (i.e., "resistance surveillance program"), the methods used by IFOP detect a loss of susceptibility in the tested pathogens which is not specifically the same as resistance in the case of cultured fish.

In 2020, 76 isolates of *P. salmonis* were obtained from 106 sampled farm sites in 34 neighborhood ACSs. In the case of florfenicol 50% of the samples were classified as having reduced susceptibility or Non-Wild Type (NWT), and for oxytetracycline, 17.1%. Previous results from 110 isolates of *Flavobacterium psychrophilum* (which causes bacterial coldwater disease) showed 2.7% and 67% of the samples were NWT for florefenicol and oxytetracycline, respectively, and in the case of *Renibacterium salmoninarum* (which causes Bacterial Kidney Disease), categorization of the 71 isolates defined that 11% and 15% of the samples were NWT for florfenicol and oxytetracycline respectively. The 2019 sampling for *P. salmonis* showed similar results across Regions X and XI, with approximately 40% of isolates classified as NWT for florfenicol and approximately 8% NWT for oxytetracycline. Only one isolate of *P. salmonis* was obtained from a coho farm and it was of the highly susceptible wild type. In terms of trends, the IFOP reports show that in 2017 when the sampling began, 56% of isolates of *P. salmonis* were of NWT for florfenicol compared to 50% in 2020, indicating apparent stability in the results over time.

These reduced susceptibility results of the IFOP program are broadly similar to the published academic studies cited above, which imply antimicrobial resistance of *P. salmonis* to florfenicol or oxytetracycline is uncommon (e.g., Happold et al.,2020). Henriquez et al. (2016), described resistance in Chile as "in the onset" of happening, but any definitive conclusion regarding the development of resistance or reduced susceptibility due to the repeated antimicrobial use (of florfenicol particularly) does not seem possible.

Despite this uncertainty regarding the status of developed resistance in *P. salmonis,* the repeated use of antimicrobials can also still select for resistance in other non-target bacterial

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[46] Vigilancia de la resistencia de los agentes patógenos a los antimicrobianos de uso habitual en la salmonicultura nacional. https://www.ifop.cl/ifop-realizara-difusion-de-resultados-de-programa-de-vigilancia-de-resistencia-bacteriana-en-acuicultura-via-streaming/

populations (the IFOP program is to study antimicrobial susceptibility in non-pathogenic bacteria associated with salmon farming beginning in 2021). Higuera-Llantén et al. (2018) demonstrated that the high use of florfenicol and oxytetracycline has, as a consequence, selected for multi-resistant bacteria in the gut microbiota of farmed Atlantic salmon in marine farms in Chile, and the phenotypic resistance of these bacteria can be correlated with the presence of antimicrobial resistance genes. In the case of florfenicol, the resistance gene is known as the floR gene, and due to the widely recognized phenomenon of horizontal gene transfer (HGT), florfenicol has the potential to co-select for a diversity of resistances. For this reason, human health as well as animal health can potentially be impacted by the use of antimicrobials in aquaculture (Fernandez-Alarcon et al., 2010). Several recent studies further highlight the concern for the development and transfer of antimicrobial resistant genes in both freshwater and marine environments in Chile, as part of highly complex connections between heavy antimicrobial use and fish-, human- and environmental-health (Dominiguez et al., 2019; Cabello et al., 2020; Cabello & Godfrey, 2019, Quiñones et al., 2019). However, it is important to note strong differences in expert opinion on these findings; for example, Avendaño-Herrera (2021) commented on Cabello and Godfrey (2019) disagreeing with their findings and highlighting the complex nature of *P.* salmonis, which was followed by further disagreement in a response by Cabello and Godfrey (2021).

Lulijwa et al. (2019) noted that in developed countries (such as those with salmon farming industries), the use of antimicrobials in aquaculture is highly controlled, and although no limits on frequency of use or total use exist in Chile, salmon farms generally follow prudent use guidelines for antimicrobial use (i.e., veterinary oversight and prescription for diagnosed disease outbreaks, testing for efficacy/resistance, and no prophylactic use). Sernapesca has a Manual of Good Practices for the Use of Antimicrobial and Antiparasitic Agents in Chilean Salmon (*Manual de Buenas Prácticas En El Uso De Antimicrobianos Y Antiparasitarios En Salmonicultura Chilena*), which includes a list of best management practices relating to antimicrobial use, and Chile has a National Plan against Antimicrobial Resistance (*Plan Nacional Contra la Resistencia a los Antimicrobianos* – relating to all industries and public health). With regard to the latter, Avendaño-Herrera (2018) note that the indicators of the success within the plan are associated with decreasing the total volume of antimicrobials used in the industry, without providing an in-depth analysis of how usage decreases should be achieved. The Chilean salmon farming industry has also committed to reduce antimicrobial use (e.g., the CSARP program mentioned above).

Overall, the ongoing routine use of the same antimicrobials for decades (particularly those listed as highly-important for human medicine) remains a matter of serious concern, and the widespread, prolonged exposure of bacteria to sub-lethal concentrations of florfenicol and oxytetracycline in farms has likely resulted in some bacterial communities evolving and adapting to both treatment drugs. Yet a conclusive link between antimicrobial use in salmon aquaculture with developed resistance in the bacterial populations observed to date does not exist.

Pesticides

The primary target of pesticide use in Chile is the parasitic sea louse *Caligus rogercresseyi*. Currently, licensed treatments for immersion baths are deltamethrin, cypermethrin, azamethiphos, hexaflumuron, and hydrogen peroxide, while orally delivered treatments are emamectin benzoate, diflubenzuron, and lufenuron (Sernapesca[47]). Sernapesca collects data on the amount and types of pesticide used at each site and ACS, but it is not readily accessible outside Chile. SalmonChile publishes company-level data on relative pesticide use (in grams active ingredient per metric ton of production; g/mt), but these data are aggregated by pesticide type (including those administered in feed and in bath treatments). Bravo et al. (2011) reported numbers of lice on coho salmon were very low in Chile and noted that this species is considered to be resistant to significant sea lice infection. As noted below, this is confirmed by the available data and it is considered here that pesticides are not currently used in significant quantities in coho.

The SalmonChile data cover their 15 member companies (i.e., not including non-member companies such as Mowi) and are shown in Figure 24. These data show a mostly steady increase in pesticide use from 2013 to 2019.

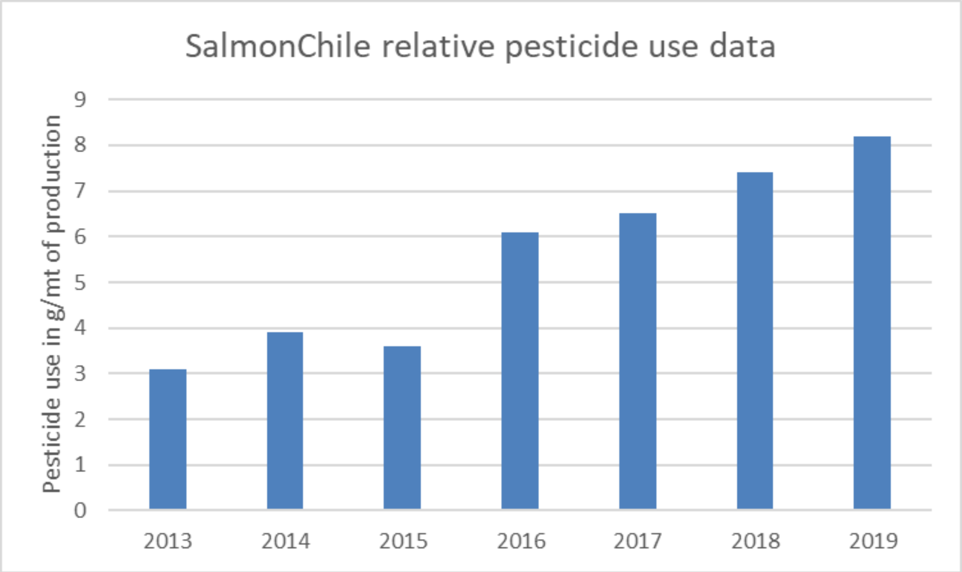

Figure 24: Relative pesticide use in g/mt, aggregated across all species (including trout) and all pesticide types. Data from SalmonChile.

A second dataset is available for eight Chilean companies reporting through the GSI from 2013 to 2020, and these data are separated into in-feed and bath treatments, and by species. The GSI data for Atlantic salmon only are shown in Figure 24 (not including hydrogen peroxide), and do not show the clear increasing trend in the SalmonChile data in Figure 23. The GSI data for hydrogen peroxide in kg/mt of production are shown in Figure 25, and show a rapid increase in recent years. The 2020 average value of 8.2 kg/mt equates to 6,454 mt of hydrogen peroxide

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[47] http://www.sernapesca.cl/sites/default/files/medicamentos_registrados_contra_caligidosis.pdf

for the 787,131 mt of Atlantic salmon produced. The GSI data show zero pesticide use for coho in any year of this time series.

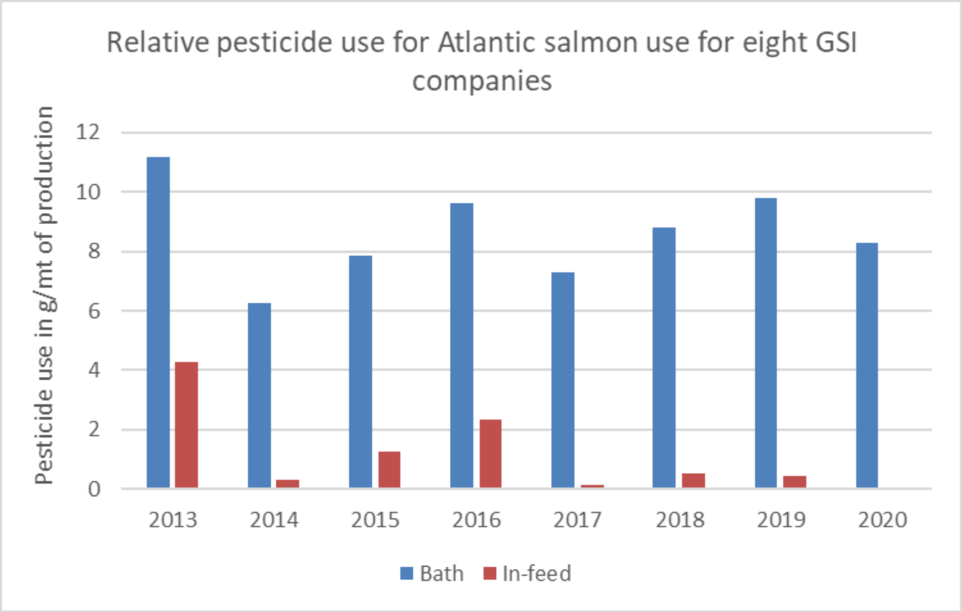

Figure 25: Relative pesticide use (not including hydrogen peroxide) in g/mt for Atlantic salmon in Chile for eight companies reporting through the GSI. Pesticides administered through bath treatments are shown in blue, and by in-feed treatments in red. Data from GSI.

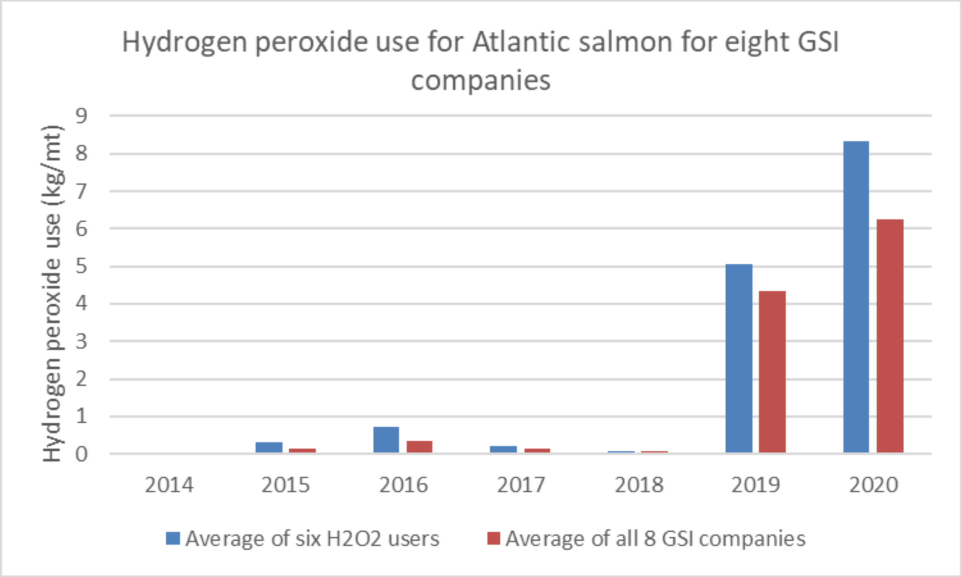

Figure 26: Relative hydrogen peroxide (H2O2) use in kg per mt of production for Atlantic salmon for the six out of eight GSI companies reporting hydrogen peroxide use (blue bars) and for all eight companies (red bars). Data from GSI.

The GSI data show substantial variability across the reporting companies, for example, the bath treatments per company in 2020 range from 3.9g/mt to 25.12 g/mt, and for hydrogen peroxide from 0kg/mt to 16.93 kg/mt.

The GSI data do not differentiate pesticide types beyond the bath and in-feed categories, but a third dataset published by industry media shows the breakdown of pesticide types in 2018 and 2019 (Intrafish, 2020[48] – referenced to Sernapesca). These data are shown in Table 2.

Table 2: Pesticide use in 2018 and 2019 listed by type and method of application. Data from Sernapesca, published in Intrafish (2020).

Active ingredient	Method	Total in 2018 (kg)	Total in 2019 (kg)	% change
Emamectin benzoate	In feed	44.8	129.2	+188
Diflubenzuron	In feed	324	147.7	-54
Cypermethrin	Bath	0.0	2.4	
Deltamethrin	Bath	42.8	145.8	+241
Azamethiphos	Bath	6,809.0	15,915.0	+134
Hexaflumuron	Bath	0.0	763.1	
Lufenuron*	In feed	267.2	2,455.0	+819
Total active ingredient		7,487.8	19,621.2	+162
Hydrogen peroxide†	Bath	195,097.4	3,215,541.0	+1,549

* Lufenuron is used in salmon hatcheries to treat smolts prior to their transfer to sea. It is considered to have a lower ecological concern than the related diflubenzuron (and teflubenzuron) (Poley et al., 2020).
† Hydrogen peroxide data are typically presented separately due to the high volume of use. It is not considered to be included in the other SalmonChile or GSI datasets presented here.

These data show a decrease in the use of diflubenzuron from 2018 to 2019, but large increases in all other treatments. Azamethiphos has the largest use with near 16 metric tons used on Atlantic salmon farms in 2019. The large increases in Table 2 are greater than the apparent increase in the SalmonChile data over the same years (Figure 24) and are not apparent in the GSI data for eight companies shown in Figure 25, highlighting the uncertainty in the pesticide data overall. The large increases in pesticide use from 2018 to 2019 apparently highlight the industry's ongoing struggle to control sea lice, resulting in the use of 19.6 mt of pesticide active ingredient in 2019. According to this dataset, hydrogen peroxide use increased 1,549% from 2018 to 2019, likely as response to increasing resistance in other treatments (see the resistance section below).

Table 2 shows eight pesticide types were in use in Chile in 2019. Azamethiphos was the largest by weight (with the exception of hydrogen peroxide which is used in very large volumes per treatment) and increased by 134% from 2018 to 2019. Hexaflumuron (trade name Alpha Flux) was launched in Chile in late 2019[49], and like the other treatments, it is classed as a category 1

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[48] Intrafish. 2020. As sea lice build resistance, Chile's farmed salmon producers search for new strategies. Intrafish June 15 2020 John Evans. https://www.intrafish.com/salmon/as-sea-lice-build-resistance-chiles-farmed-salmon-producers-search-for-new-strategies/2-1-811804

[49] https://thefishsite.com/articles/new-sea-lice-treatment-launched-in-chile

hazard according to EU regulations: hazardous to the aquatic environment and a long-term aquatic hazard, and very toxic to aquatic life with long lasting effects (Pharmaq, 2020).

Regional Pesticide Use

Sernapesca collects data on pesticide use from every site, but the publicly available data do not differentiate the regional use. An indication of likely regional pesticide use can be obtained by considering the respective sea lice loads. Figure 27 shows weekly average sea lice numbers are much higher in Region XI (and similar in Region X – not shown) than in Region XII.

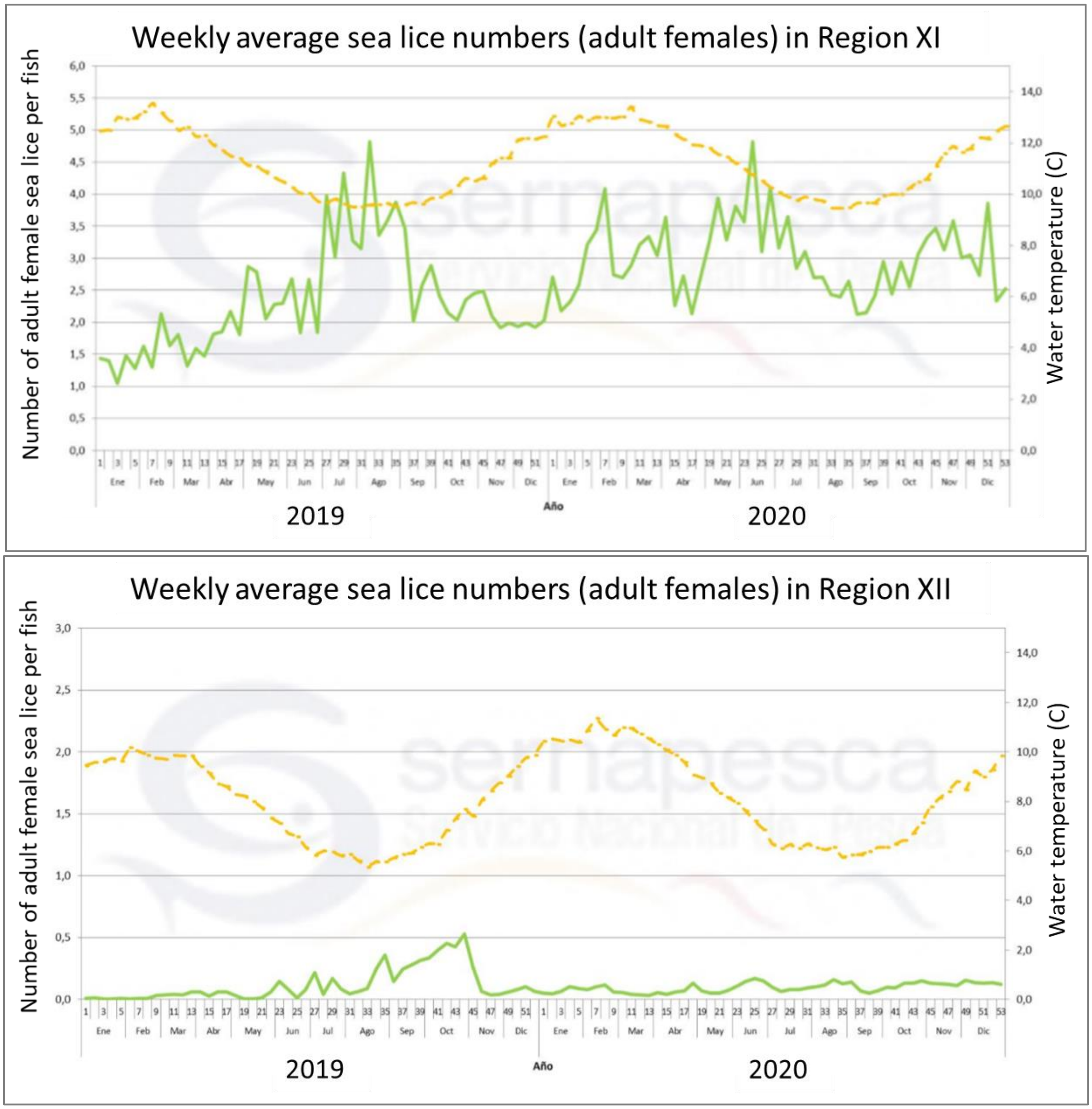

Figure 27: Weekly average sea lice (green line) in Region XI (top) and Region XII (bottom) in 2019 and 2020. Water temperature is also shown (yellow line and secondary y-axis). Note the different scales of the primary y-axis in each region.

The first sea lice were reported on farms in Region XII in 2017, with eight farms detecting lice and three farms presenting epidemic behavior requiring treatment (Arrigada et al., 2019), and Figure 27 shows lice levels currently continue to be low with a limited requirement for treatments. As such, the bulk of the total Chilean pesticide use is considered to be administered in Regions X and XI.

Resistance to sea lice treatments

The extensive use of sea lice medicines has resulted in an inevitable drift towards resistance which imposes a threat for fish health and welfare, the environment, and the economy of salmonid production (Aaen et al., 2015). IFOP considers the range of products licensed in Chile to be insufficient for the control of *C. rogercresseyi,* due, among other causes, to the potential for generating resistance to antiparasitics, and resistance is therefore a key concern in Chile and has been a recurring problem for at least a decade (Yatabe et al., 2011; Bravo et al., 2013, Jones et al., 2013).

Researchers at INCAR are developing molecular tools to evaluate the susceptibility of sea lice to different pesticides, and similar to the antimicrobial resistance surveillance program described above, IFOP uses these techniques in a national surveillance program for the resistance of sea lice to pesticides, accompanied by an annual report (e.g., IFOP, 2020b). To date, the program has focused on developing standardized bioassay methodologies, and on the development of baseline susceptibility profiles of *C. rogercresseyi* to three pesticide treatments (azamethiphos, deltamethrin and cypermethrin) with which to monitor developing resistance, and on which to base science-based management decisions (IFOP, 2020b).

Previous research has provided evidence of developed resistance to multiple sea lice treatments in Chile (Helgesen et al., 2014; Aaen et al., 2015; Bravo et al., 2013), although the scale of the reduction in efficacy is not clear. The IFOP pilot monitoring results have concluded that the numbers of parasites affected or killed by the three treatments tested has decreased over time[50], probably due to the increasingly frequent appearance of parasites with reduced susceptibility.

Despite the different species of sea lice that is the primary target of pesticide use in northern hemisphere salmon farming (*L. salmonis)*, it is also useful to consider the evidence of developing resistance to the same pesticides elsewhere. For example, regarding azamethiphos (a commonly used bath treatment in Chile), the pattern of use and demonstrated resistance in Norway implies a high risk of resistance developing in Chile. For example, Kaur et al. (2015) state azamethiphos was first introduced in Norway in 1994, and when its use was terminated in 1999, resistance was widespread; it was re-introduced in 2008, and reports of reduced efficacy were received by 2009. For reference, the Norwegian national surveillance program (Helgesen et al., 2021) notes widespread resistance to anti-louse chemicals all along the coast, and aquaculture has thus been described as a major driver of salmon louse population structure (Fjørtoft et al., 2017, 2019). Helgesen et al. (2021) note that resistance remains present in

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[50] The specific timeframe is not clear from the IFOP report.

Norway despite a large reduction in pesticide use, and they consider it likely to be because resistance genes are now well established within all lice populations (i.e., those found on both wild and farmed salmon) and because all use of medicine selects for resistance.

Initial cases of resistance to hydrogen peroxide amongst sea lice populations in Norway were noted in 2013 (Helgesen et al., 2015), and Helgesen et al. (2021) report that reduced sensitivity to hydrogen peroxide is increasingly widespread. With the large and rapidly increasing use of hydrogen peroxide in Chile, it seems inevitable that sea lice will also develop resistance to this chemical.

Ultimately, the IFOP resistance surveillance program in Chile and the developing information being generated by it is welcomed, and these results in addition to previous academic studies clearly show that resistance to some treatments used has developed and/or is developing (Yatabe et al., 2011; Bravo et al., 2013, Jones et al., 2013; Helgesen et al., 2014; Aaen et al., 2015). The continued and increasing use would be expected to result in continued and/or increased resistance.

Environmental impacts of sea lice pesticides

The pesticides used in Chile are non-specific (i.e., their toxicity is not specific to the targeted sea lice) and, therefore, may affect non-target organisms – in particular crustaceans – in the vicinity of treated net pens (Grefsrud et al., 2021a,b). The fate and environmental impact of discharged sea lice treatments and their metabolites varies according to the chemical type and the treatment method, so understanding the impacts to the ecosystems which receive them upon discharge is challenging. The presence of a chemical in the environment does not necessarily mean that it is causing harm (SEPA, 2018).

Grefsrud et al. (2021a,b) have a useful review of the different sea lice treatments and the aspects of concern regarding their use and potential subsequent impacts, but while the impacts continue to be studied and reviewed, the real effects of these pharmaceuticals on the marine environment remain largely uncertain (Urbina et al., 2019).

Large proportions of both treatment types (in-feed and bath) can be discharged from the farms after treatment. In-feed treatments tend to be dispersed in uneaten feed and fecal particles that settle to the seabed (Burridge et al., 2010), and Samuelsen et al. (2015) and references therein showed that residues in settling organic particles (feces) can be more concentrated than in the feeds. Persistence in the sediment ultimately depends on the chemical nature of the product used and the chemical properties of the sediment, and toxicity to non-target organisms of in-feed sea lice treatments tends to be of a chronic nature at low concentrations (Macken et al., 2015; Lillicrap et al., 2015). Importantly, Samuelsen et al. (2015) showed that while pesticide residue levels in the sediments are low, particles containing residues have been found as far as 1,100 m from the treatment site.

There does not appear to be any specific monitoring for residues or evidence of impacts at salmon farm sites in Chile, but as an example from another country, the Scottish Environment

Protection Agency (SEPA) conducted an independent review of the environmental impact of emamectin benzoate on Scotland's seabed from its use on salmon farms. The results of the analysis (published by SEPA, and in a peer-reviewed academic journal as Bloodworth et al., 2019) indicate that the impacts of farms may extend beyond their immediate vicinity and have confirmed that the existing Environmental Quality Standards (EQS) were not adequately protecting marine life (SEPA, 2018).

Sea lice chemicals administered as bath treatments (such as azamethiphos, the dominant treatment in Chile) are released to the environment as a water column plume. Though some authors contest that such treatments may retain toxicity for a substantial period after release (Burridge et al., 2010), Macken et al. (2015) conclude that, as bath treatments such as azamethiphos, cypermethrin, and deltamethrin have a rapid release, dispersion, and dilution post treatment, they primarily impact non-target organisms in an acute manner with limited potential for chronic impacts. In their study on the epibenthic copepod *Tisbe battagliai* (Macken et al., 2015), azamethiphos was acutely toxic at high concentrations, but was found to cause no developmental effects at lower concentrations. Exposure to hydrogen peroxide (which has broadly been considered to be environmentally benign at relatively low concentrations (Lillicrap et al., 2015)) has recently been associated with irreversible negative effects on polychaete species (Fang et al., 2018). For pyrethroids (cypermethrin and deltamethrin), Tucca et al. (2020) note their use may impact non-target organisms in the water column (particularly copepod), and also report that levels detected in sediment were in the range of concentrations toxic to native invertebrate species in Chile. Parsons et al. (2020) report that azamethiphos is acutely toxic to European lobster larvae (*Homarus gammarus*) at levels below the recommended treatment concentrations, but due the hydrodynamic models of dispersion, the impact zones around farms were relatively small (mean area of 0.04–0.2 km^2). In their Norwegian risk assessment, Grefsrud et al. (2021) concluded that the risk of environmental effects on non-target species through the use of five of the main treatments (in Norwegian circumstances) was moderate for emamectin benzoate, deltamethrin, diflubenzuron, teflubenzuron and hydrogen peroxide, and low for azamethiphos.

Ten years ago, Burridge et al. (2010) noted: "No studies (lab or field) have adequately addressed cumulative effects [of chemical use in salmon aquaculture]; salmon farms do not exist in isolation." While this review is now somewhat dated, it has been further supported more recently by the conclusion of Urbina et al. (2019) that the real effects of these pharmaceuticals on the marine environment remain largely uncertain.

Conclusions and Final Score

The open nature of the net pen production system provides no barrier to infection from environmental pathogens and parasites that may subsequently require treatment by chemicals including antimicrobials and pesticides. Total Chilean antimicrobial use on salmon farms declined from 2015 to 2018 but has since increased through 2020. The average country-level use reported by Sernapesca of 350 g/mt hides considerable variability by species and production region both in total and relative terms; for example, Atlantic salmon production accounts for substantially more than coho salmon, and Regions X and XI account for more than

Region XII. The relative use of Atlantic salmon in Regions X, XI and XII in 2020 was calculated to be 588.2 g/mt, 543.9 g/mt, and 99.5 g/mt respectively, with an approximate treatment frequency of 3.1 treatments per site per year in Region X, 2.9 in Region XI, and 0.5 in Region XII. The relative use of coho salmon in Regions X, XI, and XII in 2020 was calculated to be 29.3 g/mt, 27.1 g/mt, and 5.0 g/mt respectively, with a treatment frequency per site per year of 1.0 in Regions X and XI, and 0.2 for the small amount of coho production in Region XII.

Almost all antimicrobial use (96.8% by weight in 2020) is currently of florfenicol, although oxytetracyline has until recently also been important. The direct ecological impacts of antimicrobials to the receiving environments remain unclear, but of high general concern is the potential development of antimicrobial resistance (in the treated bacterial pathogen as well as in the surrounding non-target bacterial communities) and the possible passage of mobile resistance genes to human pathogens. Although only used in veterinary applications, florfenicol is listed by the World Health Organization as highly important for human medicine due to the concern regarding the contribution to resistance in a variety of bacterial populations to other antimicrobials (via mobile resistance genes, e.g., the “floR” gene for florfenicol). Determining the drivers and scale of these processes are challenging and this is an active area of research in Chile. It is important to note a contrasting paradigm that suggests resistance genes initially enter aquatic environments primarily from the human and terrestrial sources.

Some recent studies indicate phenotypic resistance (technically the loss of susceptibility) in the primary target of antimicrobials in Chile (the bacterial pathogen *P. salmonis)* is not developing or is uncommon, and there is no evidence of clinical failures in production due to resistance. However, the government’s resistance surveillance program shows approximately 50% of the isolates of *P. salmonis* from Atlantic salmon farms tested in 2020 show reduced susceptibility to florfenicol (and approximately 17% to oxytetracycline) in laboratory in-vitro trials. Values were low for other pathogens with the exception of *Flavobacterium psychrophilum* which showed 67% of isolates had reduced susceptibility to oxytetracycline. The research on the mechanisms underlying the acquisition and dissemination of acquired antimicrobial resistance by varied bacterial populations continues to evolve, and there is no conclusive link to antimicrobial use in aquaculture. Yet, there is inevitably a high concern that the widespread, repetitive, and prolonged use of antimicrobials in Chilean salmon farms (particularly Atlantic salmon farms) has resulted in bacterial populations evolving and adapting to the two most commonly used drugs.

Pesticide use for Atlantic salmon in Chile is also high and increasing, reflecting the ongoing struggle to control parasitic sea lice. Nearly 20 mt active ingredient of pesticide was used in 2019, plus over 3,200 mt of hydrogen peroxide, with pesticide use predominantly occurring in Regions X and XI due to the low sea lice numbers to date in Region XII. The impact of these pharmaceuticals on the marine environment remains largely uncertain, particularly with regard to repetitive treatments at a single site or from coordinated treatments in a single waterbody. Widespread resistance has previously developed in Chile and is likely to recur with the repeated use of a limited number of available treatments. With a minimal presence of sea lice on coho salmon, pesticide use for coho is considered here to be zero.

Overall, there is no specific evidence indicating that antimicrobial use in Chilean salmon farms has led to the development of clinical resistance (i.e., the loss of efficacy of treatments) for the primary treated pathogens. It must also be noted that bacterial resistance genes in marine environments may have originated from human and terrestrial sources; however, the ongoing repetitive (and currently increasing) use of hundreds of metric tons of a single antimicrobial with multiple treatments per site per year for Atlantic salmon is a high concern. Florfenicol is noted for its "floR" mobile resistance gene and the potential contribution to the pool of resistant genes in the environment. This is considered a critical conservation concern for Criterion 4 – Chemical Use for Atlantic salmon in Regions X and XI where the use of florfenicol is concentrated. Pesticide use for Atlantic salmon in these two regions is also high. For Atlantic salmon in Region XII, where antimicrobial and pesticide use (and therefore contribution to the concern for resistance persistence and development) are currently lower, the final score is 6 out of 10. For coho salmon, the frequency of florfenicol use is approximately once per site per year in Regions X and XI and (with no pesticide use) the final score for Criterion 4 – Chemical use is 6 out of 10. For coho salmon in Region XII (if production were to continue) with low antimicrobial and pesticide use, the final score is 8 out of 10. It is noted here that while chemical use in Region XII is currently minor, it has increased as production has increased in the region. This assessment is based on current practices, but it is noted that while fish health and chemical use are considered within the ACS management system, there are no robust measures that would prevent the increases in antimicrobial or pesticide use seen in Regions X and XI as production increased in the past. Maintaining low reliance on chemotherapeutants in Region XII is imperative and monitoring of the industry's chemical use will be ongoing.

Criterion 5: Feed

Impact, unit of sustainability and principle

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

Criterion 5 Summary

Atlantic and coho salmon in all regions

C5 Feed parameters	Value	Score
F5.1a Forage Fish Efficiency Ratio	1.98	
F5.1b Source fishery sustainability score (0-10)		5
F5.1: Wild fish use score (0-10)		2.82
F5.2a Protein INPUT (kg/100kg fish harvested)	46.67	
F5.2b Protein OUT (kg/100kg fish harvested)	16.90	
F5.2: Net Protein Gain or Loss (%)	-63.79	3
F5.3: Species-specific kg CO2-eq kg-1 farmed seafood protein	18.94	5
C5 Feed Final Score (0-10)		3.41
Critical?	**No**	Yellow

Brief Summary

In the absence of specific feed composition information from Chilean feed mills, categorical feed composition data from salmon farming company reports was supported with specific ingredients from reference feeds in the academic literature. While not specifically accurate, the key aspects relating to this assessment were considered to be sufficiently robust. The same feeds are considered to be used for Atlantic and coho salmon in Chile, and while performance indicators such as the Feed Conversion Ratio may vary by region, there is currently insufficient regional data to assess them separately. Using total fishmeal and fish oil inclusions of 15% and 10% respectively (and typical proportions sourced from fish trimmings and byproducts) and an eFCR of 1.3, from first principles, 1.98 mt of wild fish must be caught to produce the fish oil needed to grow 1.0 mt of farmed salmon in Chile. This value was higher than the three-year average of eight companies reporting through GSI (1.61), but these eight companies cannot be considered to represent all of Chilean production; the difference is likely due to variations in feed conversion ratios, yields and inclusion rates which can be improved with greater data availability. Information on the sustainability of source fisheries obtained for three major feed companies from the Ocean Disclosure Project showed a moderate overall sustainability and resulted in a Wild Fish Use score of 2.82 out of 10. There is a substantial net loss of 63.8% of feed protein (score 3 out of 10) and a moderate feed ingredient footprint of 18.94 kg CO2-eq. per kg of harvested protein (score of 5 out of 10). Overall, the three factors combine to result in a final feed score of 3.41 out of 10.

Justification of Rating

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

Feed composition

The feed composition data for this assessment were compiled from global and regional data in Mowi's Salmon Industry Handbook[51] and company reports, and specific ingredients in two salmon reference diets in Mørkøre et al. (2020) and Aas et al. (2019), both based on Norwegian feeds. Categorical data from industry reports highlight the key differences between European (i.e., the Norwegian and Scottish) salmon feeds and those in Chile (and Canada); i.e., Europe typically does not use land animal ingredients in feeds, while Chile (and Canada) do. Therefore, the available data sources have been used to create a best-fit feed composition for Chile as shown in Table 3 along with each ingredient's Global Feed Lifecycle Institute (GFLI) CCI/mt value (see Factor 5.3). While the feed composition used here might not reflect the exact ingredients and their inclusions in practice, it is considered to be sufficiently representative of a typical Chilean salmon feed for this assessment.

Table 3: Best-fit feed composition and GFLI CCI/mt values from the available data.

Feed Ingredient	Inclusion (% of total feed)	GFLI value
Fishmeal	9	1.1843
Fishmeal byproducts	6	1.1843
Fish oil	7.5	0.8176
Fish oil byproducts	2.5	0.8176
Wheat gluten	10	3.9989
Soy protein concentrate	15	6.4170
Corn gluten	4	1.5647
Pea protein concentrate	4	1.3535
Rapeseed (canola) Oil	16	2.9154
Poultry meal	16	1.2334
Poultry oil	2	3.1717
Vitamin/minerals	8	No data
Total	100	

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

The proximate and ingredient composition values are primarily referenced to Atlantic salmon feeds, but there are not considered to be significant volumes coho-specific feeds in Chile (and no evidence was found of any).

Economic feed conversion ratio (FCR)

A general eFCR value from the academic literature for Atlantic salmon (i.e., not specific to any region) is 1.3 (Tacon et al., 2021; Naylor et al., 2021, Tacon, 2020). The Chilean value in Mowi's Industry Handbook (which represents all salmon farming companies, not just Mowi), and in Aas et al. (2019) are 1.3. Without other specific values direct from Chile, or species-specific values for Atlantic salmon and coho (or region-specific values), the value of 1.3 is used here for both species for both species and all regions.

Factor 5.1. Wild Fish Use

Factor 5.1a – Feed Fish Efficiency Ratio (FFER)

Using the data in Table 3 along with the eFCR value of 1.3 and the standard yield values for fishmeal and fish oil (22.5% and 5% respectively), the Forage Fish Efficiency Ratio (FFER) is 0.54 for fishmeal and 1.98 for fish oil. This means that from first principles, 1.98 mt of wild fish would need to be caught to supply the fish oil needed to produce 1.00 mt of farmed salmon. This is slightly higher than the three-year average (2018-2020) of eight Chilean companies that report FFDR values (FFDR is the same as FFER) for fishmeal (0.32) and fish oil (1.62) through GSI (Figure 28). The GSI data show the FFDR values for both fishmeal and fish oil have been decreasing since 2013, particularly for fishmeal due to reduced inclusion levels. There was a slight increase in the FFDR value for fish oil from 2019 to 2020.

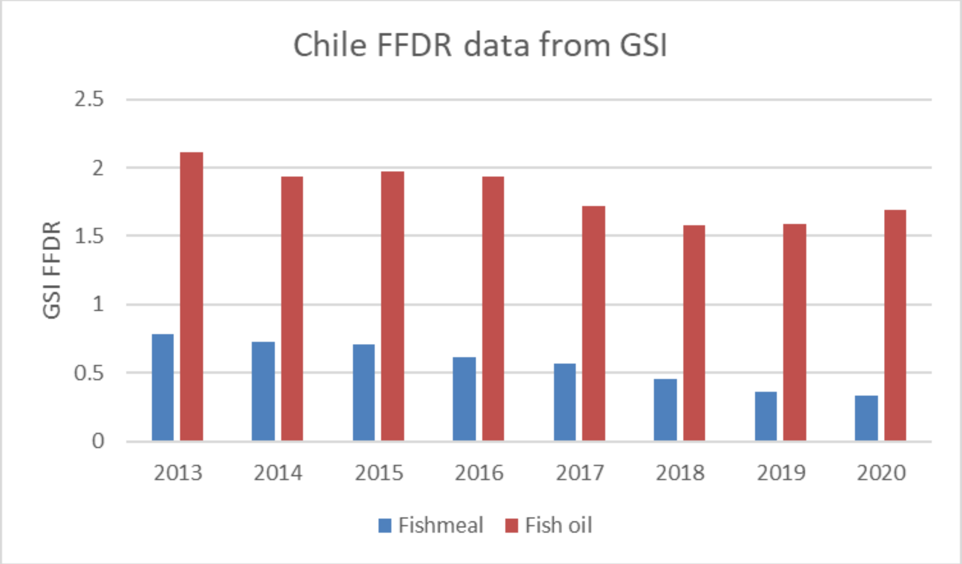

Figure 28: Forage Fish Dependency Ratios (FFDR) for eight Chilean companies reporting through GSI from 2013 to 2020. Data from GSI.

The GSI values from only eight companies cannot be considered to represent all companies in Chile, and the FFER (and FFDR) calculations are sensitive to the eFCR and the yield values used, in addition to the inclusion levels of fishmeal and fish oil. The variations in the results calculated can be minimized by improved data availability from Chile. The FFER value of 1.98 for fish oil is used here.

Factor 5.1b –Sustainability of the Source of Wild Fish

Without specific data for source fisheries supplying fishmeal and fish oil to Chilean salmon feeds, the global data for three major feed companies (Biomar, Ewos-Cargill, and Skretting) reporting through the Ocean Disclosure Project were used[52]. While each company has a sustainable sourcing policy, the fisheries used are the more practical manifestation of their sourcing policies.

The Ocean Disclosure Project data covered approximately 38 different fisheries used by the three companies and include the management status of the fishery (certified, well-managed, managed, needs improvement, and not rated[53]). It is not known which fisheries supplied fishmeal, fish oil, or both, nor are the weightings of each source known (i.e., which sources are most commonly used in Chilean feeds and how much). Therefore, an aggregated sustainability score for fishmeal and fish oil has been generated across all three feed companies and used here for Chile. Again, this may not reflect the exact fisheries sources used in Chilean salmon feeds but is considered to be acceptably representative and the best estimate available.

Table 4: Source fishery sustainability categories from the Ocean Disclosure Project

Fishery status	Percent of fisheries	SFW Sustainability score	Weighted score
Certified	38.4	7	2.7
Well Managed	7.2	6	0.4
Managed	25.8	4	1.1
In need of improvement	19.2	3	0.4
Not rated	9.4	2	0.2
		Weighted sustainability score (0-10)	**4.8**

The weight-calculated sustainability score is 4.8 out of 10. Rounding this score to the nearest integer, the final Seafood Watch sustainability score is 5 out of 10, and in combination with the FFER value of 1.98, results in a final score for Factor 5.1 - Wild Fish Use of 2.82 out of 10.

Factor 5.2. Net Protein Gain or Loss

Values for the total protein content of typical salmon feeds from the suite of references stated above average to 35.9% (with a small range of 35% to 36.4%). Aas et al. (2019) specify a whole-body composition of farmed salmon of 16.9% crude protein, and this value is used here.

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[52] https://oceandisclosureproject.org/

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

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

Factor 5.3. Feed Footprint

This factor is an approximation of the embedded climate change impact (CCI, in units of kg CO_2-eq including land-use change) of the feed ingredients required to grow one kilogram of farmed seafood protein. The calculation is performed by mapping the ingredient composition of a feed used against the Global Feed Lifecycle Institute (GFLI) database[54] to estimate the CCI of one metric ton of feed, followed by multiplying this value by the eFCR and the protein content of whole harvested salmon. If an ingredient of unknown or unlisted origin is found in the GFLI database, an average value between the listed global "GLO" value and worst listed value for that ingredient is applied; this approach is intended to incentivize data transparency and provision. Detailed calculation methodology can be found in Appendix 3 of the Seafood Watch Aquaculture Standard.

Calculations based on the GFLI values presented in Table 3 above and following the methodology in the Seafood Watch Aquaculture Standard, indicate the CCI is 18.94 kg CO_2- eq per kg of farmed salmon protein. This results in a score of 5 out of 10 for Factor 5.3.

Conclusions and Final Score

The final score is a combination of the three factors with a double weighting for the Wild Fish Use factor. Factors 5.1 (2.82 out of 10), 5.2 (3 out of 10), and 5.3 (5 out of 10) combine to result in a final score of 3.41 out of 10 for Criterion 5 – Feed.

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

Criterion 6: Escapes

Impact, unit of sustainability and principle

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

Criterion 6 Summary

Atlantic salmon, all regions

C6 Escape parameters	Value	Score
F6.1 System escape risk (0-10)	2	
F6.1 Recapture adjustment (0-10)	1	
F6.1 Final escape risk score (0-10)		3
F6.2 Invasiveness score (0-10)		6
C6 Escape Final Score (0-10)		**4**
Critical?	No	Yellow

Coho Salmon, all regions

C6 Escape parameters	Value	Score
F6.1 System escape risk (0-10)	2	
F6.1 Recapture adjustment (0-10)	1	
F6.1 Final escape risk score (0-10)		3
F6.2 Invasiveness score (0-10)		0
C6 Escape Final Score (0-10)		**1**
Critical?	Yes	Critical

Brief Summary

Large escape events of farmed salmon continue to occur in Chile. 410,000 escapes were reported in 2020, and although large losses only affect a small proportion of farm sites each year, they continue to highlight the vulnerability of the net pen production system. Over the last decade, 4.6 million escaped fish have been reported, and undetected or unreported trickle losses may also be substantial. Recapture efforts are apparent and considered to account for approximately 14% of escapes on average (noting some, e.g., by local fishermen, may not be reported), but large numbers of salmon still enter the environment every year, and the production system remains vulnerable in all regions.

Mature Atlantic salmon are occasionally caught by anglers in rivers in Chile, but after decades of repeated escapes, the available evidence indicates this species is highly unlikely to establish viable populations in Chile. In contrast, the evidence of the establishment and increasing range of coho salmon is now clear in the far south of Chile. Recent research at the southern tip of Chile (in Region XII) has added new records of established populations of coho in the Beagle Chanel and in the Cape Horn Biosphere Reserve. In the IFOP's annual research fishing, an average of 8.4% of all fish caught from 2016 to 2019 (wild and farmed fish of any species) were coho salmon, and from a regional perspective, the proportions of coho increased in more southern regions (4.2% of all fish caught in Region X were coho salmon, with 12.8% in Region XI and 27.4% in Region XII). IFOP has used genetic profiling to assign rainbow trout caught in the wild as wild spawned or as direct farm escapes, but these techniques are still in development for coho salmon. It is therefore not yet known if these captures of coho and their apparent establishments and/or range expansion are due to previous ranching efforts (where coho and other salmonid species were deliberately introduced into Chilean rivers) or, as some recent authors have suggested, due to more recent aquaculture escapes. In Regions X and XI, despite the common occurrence of mature coho salmon returning to rivers in Region X in the 1980s, it does not appear that spawning has been successful. It is currently unclear what the impacts of coho would be in addition to those of the other non-native salmonids already widely established in Chile (rainbow, brown and brook trout, and Chinook salmon), but southern Chile has unique ecosystems with high degrees of endemism, and due to the demonstrated piscivorous nature of coho salmon, there is a high potential for impacts to native species, some of which are endangered.

The final score for Criterion 6 – Escapes combines the escape risk (Factor 6.1) with the risk of competitive and genetic interactions (Factor 6.2). For both species, the vulnerability of net pen systems to escape, with a small adjustment for recaptures, results in a Factor 6.1 score of 3 out of 10. For Atlantic salmon, which are considered to be highly unlikely to establish in Chile, the score for Factor 6.2 is 6 out of 10, and the final score for Criterion 6 – Escapes is 4 out of 10. For coho salmon, given their well-established migratory abilities, it is not clear how much (if any) aquaculture escapes in any of the three regions contribute to the apparent ongoing establishment and/or range expansion of coho in Region XII, but the potential impacts in Chile's unique ecosystems are a high concern; therefore, the score for Factor 6.2 in all three regions is 0 out of 10. For coho, the vulnerable containment system combined with the increasing evidence of ecological establishment and range expansion (with uncertain impacts to non-native species, some of which are endangered) results in a final score for Criterion 6 - Escapes of 1 out of 10 for coho in Region XII. This is considered a critical conservation concern.

Justification of Rating

This criterion assesses the risk of escape (Factor 6.1) with the potential for impacts according to the nature of the species being farmed and the ecosystem into which it may escape (Factor 6.2). Evidence of recaptures is a component of Factor 6.1.

Factor 6.1. Escape risk

Despite the presence of regulations and financial penalties for escapes in Chile, as long as aquaculture facilities are not fully contained, the escape of farmed fish into the wild is considered to be inevitable, and the net pens used in salmon farming offer the greatest opportunity for escapes as there is only a net barrier between the fish and the wild (Glover et al., 2017; Atalah and Sanchez-Jerez, 2020).

Sernapesca publishes escape data aggregated across salmonid species for total reported escaped fish and the number of reported escape events[55]. SalmonChile also presents escape data from 2013 to 2018, but those data appear incomplete and do not match Sernapesca's figures. The Sernapesca data are used here and shown in Figure 29 from 2010 to 2020.

Figure 29: Reported total salmonid escapes (i.e., Atlantic and coho salmon, and rainbow trout) from 2010 to 2020 (blue bars and primary y-axis) and the annual number of reported escape events (red line and secondary y-axis). Data from Sernapesca.

The Sernapesca data show the number of reported escape events each year is low (five in 2019 and eight in 2020), and they affect a very small percentage of active sites. However, the numbers of escaped fish can be extremely high. Over 1.2 million fish were reported to have escaped in the last four years (2017 to 2020), and in the last decade over 4.6 million escaped fish were reported. While media sources have indicated the large majority of major escape events have been of Atlantic salmon, the fundamental risk of the open net pen system is considered to be similar for both Atlantic and coho salmon, and the escape events are primarily a reflection of the much greater production and number of Atlantic salmon sites in Chile.

Although the mature salmon farming industry in Chile (as elsewhere) is considered to operate best management practices for the design, construction, and management of farms, according

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[55] http://www.sernapesca.cl/informacion-utilidad/escape-de-peces-de-la-salmonicultura

to Sernapesca's escape report, the causes of escapes include adverse weather conditions, poor maintenance of farm infrastructure, problems associated with management, boat collisions, theft/vandalism[56], and predator action. With the possible exception of theft and predator damage, these causes are all directly or indirectly linked to human error in the design, construction, or operation of net pen systems.

From a regional perspective, Figure 30 shows Region X has the highest reported total escapes from 2010 to 2020 and Region XII has low reported total escapes, but this is likely to be largely due to the much lower scale of production in the far south (as opposed to an inherently lower escape risk). While Region XII appears to have a lower number of escapes relative to the scale of production, the risk is likely to be similar (or perhaps greater given more severe weather conditions) and the large escape events that have occurred in Regions X and XI have simply not yet occurred within the smaller total number of sites.

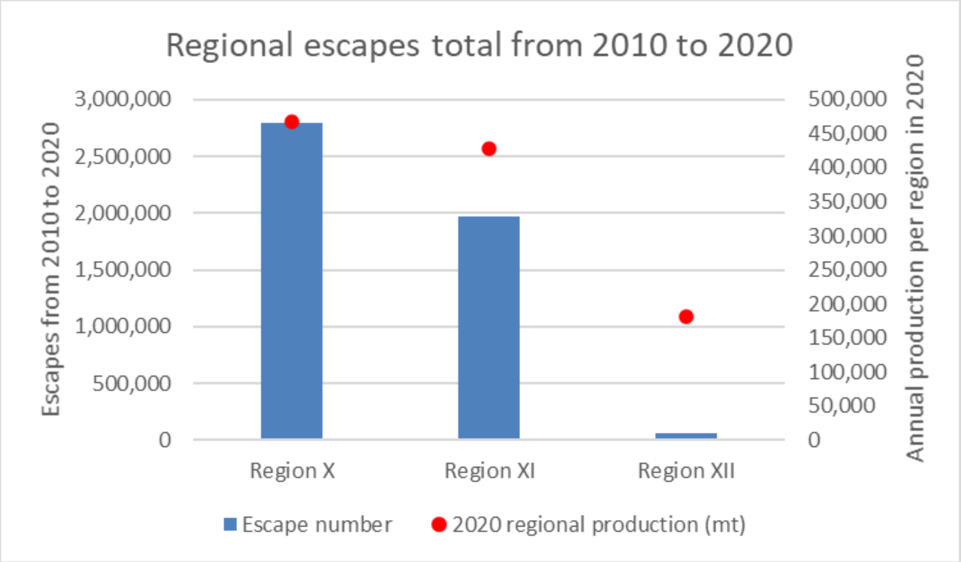

Figure 30: Total escapes per region from 2010 to 2020 (blue bars and primary y-axis) and annual production per region in 2020 (red dots and secondary y-axis). All salmonid species are aggregated (i.e., Atlantic and coho salmon, and rainbow trout). Data from Sernapesca.

From a species perspective, Sernapesca escapes data from 2016 to 2020 separated by Atlantic and coho salmon and rainbow trout were provided (Pablo Cajtak, pers. comm., 2021). After analysis, these data show the percentage of total escapes per species is consistent with the percentage of total production, and the percentage of escape incidents per species was consistent with the number of sites (Figure 31). This indicates that the risk of escapes is the same regardless of the species produced and is perhaps to be expected given the similar net pen production system. It is therefore considered that there is no difference in the risk of escape for each species.

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[56] For example, in July 2020, nearly 93,000 salmon were released from nets by vandals in Region X. Intrafish, July 7. 2020: "Chilean salmon farmer Camachanca loses 93,000 coho in attack by vandals"

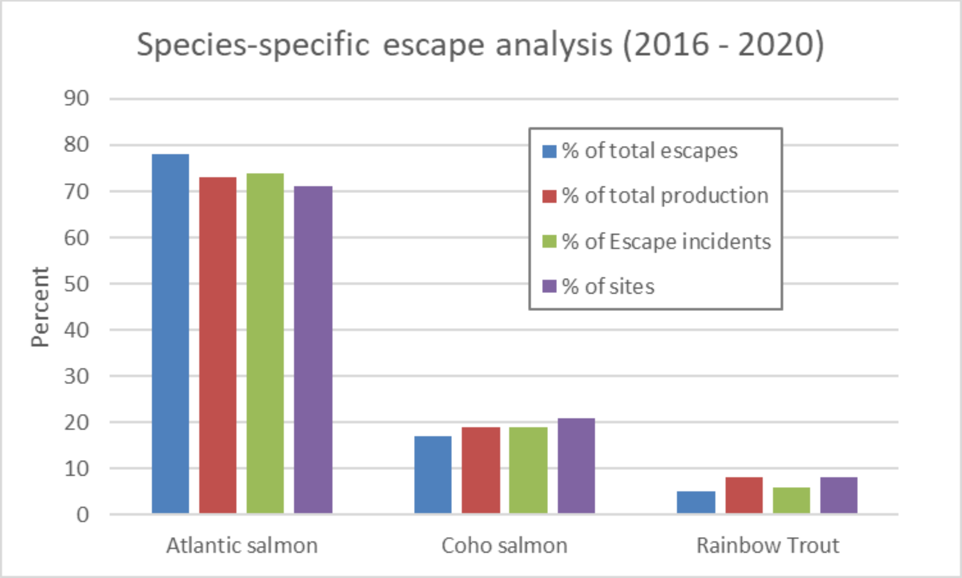

Figure 31: Analysis of Sernapesca escapes data from 2016 to 2020 separated by species. Data from Sernapesca, provided by P. Cajtak, pers. comm. (2021).

Escape data are usually based on reports by the farmers themselves and are likely to underestimate, significantly in some circumstances, the actual number of fish escaping from farms (Glover et al., 2017). Large-scale catastrophic escape events are clearly limited to a very small proportion of the sites in Chile, but the small-scale 'trickle losses' of tens or dozens of fish can also be significant and (from sites commonly holding up to a million fish) likely to be undetected and therefore unreported (Taranger et al., 2011). Sistiaga et al. (2020) noted the escape of small smolts through farm cage netting is a major challenge when the smolts placed in the net pens are smaller than the size estimated by the farmers. Importantly, Skilbrei and Wennevik (2006) note small-scale unreported escape events may make up a large portion of the total escaped farmed fish (in Norway), and the analysis by Skilbrei et al. (2015) suggests that the total numbers of post-smolt and adult escapees have been two- to four-fold higher than the numbers reported to the authorities.

In conclusion, it is clear from the reported data that the large total escape numbers in recent years are dominated by infrequent mass-escape events, and overall, the reported escape events are limited to a small minority of farms in Chile. Yet, very high numbers of farmed salmon escapes continue to occur, largely as a result of human error. Grefsrud et al. (2021) contend that as long as farmed salmon are produced with open net pens in the sea, there is a high probability that there will also be major escape episodes in the coming years. Trickle losses are likely to be substantial yet may not be detected and/or reported. Ultimately, it is clear that Chilean net pens continue to be vulnerable to both large-scale and small-scale escapes. As such, the initial score for Factor 6.1 Escape Risk is 2 out of 10 for both Atlantic and coho salmon in all regions.

Recaptures

Chilean legislation mandates the existence and application of contingency plans to manage escape events at each farm, but in 2013, Niklitschek et al. (2013) considered there to be a lack of sufficient incentives or sanctions to stimulate relevant recapture efforts. Since then, the General Law of Fisheries and Aquaculture has been amended to require the company to recapture at least 10 percent of the escaped fish or face a fine or even the withdrawal of its license.

There do not appear to be any official recapture data from Sernapesca or elsewhere, but a search of industry media reports yields examples of escape reports with associated recapture figures. These reports are typically for large escape events, and an analysis of nine such events from 2013 to 2020 show an average of 14.6% recapture (range of 1% to 30%). These data illustrate recaptures do occur, but do not provide sufficient coverage to provide a robust estimate of recapture rates across all escape events.

It is also likely that recaptures are not robustly counted or reported (particularly by local fisherman for local sale); for example, in response to a record fine relating to a large escape in 2018, the company (Mowi) reported that "it was public knowledge that a large quantity of salmon was caught by third parties and later sold en masse in the informal trade",[57]. Part of the CLP 5.3 billion fine ($6.7 million USD) related to an insufficient recapture rate (i.e., at approximately 5.7%, it was less than the regulated 10%)[58].

Overall, recaptures do occur and may be substantial in some escape events. Using the limited data available, the recapture adjustment is 1 out of 10. The final score for Factor 6.1 Escape Risk score is 3 out of 10.

Factor 6.2. Competitive and Genetic Interactions

After fish escape, their potential for impact is dependent on their ability to compete for resources, their attempted and/or successful spawning with wild conspecifics or congeners, and whether and how soon after escape they experience mortality. For escaped salmon in Chile, mortality is likely to be high due to a limited feeding ability in the wild and predation (e.g., Arismendi et al., 2014). For example, in contrast to the South American sea lions (*Otaria byronia*) sampled in the north of Chile, Guererro et al. (2020) noted some of those sampled in the south region (i.e., in areas with net pen aquaculture) had unusually high levels of the fatty acid C18:2ω6 commonly found in terrestrial environments, suggesting consumption of farmed salmon whose diet is usually based on terrestrial sources. Similarly, Sepulveda et al. (2015) showed approximately 15-20% of South American sea lions' diet was farmed salmonids, but it is impossible to quantify this predation in terms of the proportion of total escapees and with typically hundreds of thousands of escaped fish each year, it is certain that the potential for impact exists.

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[57] Intrafish. 12 Aug 2020. Mowi hit by record fine for farmed salmon escape in Chile

[58] http://www.sernapesca.cl/noticias/escape-de-salmones-sernapesca-confirma-que-recaptura-fue-menor-al-10-que-exige-la-ley

Ten salmonid species have been intentionally introduced throughout Chile and Argentinian Patagonia as a consequence of governmental and private efforts since the beginning of the 20th century. Three species of trout (brown, rainbow and brook) rapidly established and are present throughout Patagonia (Pascual et al., 2007). For Atlantic salmon, fifteen years ago Bisson (2006) stated: *"Despite a long history of failure to establish Atlantic salmon from single or a few deliberate introductions, it seems possible that continuous recruitment of fish escaping from farming operations may eventually lead to locally-adapted stocks. At that point, the species may rapidly become a dangerous invasive—a pattern that is often seen in other aquatic plants and animals where a prolonged early colonization period is followed by a rapid phase of exponential growth".* Farmed Atlantic salmon escapees have indeed been found in Chilean streams and freshwater lakes (Young et al., 2009; Schröder et al., 2011; Barragan, 2010) and angler reports note the occasional capture of mature Atlantic salmon in rivers[59]. However, despite massive numbers of fish of varying sizes and maturities that have – for decades now – escaped in different locations at different times of year, it appears Atlantic salmon do not thrive well in the wild beyond their native range (e.g., Quiñones et al., 2019; Arismendi et al., 2014). Ultimately, self-sustaining populations of anadromous Atlantic salmon have not been reported in Patagonia (Quiñones et al., 2019).

Of the Pacific salmon species in Chile, Chinook salmon was initially stocked in Chile for the purposes of ocean ranching, and is successfully reproducing and rapidly extending its range in the wild in several Patagonian basins in Chile (Correa & Gross, 2008; Bravo et al., 2019; Nardi et al., 2019; Arismendi et al., 2012; Ciancio et al., 2015). In the 1990s the focus for Chinook moved from ranching to net pen aquaculture, and although the species is not currently farmed in Chile, its establishment has also been attributed to previous aquaculture escapes (Bravo et al., 2019).

Coho salmon were first introduced in Chile in the 1920s and 30s, but although the fjords of southern Chile are considered to be highly suitable habitat for coho (Soto et al., 2001), these initial attempts at establishment were unsuccessful (Chalde et al., 2019). Sea ranching of coho (and Chinook) began in Region X and XII in the 1970s with coho smolts stocked in rivers and lakes, and coho were also stocked in Region XII in 1982 (Santa Maria River, 53.1°S). There were minor returns in Region X, and returns in Region XII continued intermittently until 1991 before they disappeared (Gomez-Uchida et al., 2018, and references therein).

More recently, after many years of coho aquaculture and subsequent escapes, there is now substantial evidence of the species establishing self-sustaining populations. WWF-Chile (2009) initially raised the concern, and since then, there is published evidence of wild coho salmon populations in three southern Patagonian river systems (at approximately 51°S) (Górski et al., 2017). Chalde et al. (2019) reported a returning population in the Beagle channel further south at the very southern tip of Chile (55°S).

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[59] https://www.pescador.cl/index.php?option=com_content&task=view&id=461&Itemid=40
https://www.lavaguada.cl/reportajes/atlantic-salmon-chile/salar-fishing.htm

Chile's Fisheries Development Institute (*Instituto de Fomento Pesquero*, IFOP) has conducted research fishing since 2014 for wild and feral fish in Chile (in lakes, estuaries and the sea) to monitor the presence of pathogens of concern (IFOP, 2019). Of the total number of fish caught between 2013 and 2019 (13,422) 54% were salmonid species and 46% were native species; however, of the salmonid species of interest here (i.e., Atlantic and coho salmon), the numbers are substantially lower (IFOP, 2019). For example, in the three sampling seasons from 2016-2019, Atlantic salmon represented 0.4%, 0.0% and 0.2% in 2016/17, 2017/18 and 2018/19 respectively (i.e., 9 out of 4,192 fish caught in 2018/19 were Atlantic salmon) (IFOP, 2017, 2018, 2019). Coho numbers are higher, representing 9.5%, 8.0% and 7.6% in the same three sampling seasons (i.e., 319 out of 4,192 fish caught in 2018/19 were coho salmon, or an average of 8.4% of all fish caught between 2016 and 2019). For comparison, the highest number of fish caught were wild Robalo (*Eleginops maclovinus*) representing 29.2% of all captures, and rainbow trout were 15.9%.

The proportion of each species in the IFOP catches also varies by region; for example, in Region X where 39.6% of all fish in the 2018/19 fishing season were caught, 4.2% were coho salmon (0.1% were Atlantic salmon), while in Region XI where 23.7% of all fish were caught, 12.8% were coho salmon (0.8% were Atlantic salmon), and in Region XII where 9% of the total catch were caught, 27.4% were coho salmon (0% were Atlantic salmon).

The sizes of the salmon caught vary considerably. For example, the time series of data show coho captures from 58 g to more than 5 kg (unpublished data, IFOP, pers. comm., 2020). The condition factor of the recaptured fish has on average been good, with a Fulton Fish Condition Factor score of 1.02 for Atlantic salmon and 1.14 for coho (where 1.0 on the Fulton scale, which is based on a simple length-weight relationship, represents "normal" or "typical" condition). (Data from IFOP, 2019).

While the IFOP research currently uses genetic profiles to assign rainbow trout caught in the wild as wild spawned or a direct farm escape, these techniques are still in development for coho salmon and have not been applied to Atlantic salmon due to the low recapture numbers (IFOP, 2019). Therefore, other than the knowledge that coho salmon have not been farmed in Region XII since 2004 (Gorski et al., 2017, with minor production in 2019 and 2020 noted here), it is not possible to determine which of these fish, if any, are the result of reproduction in the wild as opposed to direct escapes from salmon farms in any of the three regions (noting they are likely to be capable of travelling considerable distances between regions).

Most recently, Maldonado-Márquez et al. (2020) also studied coho salmon at the southern tip of Chile in the Cape Horn Biosphere Reserve (CHBR), and believe the population is established there and the species is in the process of settling in the broader basin. Their sampling captured 61 parr and smolts of coho salmon and different cohorts have been found during different seasons throughout their monitoring campaigns. During their 2019 field work, a sexually mature female coho salmon was found in the same area. This is the most southerly population of coho in Chile, and indicates the species is expanding its range. As noted previously, coho salmon have been farmed in all three regions assessed here (X, XI, XII), but production stopped in Region XII in 2004 (Gorski et al., 2017, again noting minor subsequent production in 2019 and 2020), and similar to the IFOP catch results, it is impossible to conclusively determine if these populations detected by Gorski et al. (2017) or Maldonado-Márquez et al. (2020) are the offspring of previous aquaculture escapes, or if they result from the repeated deliberate past efforts to establish the species in these regions. Nevertheless, Gorski et al. (2017) imply aquaculture escapes are the more likely cause.

Continuing the focus on regional differences in Chile, in contrast to the apparent situation regarding coho salmon in Region XII, it is of note that it was common in the 1980s to observe runs of returning mature coho salmon to the rivers of Region X, but without spawning success the species (in contrast to Chinook) has not become established in Regions X or XI (S. Bravo, pers. comm., 2021).

The sub-Antarctic Magellanic ecoregion (42–56°S) is considered to be unique and presents remarkably high levels of endemism, with 50% of the fish species being endemic to the biome (Armesto et al., 1998). Vargas et al. (2015) show that species introductions and invasions have altered historical fish assemblages and affected the uniqueness of isolated and endemic freshwater fish diversity. Similarly, Schröder and Garcia de Leaniz (2011) and references therein conclude that the encroachment of salmonids is one of the biggest threats to native fish biodiversity in Chile, but these references highlight a challenge in interpreting the scientific literature with regard to the impacts of any one species of salmonid among the several species introduced and still farmed in Chile (e.g., De Leaniz et al., 2010; Soto et al., 2001; Buschmann et al., 2009).

Six years ago, Habit et al. (2015) proposed that if coho salmon escapes from the salmon industry continued or increased, this species would be able to settle and naturalize in southern Chile due to an increase in propagules and optimal habitats. In this context, and in accordance with Chalde et al. (2019), Maldonado-Márquez et al. (2020) hypothesize that the establishment of coho at 55°S is due to escapes reported from salmon farms located in the Aysen region at 51°S, the closest region in Chile in which this species is farmed.

Although clearly somewhat slow to establish (e.g., compared to non-native trout species), the fact that the present populations of coho may be the result of aquaculture escapes (rather than deliberate stocking) indicates further self-sustaining populations could establish. Chalde et al. (2019) note established non-native trout species have interacted with native species for a long time and probably reached a balance that allows them to cohabit. Maldonado-Márquez et al. (2020) also caught other non-native salmonids in the CHBR (rainbow, brown and brook trout), therefore predicting the additional impact of escaping coho with or without the establishment of additional populations is largely impossible (Quiñones et al., 2019), however, some small river systems in some southern fjords areas (e.g., the Alacalufes National Park) were salmonid-free (i.e., had no reports of the most widespread brown trout and rainbow trout) before the establishment of the coho salmon populations (Górski et al., 2017).

In their natural habitats, salmon, particularly chinook and coho, are placed as top predators in pelagic food webs where they act mostly as piscivorous fish (Welch and Parsons, 1993). After massive escapes of farmed salmon in 1994 and 1995, Soto et al. (2001) analyzed stomach contents of recaptured rainbow trout, coho salmon, and Atlantic salmon. Coho salmon showed some of the lowest levels of empty stomachs and the highest frequency of fish in the diet, and coho juveniles that had spent a year at sea post-escape had the highest growth rates as well as the highest rates of piscivory compared to Atlantic salmon and rainbow trout caught in the same locations (Soto et al., 2001). Further, between 40% and 80% of the coho captured in 2006 were sexually mature, showing well-developed gonads.

The IFOP studies also report stomach contents, and these also varied according to the species of interest here. While only one of the nine Atlantic salmon captured in 2018/19 had organic matter in its stomach (the rest were empty or mucosal), Figure 32 shoes 15% of the coho salmon had fish in their stomachs, and a further 28% had organic matter, crustacea or worms, and 2% of the fish had feed pellets (IFOP, 2019).

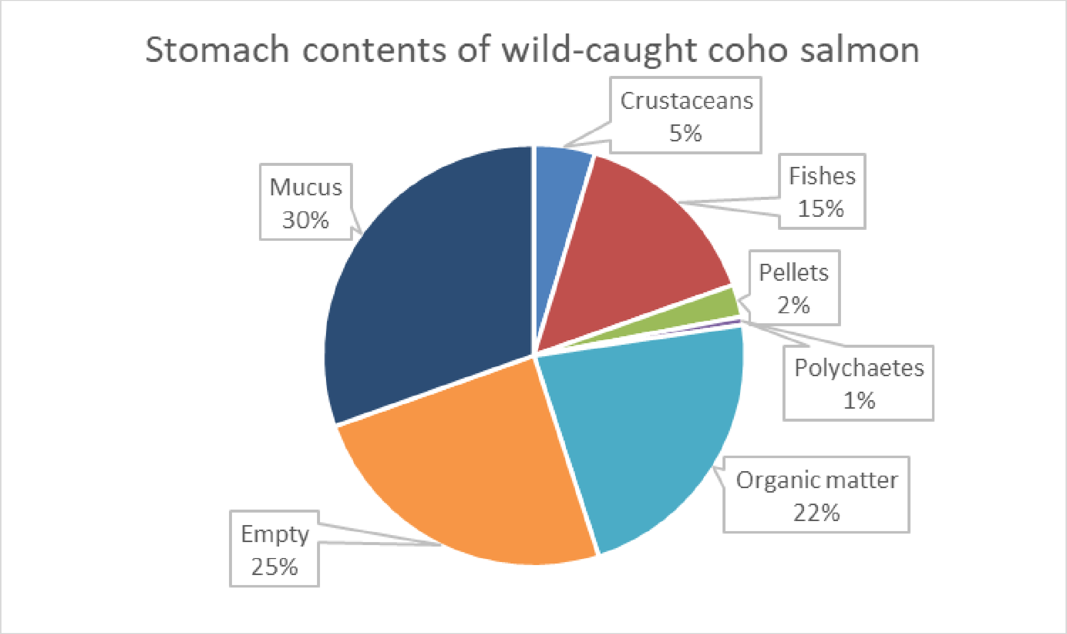

Figure 32: Stomach content analysis of coho salmon. The data shown are the percentage of fish that had an empty stomach, a stomach that contained only mucous, or a stomach that contained a measurable amount of each of the remaining categories. Note the possibility of a fish's stomach containing contents belonging to more than one category. Data from IFOP (2019).

The primary concern, in Chile and elsewhere in the southern hemisphere, is the impact of non-native salmonids on native galaxiid fish. According to De Leaniz et al. (2010), "Across the southern hemisphere, exotic salmonids directly impact native galaxiids by reducing their foraging efficiency, limiting their growth, restricting their range, forcing them to seek cover or to use suboptimal habitats, and also by preying upon them." In the CHBR, Maldonado-Márquez et al. (2020) reported three native species that have been classified by Chile's Ministry of the Environment as endangered since 2011. While the classification is based on limited data, the species are considered to be facing a very high risk of extinction (Ministerio del Medio Ambiente, 2011). Pérez et al. (2021) evaluated the effect of the presence of Coho (and Chinook) juveniles on the diet of native galaxids in lakes and estuaries of Patagonia at approximately 51°S to 52°S (southern Region XII). In salmon-free lakes, *Galaxias maculatus* fed primarily on insects, while those coexisting with coho consumed primarily benthic macroinvertebrates. In estuaries, the diet of *G.* maculatus was not affected by coho, possibly due to higher prey availability or higher turbidity of estuaries compared to lakes which may impede territorial behavior of salmon based on visual cues (Pérez et al., 2021).

Maldonado-Márquez et al. (2020) consider their findings on the apparent establishment of coho to generate a warning signal for the conservation of native and endemic fish in their study area (the CHBR), and they consider it urgent to rethink conservation strategies for native fish in one of the most pristine areas left in the world by developing monitoring and control programs of salmonid populations for this region in the short and long term.

Overall, the probability of aquaculture escapees forming self-sustaining populations in the wild depends on complex density-dependent and density-independent biological and environmental factors in both marine and freshwater habitats (Arismendi et al., 2014; Soto et al., 2001).

Atlantic salmon are considered to be present in the wild in Chile but not established, and highly unlikely to establish viable populations. The score for Atlantic salmon for Factor 6.2 is 6 out of 10 in all production regions.

For coho salmon, this non-native species is considered to be partly established, with the potential to extend the species range. Competition, predation, disturbance, or other impacts to wild species have the potential to affect the population status of impacted wild species. Further, given the unique nature of the Patagonian ecosystem, coho – as a seemingly expanding non-native species – is considered to have a high potential for impact. Although research is limited, in the context of the other non-native salmonid species already established for a long time in Chile, coho is not currently considered to be having a population-level impact to wild species, including those that are endangered or protected, and Factor 6.2 is therefore not currently considered critical at this time. In Regions X and XI, it is not clear how much (if any) coho escapes contribute to the potential ongoing establishment of coho in Region XII via salmon's well-established migratory abilities. On a precautionary basis, following the hypothesis of Maldonado-Márquez et al. (2020), the score for Factor 6.2 for coho salmon is 0 out of 10 for all three production regions.

Conclusion and Final Score

Large escape events of farmed salmon continue to occur in Chile. 410,000 escapes were reported in 2020, and although large losses only affect a small proportion of farm sites each year, they continue to highlight the vulnerability of the net pen production system. Over the last decade, 4.6 million escaped fish have been reported, and undetected or unreported trickle losses may also be substantial. Recapture efforts are apparent and considered to account for approximately 14% of escapes on average (noting some, e.g., by local fishermen, may not be reported), but large numbers of salmon still enter the environment every year, and the production system remains vulnerable in all regions.

Mature Atlantic salmon are occasionally caught by anglers in rivers in Chile, but after decades of repeated escapes, the available evidence indicates this species is highly unlikely to establish viable populations in Chile. In contrast, the evidence of the establishment and increasing range of coho salmon is now clear in the far south of Chile. Recent research at the southern tip of Chile (in Region XII) has added new records of established populations of coho in the Beagle Chanel and in the Cape Horn Biosphere Reserve. In the IFOP's annual research fishing, an average of 8.4% of all fish caught from 2016 to 2019 (wild and farmed fish of any species) were coho salmon, and from a regional perspective, the proportions of coho increased in more southern regions (4.2% of all fish caught in Region X were coho salmon, with 12.8% in Region XI and 27.4% in Region XII). IFOP has used genetic profiling to assign rainbow trout caught in the wild as wild spawned or as direct farm escapes, but these techniques are still in development for coho salmon. It is therefore not yet known if these captures of coho and their apparent establishments and/or range expansion are due to previous ranching efforts (where coho and other salmonid species were deliberately introduced into Chilean rivers) or, as some recent authors have suggested, due to more recent aquaculture escapes. In Regions X and XI, despite the common occurrence of mature coho salmon returning to rivers in Region X in the 1980s, it does not appear that spawning has been successful. It is currently unclear what the impacts of coho would be in addition to those of the other non-native salmonids already widely established in Chile (rainbow, brown and brook trout, and Chinook salmon), but southern Chile has unique ecosystems with high degrees of endemism, and due to the demonstrated piscivorous nature of coho salmon, there is a high potential for impacts to native species, some of which are endangered.

The final score for Criterion 6 – Escapes combines the escape risk (Factor 6.1) with the risk of competitive and genetic interactions (Factor 6.2). For both species, the vulnerability of net pen systems to escape, with a small adjustment for recaptures, results in a Factor 6.1 score of 3 out of 10. For Atlantic salmon, which are considered to be highly unlikely to establish in Chile, the score for Factor 6.2 is 6 out of 10, and the final score for Criterion 6 – Escapes is 4 out of 10. For coho salmon, given their well-established migratory abilities, it is not clear how much (if any) aquaculture escapes in any of the three regions contribute to the apparent ongoing establishment and/or range expansion of coho in Region XII, but the potential impacts in Chile's unique ecosystems are a high concern; therefore, the score for Factor 6.2 in all three regions is 0 out of 10. For coho, the vulnerable containment system combined with the increasing evidence of ecological establishment and range expansion (with uncertain impacts to non-native species, some of which are endangered) results in a final score for Criterion 6 - Escapes of 1 out of 10 for coho in Region XII. This is considered a critical conservation concern.

Table 5: Layout of scoring factors for Criterion 6 - Escapes for Atlantic and coho salmon in Regions X, XI, and XII.

Region	**F6.1** System escape risk (0-10)	**F6.1** Recapture adjustment (0-10)	**F6.1** Final escape risk (0-10)	**F6.2** Competitive and genetic interactions (0-10)	**C6 Escapes Final score (0-10)**	Critical?
Atlantic salmon						
X	2	1	3	6	4	No
XI	2	1	3	6	4	No
XII	2	1	3	6	4	No
Coho Salmon						
X	2	1	3	0	1	Yes
XI	2	1	3	0	1	Yes
XII	2	1	3	0	1	Yes

Criterion 7: Disease; pathogen and parasite interactions

Impact, unit of sustainability and principle

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

Criterion 7 Summary

Atlantic and Coho salmon

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

Brief Summary

Disease-related losses and increased production costs have been a defining characteristic of the development of salmon farming in Chile, but with improving control, the mortality due to disease is relatively low. While coho have a higher average monthly mortality than Atlantic salmon (1.24% for coho versus 0.96% for Atlantic salmon), coho are not significantly infected by parasitic sea lice. The IFOP monitoring of wild-caught fish for the presence of pathogens of concern to salmon farming (nine viral and nine bacterial pathogens, most of which are not salmonid-specific) shows a low presence in the wild. Similarly, the detection of external and internal parasites on wild fish was low (88.9% of the wild fish caught in IFOP sampling had no detectable parasites, and of the remaining 11.1%, two-thirds were infected with internal parasites, and only one-third had external parasites such as the sea lice that dominates farmed Atlantic salmon production). While encouraging, these data do not provide information on any other potential pathogens of concern to wild fish or any indications of subsequent mortality, nor do they account for the challenges of detecting diseases (including capturing diseased fish) in the wild. Unlike other major salmon farming regions (in the North Atlantic and North Pacific), there are no native salmonid populations of concern in Chile, but salmon farms still represent a chronic reservoir of known and probably unknown infectious pathogens and parasites which may be transmitted to wild fish (including species endemic to Chile). Parasitic sea lice in Region XII appear to have originated in Atlantic Argentina and moved to the Chilean Pacific with movements of wild fish through the Straits of Magellan (as opposed to being introduced from salmon farms in Regions X and XI), but the recent establishment of parasitic sea lice at high prevalence on a small number of farms in the southernmost Region XII, where it was previously undetected, is an additional concern as production increases.

Without a robust understanding of how on-farm diseases impact or do not impact wild fish, the Risk-Based Assessment method is used. Ultimately, despite the widespread employment of biosecurity protocols, Chilean salmon farms are challenged with disease and the openness of the net pen production system directly connects farmed salmon of both species to wild populations. Although the disease, parasite, and mortality profiles of Atlantic salmon and coho differ, the overall risks are considered similar and the final score for Criterion 7 – Disease is 4 out of 10 for both Atlantic and coho salmon.

Justification of Rating

Without a robust understanding of how on-farm disease impacts wild organisms (i.e., Criterion 1 score of 5 out of 10 for the disease category), the Seafood Watch Risk-Based Assessment methodology was utilized.

The rapid growth of the salmon farming industry in Chile has led to the appearance of various viral, bacterial, parasitic, and fungal pathogens affecting farmed fish (Figueroa et al., 2019). The primary source of information on diseases in Chilean aquaculture is Sernapesca's annual health report (*Informe Sanitario De Salmonicultura En Centros Marinos*[60]). Sernapesca's Animal Health Unit (*Unidad de Salud Animal*) manages prevention and surveillance programs for diseases in Chile under the Control System for Aquaculture (*Sistema de Fiscalización de la Acuicultura*, SIFA). After the infectious salmon anemia (ISA) outbreak in Chile in 2007-9, the focus of regulatory disease management shifted within the area management ACS system to concentrate on specific diseases under a program of health surveillance and control (*Programa Sanitario Específico de Vigilancia y Control*). These programs focus on diseases categorized as "high risk", specifically ISA, Salmon Rickettsial Septicemia/syndrome (SRS), and parasitic sea lice (*Caligus rogercressyi*).

The Chilean industry and the government have invested heavily in research, particularly of key diseases such as SRS, and there is a large volume of literature linked to projects such as the Program for Sanitary Management in Aquaculture (*Programa para la Gestión Sanitaria en Acuicultura*, PGSA)[61]. While this research is important to reduce the impact of diseases on farms and secondary aspects such antimicrobial use, it is not directed at the potential external impacts of pathogen and parasite transmission from farms to wild fish that are the focus of this criterion.

Disease related mortality on farms

Sernapesca's annual health report provides a comprehensive annual review of the causes of mortality for salmonids farmed in Chile. Total monthly mortality figures of Atlantic and coho salmon ranged from approximately 0.60% to 1.3% in 2020, with an average of 0.97% per month or 9% per year (compared to 0.67% per month in 2019). Mortality rates vary from month to month with higher values occurring with water temperatures in the austral summer (January to April). Across the species, coho salmon have slightly higher average monthly mortality rates

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[60] www.sernapesca.cl

[61] http://pgsa.sernapesca.cl/

than Atlantic salmon, with 1.24% per month for coho in 2020 and 0.96% for Atlantic salmon (with an intermediate value of 1.18% per month for rainbow trout). Average monthly mortality rates are generally substantially lower in Region XII than Regions X and XII (1.18%, 1.06% and 0.53% in Regions X, XI and XII respectively in 2020 (Sernapesca data)).

There are a wide variety of causes of mortality on salmon farms. Infectious diseases of interest here were responsible for 24.6% and 14.8% of mortalities in Atlantic and coho salmon respectively in 2020. For Atlantic salmon (Figure 33), SRS is the dominant disease (47.8% of disease related mortality), followed by Tenacibaculosis (caused by the bacterium *Tenacibaculum maritimum)* and Bacterial Kidney Disease (BKD) with another six diseases plus "others" listed. SRS is caused by *Piscirickettsia salmonis*, an intracellular bacterium resulting in mortality during the final stage of the productive cycle at sea (Flores-Kossack et al., 2020). For coho salmon (Figure 34), icteric syndrome (of unknown etiology) is the leading cause of mortality, followed by BKD, and heart and skeletal muscle inflammation.

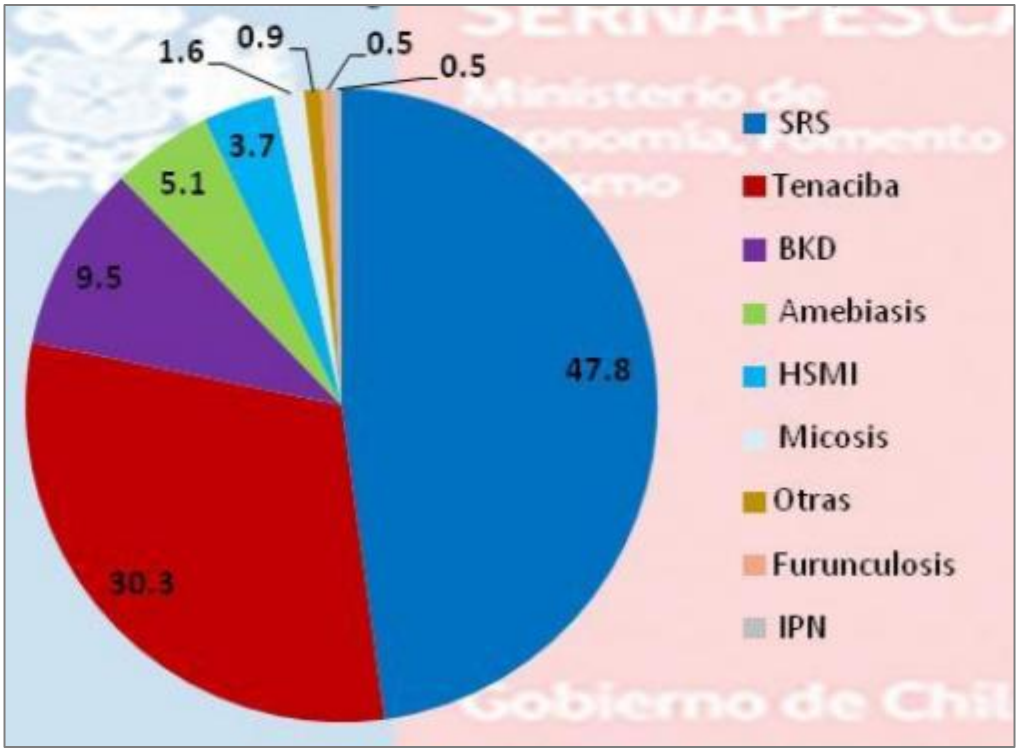

Figure 33: Components of infectious disease mortality for Atlantic salmon in Chile in 2020. SRS = Salmon Rickettsial Septicemia, Tenaciba = Tenacibaculosis; BKD = Bacterial Kidney Disease, Amebiasis = Amoebic Gill Disease; HSMI = Heart and Skeletal Muscle Inflammation, Micosis = fungal mycosis; Otras = others, Furunculosis = Furunculosis; IPN = Infectious Pancreatic Necrosis. Image copied from Sernapesca.

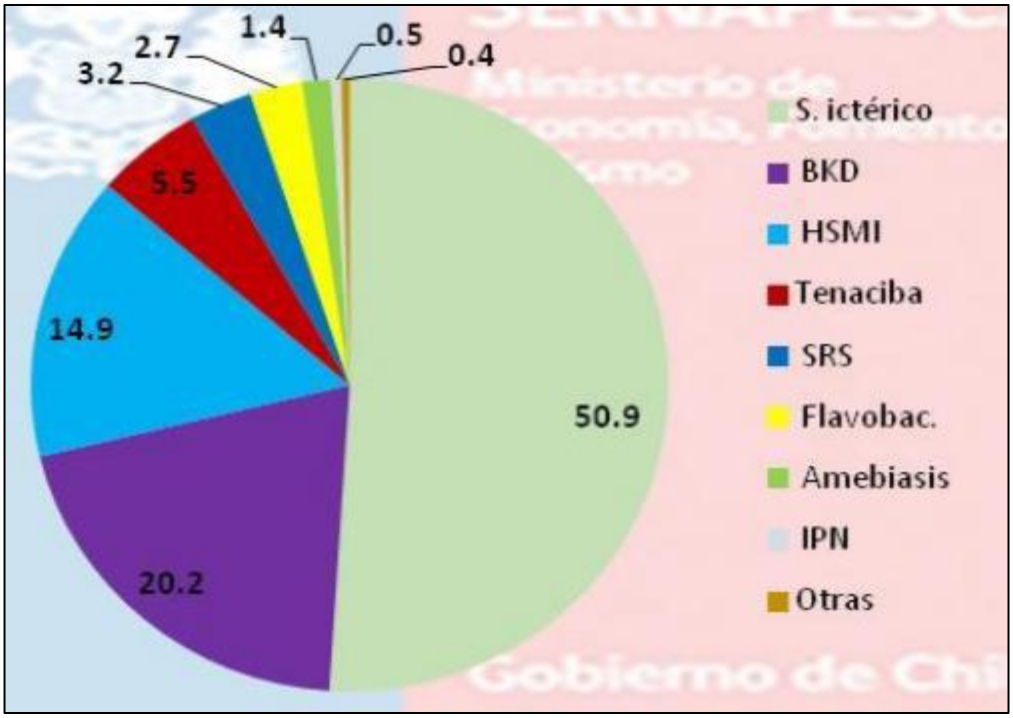

Figure 34: Components of infectious disease mortality for coho salmon in Chile in 2020. For acronyms, see Figure 34, plus Flavobac = Flavobacteriosis. Chart copied from Sernapesca.

The presence of pathogens and parasites, or disease, in wild fish

Of primary concern for ecological impact is the amplification of pathogens on fish farms and their potential retransmission to wild fish. While farmed fish are commonly infected by environmental pathogens, they can also be vectors of pathogen discharge into the marine environment prior to any disease related mortality (e.g., Shea et al., 2021).

While there are relatively few sites classified as centers of high pathogen dissemination (*Centros de Alta Diseminación* – CAD) for high-risk diseases (*Enfermedades de Alto Riesgo*) such as SRS, there are many sites classified as high vigilance (*Alta vigilancia*) where pathogens are present. This is the same for the parasitic sea lice *Caligus rogercresseyi.* Despite the focus in Chile on four high-risk diseases (SRS, ISA, BKD and sea lice), the breakdown of pathogens causing mortality in Chile (Figures 33 and 34) shows other diseases, including some with uncertain etiology such as Icteric Syndrome in coho salmon, are also present. Salmon farms in Chile are therefore considered to be sources of a variety of pathogens and parasites that could potentially infect and impact wild fish.

Chile's Fisheries Development Institute (*Instituto de Fomento Pesquero*, IFOP) has conducted research fishing since 2010 for wild and feral fish in Chile (in lakes, estuaries and the sea) to monitor the presence of pathogens considered high concern in salmon farms (IFOP, 2019). The results show a low level of pathogen detection (by PCR) in fish caught in the wild in Chile; of 4,190 samples analyzed for the high-risk pathogens of IPN, PRV, *P. salmonis*, *F . psychrophilum*, and *R. salmoninarum*, 71 (1.69%) were positive. When considering only the salmon farming Regions X, XI and XII, the percent of positive detections of this group of pathogens was slightly higher, at 1.92%. The highest prevalence of any single pathogen (averaged across all the fish species caught) was 0.9% for *P. salmonis*, but the wild species that was most frequently caught during research fishing (Robalo, *Eleginops maclovinus*) had a 1.8% positivity rate (IFOP, 2019). The highest regional detection of *P. salmonis* was in Region XI, but an IFOP analysis of farm-level salmon mortality per ACS due to this pathogen compared to the detected prevalence of the same pathogen in wild fish caught in the same area showed no conclusive relationship (IFOP, 2019).

Lozano-Muñoz et al. (2021) noted Piscirickettsias are widely distributed in diverse aquatic environments (both freshwater and seawater) and are present in various teleost species, but noted that despite *P. salmonis* being prevalent in wild fish, no pathognomonic signs were observed in any of their captured specimens. They suggest Rickettsia like organisms (RLOs) are a part of the normal microbiota of aquatic animals (and proposed as a hypothesis that it is an alteration in the balance of the bacterial population in fish that leads to the development of the pathology piscirickettsiosis in farmed fish). Quintanilla et al. (2021), note Robalo transferred *P. salmonis* to rainbow trout in cohabiting challenge tests, and while the trout developed characteristic pathological lesions with 46% mortality, the Robalo did not, and did not suffer any mortality. Similarly, Robalo that were inoculated with two strains of *P. salmonis* by Soto-Dávila et al (2020) showed no mortality.

For parasites, 88.9% of the wild fish caught in IFOP sampling (IFOP, 2019) had no detectable parasites, and of the remaining 11.1%, two-thirds were infected with internal parasites, and only one-third had ectoparasites such as the sea lice that dominates farmed Atlantic salmon production. Nevertheless, of concern is the recent establishment of sea lice on Atlantic salmon farms in Region XII in the far south of Chile; the first sea lice were reported there in 2017, with eight farms detecting lice and three farms presenting epidemic behavior (i.e., with lice levels reaching nearly 40 lice per fish[62]) (Arrigada et al., 2019). The appearance of a pathogen in a region where it had not previously been present in significant numbers is a concern that implies challenges for both the industry and authorities, but it is not clear if the parasite was present in this region prior to the noted epidemic behavior. While Arrigada et al. (2019) note the parasite may have been introduced to Region XII via the frequent movements of fish farm vessels from Regions X and XI (Arrigada et al., 2019), Bravo et al. (2006) note the presence of *C. rogercreseyi* in Argentina. Arrigada et al. (2019) also noted a very high response of these sea lice to treatment (with the pesticide azamethiphos) which implied a naïve native population in Region XII rather than the recent transmission of exposed sea lice from the frequently treated farms in Regions X and XII (see Criterion 4 – Chemical Use). Bravo et al. (2006) also noted the natural movements of Robalo (a known sea lice host) through the Strait of Magellan into Argentinean Atlantic waters.

In other salmon farming regions of the world, a review of infectious pathogen occurrence in wild salmonids in British Columbia (Jia et al., 2020) indicated low numbers of infected fish in the

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[62] Arrigada et al. (2019) also note that the lice responded well to a pesticide treatment but fish were re-infected a few weeks later.

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

It is important to note that these studies focused on impacts to wild salmonids, and indeed some of the pathogens are specific to salmonids (e.g., SRS and ISA), but a key characteristic of Chile is that it does not have any native wild salmonids. Nevertheless, it is important to note the novel research of the SSHI in British Columbia has identified over 50 infectious agents in wild and farmed salmon, including 15 previously uncharacterized viruses, and Mordecai et al. (2019, 2020) discovered several previously unknown viruses in dead and dying farmed fish, and showed them to also occur in wild and hatchery-reared fish. It is therefore possible that the pathogen profile of farmed salmon in Chile includes uncharacterized pathogens that may impact wild species in Chile.

The detection of pathogens in wild fish does not inherently indicate disease presence, but the epidemiology of disease in wild fish is poorly understood, and information on which to make judgments about pathogen spillback is sparse (Jones et al., 2015). Due to the challenges of sampling diseased fish in the wild, it is difficult to quantify the impacts (if any) to wild fish; for example, it is expected that predators will remove individuals that are even at early stages of diseases if they show compromised swimming performance, visual acuity, or shifts in behavior; therefore, the probability of randomly sampling wild fish in a late stage of disease is low (Miller et al., 2014, 2017; Mordecai et al., 2021).

Conclusions and Final Score

Disease-related losses and increased production costs have been a defining characteristic of the development of salmon farming in Chile, but with improving control, the mortality due to disease is relatively low. While coho have a higher average monthly mortality than Atlantic salmon (1.24% for coho versus 0.96% for Atlantic salmon), coho are not significantly infected by parasitic sea lice. The IFOP monitoring of wild-caught fish for the presence of pathogens of concern to salmon farming (nine viral and nine bacterial pathogens, most of which are not salmonid-specific) shows a low presence in the wild. Similarly, the detection of external and internal parasites on wild fish was low (88.9% of the wild fish caught in IFOP sampling had no detectable parasites, and of the remaining 11.1%, two-thirds were infected with internal parasites, and only one-third had external parasites such as the sea lice that dominates farmed Atlantic salmon production). While encouraging, these data do not provide information on any other potential pathogens of concern to wild fish or any indications of subsequent mortality, nor do they account for the challenges of detecting diseases (including capturing diseased fish) in the wild. Unlike other major salmon farming regions (in the North Atlantic and North Pacific), there are no native salmonid populations of concern in Chile, but salmon farms still represent a chronic reservoir of known and probably unknown infectious pathogens and parasites which may be transmitted to wild fish (including species endemic to Chile). Parasitic sea lice in Region XII appear to have originated in Atlantic Argentina and moved to the Chilean Pacific with movements of wild fish through the Straits of Magellan (as opposed to being introduced from salmon farms in Regions X and XI), but the recent establishment of parasitic sea lice at high prevalence on a small number of farms in the southernmost Region XII, where it was previously undetected, is an additional concern as production increases.

Without a robust understanding of how on-farm diseases impact or do not impact wild fish, the Risk-Based Assessment method is used. Ultimately, despite the widespread employment of biosecurity protocols, Chilean salmon farms are challenged with disease and the openness of the net pen production system directly connects farmed salmon of both species to wild populations. Although the disease, parasite, and mortality profiles of Atlantic salmon and coho differ, the overall risks are considered similar and the final score for Criterion 7 – Disease is 4 out of 10 for both Atlantic and coho salmon.

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

Impact, unit of sustainability and principle

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

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

Criterion 8X Summary

Atlantic and Coho salmon

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

Brief Summary

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

Justification of Rating

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

Conclusions and Final Score

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

Criterion 9X: Wildlife mortalities

Impact, unit of sustainability and principle

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

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

Criterion 9X Summary

Atlantic and Coho salmon

C9X Wildlife Mortality parameters		Score
Single species wildlife mortality score		-4
System score if multiple species assessed together		n/a
C9X Wildlife Mortality Final Score (0 to -10)		**-4**
Critical?	No	Yellow

Brief Summary

The presence of cultivated salmon in net pens at high density is attractive to opportunistic coastal marine mammals, seabirds, and fish. The data availability for marine mammal and bird mortalities on salmon farms in Chile is limited and has been shown to be of questionable validity, particularly considering the remote areas in which the industry operates. As such, without a robust understanding of the impact to wildlife resulting from farm interactions, the Risk-Based Assessment method was used. Intentional mortality of marine mammals is prohibited (except in cases where human life is endangered), but animals such as Southern sea lions and birds are considered to regularly interact with farms. There are records of accidental cases of mortalities of sea lions, dolphins, humpback whales, and recently a single sei whale, and while there are no indications from other published studies that deliberate or accidental mortalities occur in quantities sufficient to affect the population status of relevant species, the data are limited. The aquaculture vessel fleet in Chile (which includes vessels servicing both the salmon and shellfish industries) is large and has a significant potential for interactions with blue whales. While the potential disturbance is addressed in Criterion 3 – Habitat, the risk of mortality to cetaceans from collisions with aquaculture vessels appears low. Overall, regulations and management practices for non-harmful exclusion and control are in place, but accidental mortalities (such as those resulting from entanglement) cannot be prevented, and mortality numbers are unknown. There is no evidence with which to distinguish Atlantic and coho salmon in this regard, and the final score for Criterion 9X – Wildlife Mortalities is -4 out of -10 for both species.

Justification of Rating
Without a robust understanding of the impact to wildlife resulting from farm interactions, the Criterion 1 – Data score for wildlife mortalities is 5 out of 10 and the Risk-Based Assessment method was used.

The presence of farmed salmon in net pens at high densities and the natural prey items that may aggregate around farm infrastructures inevitably constitute a powerful food attractant to opportunistic coastal marine mammals, seabirds, and fish that normally feed on native fish stocks (Sepulveda et al., 2015; Espinosa-Miranda et al., 2020). While some may threaten production, they can also become entangled in nets and other farm infrastructure, resulting in their mortality. The southern Chilean ecoregion is home to rare and endemic species and contains critical habitats for marine mammals of global conservation concern. A portfolio of 40 areas of high conservation value (*Áreas de Alto Valor de Conservación*, AAVC) were established primarily by World Wildlife Fund-Chile (WWF) in relation to the presence of a variety of species of whales, dolphins, seals, sea lions, otters, birds, and fish (Miethke & Galvez, 2009). Similarly, a process outlined by Vila et al. (2016) identified high value areas in Region XII. Although the salmon farming industry is located throughout much of Regions X and XI, and is expanding in Region XII, there is relatively little direct overlap with the identified high value areas except for the central region of the inland sea, and the industry in Region XII is largely expanding in areas subsequently identified as “Appropriate Areas for Aquaculture” (Vila et al., 2016).

Marine mammals
In Chile, all marine mammal species are protected by law from intentional killing[63], and it is a legal requirement to report accidental mortality to the Chilean fisheries authorities (Sernapesca) under Law No. 20.293 of 2008 (Espinosa-Miranda et al., 2020). Regulations also require farms to have an emergency plan for trapped or entangled marine mammals and requires all such events to be reported to Sernapesca, including the causes and the measures adopted by the farm to prevent repeat events.

There are no public data available on marine mammal mortalities in Chile. Data on intentional and accidental marine mammal mortalities from GSI for eight Chilean salmon farming companies show only two companies reported any mortalities in 2019 (species not defined), with an average of one accidental mortality per 200 sites and no intentional mortalities. The average marine mammal mortality for the last three years is one per 223 sites according to the GSI data, all of which were accidental.

Without industry-wide public data (and even perhaps with it), there is a concern that the required reporting to Sernapesca is not fully effective, and if datasets such as from GSI are accurate or representative of the industry as a whole. For example, with a focus on Chilean dolphins, Espinosa-Miranda et al. (2020) compiled information from three sources consisting of official government records (obtained by a freedom of information request), published and grey

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[63] With the exception of exceptional situations where human life is at risk.

literature, and eyewitness reports. They found eight reports of cetacean entanglements at salmon farms in southern Chile from 2007 to 2017: six fatal entanglements involving Chilean dolphins (*Cephalorhynchus eutropia*), and two involving humpback whales (*Megaptera novaeangliae*) (one of which, a calf, was fatal, and the other was released alive). However, only two of the dolphin mortalities and one of the humpback entanglements (the non-lethal one) were present in the official Sernapesca records (Espinosa-Miranda et al., 2020), and they considered these eight accounts to be the minimum record (i.e., there may have been more). All the entanglements occurred in the farms' large-mesh anti-predator nets designed to deter other marine mammals, primarily South American sea lions (*Otaria flavescens*).

Espinosa-Miranda et al. (2020) considered the current level of official reporting of incidents involving the accidental mortality of cetaceans (as required by Chilean law) to be neither representative nor comprehensive, and therefore the scale and magnitude of the unreported mortality and the species affected remain unknown. They note the lack of reporting suggests non-compliance with national legislation. This limitation is considered here (i.e., in this Seafood Watch assessment) to likely apply to other marine mammals, such as sea lions as discussed further below.

With regard to dolphin mortalities, Espinosa-Miranda et al. (2020) considered the death of two adult Chilean dolphins at one salmon farm during a 6-month period to raise concern over potential population-level effects, but note these are difficult to evaluate without the context of local population sizes. For humpback whales, the same authors also note it is not clear if these occasional entanglements would inhibit this species' strong recovery (from overexploitation in commercial whaling). Most recently, industry media[64] reported the entanglement and death of a sei whale (*Balaenoptera borealis*) on a farm in Region XII in May 2020.

More broadly, Heinrich et al. (2019) reported a strong positive relationship between Chilean dolphin occurrence and proximity to shellfish farms, but the opposite pattern for salmon farms; in contrast, Peale's dolphin (*Lagenorhynchus australis*) occurrence increased with increasing distance to shellfish farms, with no apparent relationship with distance to salmon farms. The most plausible explanation for these relationships is that the location of the two types of aquaculture overlapped more or less with the dolphins' preferred habitat, and thus acted as a proxy for a set of habitat characteristics (i.e., the dolphins were neither attracted nor actively avoiding shellfish and salmon farms).

With regard to pinnipeds, Sepulveda et al. (2015) and references therein report that pinnipeds are among the most troublesome of the predatory species (i.e., those species that may predate farmed salmon) because there is plasticity to their feeding strategies and individuals can learn to exploit situations where salmon are concentrated and vulnerable). In Chile, a strong operational interaction between the South American sea lion and the salmon farming industry has been previously described, but there are no reports of the fur seal (*Arctocephalus australis)*

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[64] May 7, 2020. https://salmonbusiness.com/whale-found-tangled-and-trapped-in-rope-dies-at-salmon-farm/

preying on farmed salmon in Chile, probably because its primary feeding grounds are offshore (Vilata et al., 2010).

Sepulveda et al. (2015) used satellite telemetry and stable isotope analysis to study the diet of South American sea lions; their tracking results showed that almost all the foraging areas of sea lions are within close proximity to salmon farms, and the most important prey for the individuals analyzed was farmed salmonids with an estimated contribution to their diet of approximately 15-20% (the authors noted that it is possible that sea lions may be consuming feral salmon that are not currently penned within salmon farms).

It is considered here that the uncertainty in reporting of marine mammal mortalities to Sernapesca identified by Espinosa-Miranda et al. (2020) also apply to sea lions, but Oliva et al. (2008) previously reported that the use of predator nets has been effective and that entangling or enmeshing of sea lions at salmon farms is not a significant conservation concern. The estimated Chilean population of sea lions is over 35,000 in Region X and over 10,000 in Region XI, and reported as stable (Oliva et al., 2009; Sepúlveda et al., 2011; Vilata et al., 2010; Sernapesca, 2015b).

Beyond direct interactions with the farm infrastructure, Bedriñana-Romano et al. (2021) studied potential vessel encounters with blue whales (*Balaenoptera musculus*) in northern Patagonia. Hucke-Gaeteet al. (2013) reported that the level of ship traffic has increased considerably during the last decade as a result of more cargo and supply shipping for the salmon farming industry, and Bedriñana-Romano et al. (2021) noted the relatively large size of the aquaculture fleet (which includes vessels servicing shellfish farms). However, while Bedriñana-Romano et al. (2021) clearly identified the potential for aquaculture vessels to encounter whales, their study did not include large vessels (i.e., cargo, tanker, cruise and military vessels) which are considered to have a higher probability of a lethal outcome if an interaction occurs[65]). Their research identified only three documented large whale mortality events linked to vessel collisions in the NCP (two blue whales and one sei whale) over a period of 11 years, for which the type of vessel was not reported. The potential disturbance of blue whales and other cetaceans is discussed in Criterion 3 – Habitat, but it appears likely that the risk of lethal interactions between aquaculture vessels and whales (of relevance to this criterion) is low. More robust data, however, including complete agreement between government data and independent research, would provide greater confidence in the understanding of the salmon industry’s impact on marine mammal populations.

Birds

Some bird species are attracted in high numbers to farm sites; for example, the observed abundance of omnivorous diving and carrion-feeding birds increase two- to five-fold in some

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[65] For example, Bedriñana-Romano et al. (2021) noted that industrial fishing vessels might yield a higher probability of lethal interactions if they occur, due to larger vessel size. Therefore, the exclusion of large cargo, tanker, cruise and military vessels is an important reflection of the relative potential for aquaculture vessels to impact whales due to direct collision.

areas with salmon farms compared to control areas without farms (Buschmann et al., 2006). It is considered inevitable that there are some entanglements and drowning.

There are no publicly available, industry-wide official mortality figures, but the eight companies reporting through GSI did not report any mortalities in 2019. Only two companies reported mortalities in the last three years, again of very low numbers. It is not appropriate to directly extrapolate these GSI results to the entire industry in Chile, and with a reflection on the robustness of the cetacean data (Espinosa-Miranda et al., 2020) and the author's own experience of visiting salmon farms in Chile, the GSI data on bird mortalities do not appear to be realistic; however, the mortalities that may or do occur on Chilean salmon farms are not considered likely to negatively affect population sizes.

Conclusions and Final Score

The data availability for marine mammal and bird mortalities on salmon farms in Chile is limited and has been shown to be of questionable validity, particularly considering the remote areas in which the industry operates. Without a robust understanding of the impact to wildlife resulting from farm interactions, the Risk-Based Assessment method was used. Intentional mortality of marine mammals is prohibited, and while animals such as South American sea lions and birds are considered to regularly interact with farms, and there are exceptional cases of mortalities of dolphins, humpback whales, and recently a single sei whale, there are no indications from the available data or other published studies that deliberate or accidental mortalities occur in quantities sufficient to affect the population status of relevant species. The aquaculture vessel fleet in Chile (which includes vessels servicing both the salmon and shellfish industries) is large and has a significant potential for interactions with blue whales. While the potential disturbance is addressed in Criterion 3 – Habitat, the risk of mortality to cetaceans from collisions with aquaculture vessels appears low. Overall, regulations and management practices for non-harmful exclusion and control are in place, but accidental mortalities (such as those resulting from entanglement) cannot be prevented, and mortality numbers are unknown. There is no evidence with which to distinguish Atlantic and coho salmon in this regard, and the final score for Criterion 9X – Wildlife Mortalities is -4 out of -10 for both species.

Criterion 10X: Introduction of secondary species

Impact, unit of sustainability and principle

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

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

Criterion 10X Summary

Atlantic salmon – All Regions

C10X Introduction of Secondary Species parameters	**Value**	**Score**
F10Xa Percent of production reliant on transwaterbody movements (%)	<1.0	9
Biosecurity score of the source of animal movements (0-10)		8
Biosecurity score of the farm destination of animal movements (0-10)		2
Species-specific score 10X Score		-0.2
Multi-species assessment score if applicable		n/a
C10X Introduction of Secondary Species Final Score (0 to -10)		**-0.2**
Critical?	No	Green

Coho salmon – All Regions

C10X Introduction of Secondary Species parameters	**Value**	**Score**
F10Xa Percent of production reliant on transwaterbody movements (%)	0.0	10
Biosecurity score of the source of animal movements (0-10)		n/a
Biosecurity score of the farm destination of animal movements (0-10)		n/a
Species-specific score 10X Score		-0.0
Multi-species assessment score if applicable		n/a
C10X Introduction of Secondary Species Final Score (0 to -10)		**-0.0**
Critical?	No	Green

Brief Summary

As Chile becomes self-sufficient in salmon egg production, the importation of eggs has declined to approximately 400,000 in 2020 (from a peak of 275 million in 2008); nevertheless, any movements carry a risk of introducing secondary species such as pathogens. The single permitted source of live egg movements to Chile is in Iceland, and the biosecurity is high (although never perfect). As such, there is only a small risk of unintentionally introducing secondary species during live animal shipments of Atlantic salmon to and within Chile, and the final score for Criterion 10X – Introduction of Secondary Species is a minor deduction of -0.2 out of -10. For coho, the apparent lack of egg imports or movements across ecologically distinct waterbodies results in a final deduction of 0 out of -10.

Justification of Rating

According to the UN FAO (2012), the expanded and occasionally irresponsible global movements of live aquatic animals have been accompanied by the transboundary spread of a wide variety of pathogens. In some instances, these pathogens have caused serious damage to aquatic food productivity and resulted in serious pathogens becoming endemic in culture systems and the natural aquatic environment.

Factor 10Xa. International or trans-waterbody live animal shipments

Imports of Atlantic salmon eggs (ova) into Chile peaked in 2008 at approximately 275 million (Dempster, 2011) but data from Sernapesca (*Estadística de Importación de Ovas por origen*[66]) from 2011 to 2020 show that numbers have declined to 383,000 in 2020 (Figure 35). Egg imports in the first half of 2021 (21,000) appear to continue the trend as domestic production has become largely sufficient.

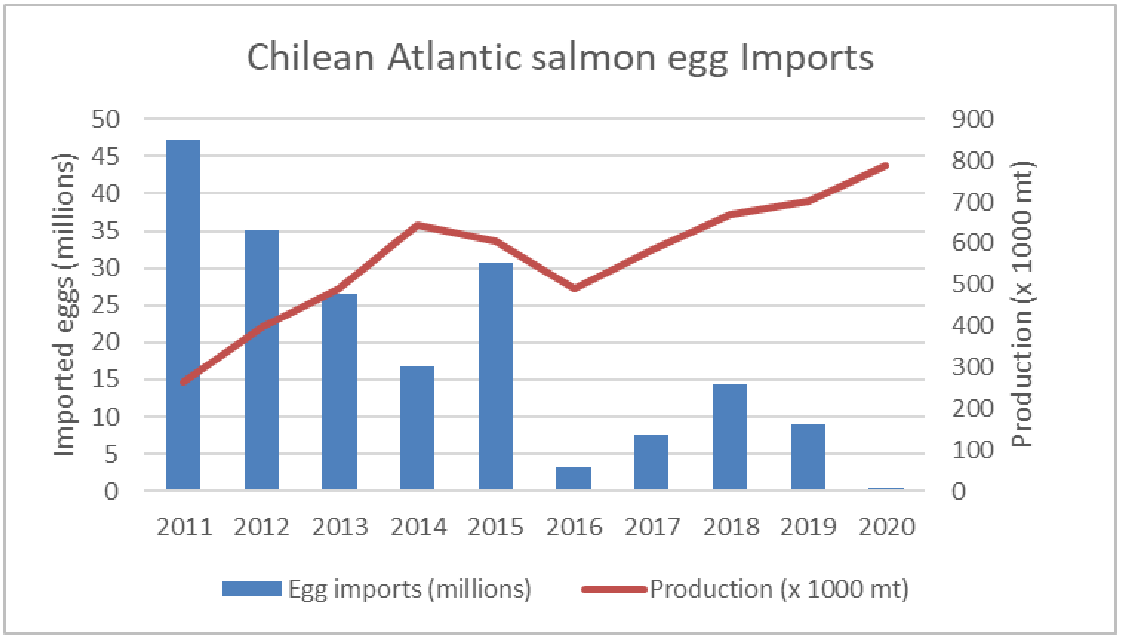

Figure 35: Blue bars show live salmon egg imports, 2011-2020. Data from Sernapesca's website - *Estadística de Importación de Ovas por origen*. Red line shows annual production x 1,000 mt (data from SalmonChile).

All of the imported salmon ova in the Sernapesca data are of Atlantic salmon, with no reported imports of coho ova in the 2011 to 2021 timeframe. Atlantic salmon eggs were imported in five separate months of 2020. Estimating the contribution of these imports to Chile's total Atlantic salmon egg use is challenging but using an annual use of approximately 1 billion eggs more than a decade ago (based on the pre-ISA data provided in Dempster, 2011) when salmon production was less than 60% of current production, the current imports are seemingly minimal. However,

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[66] http://www.sernapesca.cl/sites/default/files/estadistica_importacion_de_ovas_a_junio_2020.pdf

it is specifically non-zero; that is, shipments of live animals (as eggs) do occur and therefore there is a risk of unintentionally transporting secondary species.

Movements of smolts from hatcheries to seawater growout sites are an integral part of the salmon production system in Chile. Under Sernapesca's Control System for Aquaculture (*Sistema de Fiscalización de la Acuicultura*, SIFA), movements of fish from freshwater to marine sites must be reported within the context of the project "*Autorización de Movimiento Salmónidos*". An Application of Sanitary Movement Authorization (*Solicitud de Autorización Sanitaria de Movimiento*) must be authorized in a Movement Authorization Application (*Solicitud de Autorización de Movimiento*). In addition, the ISA crisis resulted in the implementation of regulations to ban movement of smolts from zones of poor sanitary condition to zones of better sanitary condition. The use of freshwater hatcheries in each region of Chile used for salmon farming (X, XI, and XII) or close to them (e.g., Regions IX and XIV) generally means that the movements typically occur within the same ecological waterbody. Therefore, the score for Factor 10Xa (International or trans-waterbody live animal shipments) is based on the small amounts of live egg imports (used for <1% of total Atlantic salmon production) and is 9 out of 10 for Atlantic salmon. With no imports of coho salmon eggs, the score for Factor 10Xa for coho is 10 out of 10.

Factor 10Xb. Biosecurity of source/destination

According to Sernapesca's *Estadística de Importación de Ovas por origen*, in 2011 approximately 30% of imported salmon eggs came from Australia; since then, all imported salmon eggs have come from Iceland. The only company approved by Sernapesca to export eggs to Chile is Benchmark Genetics Iceland[67] (formerly Stofnfiskur), which is also the only company to be certified to the World Organisation for Animal Health's (OIE) biosecurity Compartment Standard (originally approved by Sernapesca in 2016 and renewed in 2020[68]). It is of note that an Icelandic strain of the Piscine Reovirus has been identified in escaped farmed salmon in British Columbia (BC) that are assumed to have come from the 2017 Cypress Island escape in northern United States just south of BC. These escaping fish were raised from broodstock whose genomes show Icelandic origin (Miller et al., 2020). It is not known if these fish came directly from Benchmark Genetics Iceland or if they were hatched locally from broodstock whose genomic origins were Icelandic, but the company's screening statement[69] notes screening for some pathogens may be at the customer request (so is perhaps not done as a routine on all shipments of eggs).

While the eventual destination of the imported Atlantic salmon eggs is open net pens in Chile, the high biosecurity characteristics of the Icelandic source (while not perfect) mean the score for Factor 10Xb (Biosecurity of source/destination) is 8 out of 10 for Atlantic salmon. For coho salmon, as the score for Factor 10Xa is 10 out of 10, Factor 10Xb does not need to be assessed.

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[67] https://bmkgenetics.com/services/salmon/

[68] The Fish Site: 17 April 2020. StofnFiskur retains Chilean import approval. https://thefishsite.com/articles/stofnfiskur-retains-chilean-import-approval

[69] https://bmkgenetics.com/about/benchmark-genetics/biosecurity/the-benchmarks-genetics-way/

Conclusion and Final Score

As Chile becomes self-sufficient in salmon egg production, the importation of Atlantic salmon eggs has declined to approximately 400,000 in 2020 (from a peak of 275 million in 2008). There have not been any reported coho eggs in Sernapesca's 2011 to 2021 dataset. Any animal movements carry a risk of introducing secondary species such as pathogens. The single permitted source of Atlantic salmon egg movements to Chile is in Iceland, and the biosecurity is high (although never perfect). As such, there is only a small risk of unintentionally introducing secondary species during live animal shipments of Atlantic salmon to and within Chile, and the final score for Criterion 10X – Introduction of Secondary Species is a deduction of -0.2 out of -10. For coho, the apparent lack of egg imports or movements across ecologically distinct waterbodies results in a final deduction of 0 out of -10.

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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.

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Appendix 1 - Data points and all scoring calculations

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

Atlantic and Coho salmon

Criterion 1: Data	
Data Category	**Data Quality**
Production	7.5
Management	7.5
Effluent	7.5
Habitat	5.0
Chemical Use	7.5
Feed	5.0
Escapes	5.0
Disease	5.0
Source of stock	10.0
Wildlife mortalities	5.0
Escape of secondary species	7.5
C1 Data Final Score (0-10)	**6.591**
	Yellow

Atlantic and Coho salmon Regions X and XI

Criterion 2: Effluent	
Effluent Evidence-Based Assessment	**Data and Scores**
C2 Effluent Final Score (0-10)	**6**
Critical?	NO

Atlantic and Coho salmon Regions XII

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

Atlantic and Coho salmon

Criterion 3: Habitat	
F3.1. Habitat conversion and function	**Data and Scores**
F3.1 Score (0-10)	8
F3.2 – Management of farm-level and cumulative habitat impacts	
3.2a Content of habitat management measure	3

3.2b Enforcement of habitat management measures	4
3.2 Habitat management effectiveness	4.8400
C3 Habitat Final Score (0-10)	**6.933**
Critical?	No

Atlantic salmon

Chemical Use

Region	Score	Critical?	Trend
Region X	Critical	Yes	No
Region XI	Critical	Yes	No
Region XII	6	No	No

Coho salmon

Chemical Use

Region	Score	Critical?	Trend
Region X	6	No	No
Region XI	6	No	No
Region XII	8	No	No

Atlantic and Coho salmon

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

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

Final Factor 5.1 Score	**2.820**

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

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

Atlantic Salmon

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	2
Percent of escapees recaptured (%)	14.000
F6.1 Recapture adjustment	1.120
F6.1 Final escape risk score	3.120
F6.2 Invasiveness score	6
C6 Escape Final Score (0-10)	**4.0**
Critical?	No

Coho salmon

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	2
Percent of escapees recaptured (%)	14.000
F6.1 Recapture adjustment	1.120
F6.1 Final escape risk score	3.120
F6.2 Invasiveness score	0

C6 Escape Final Score (0-10)	**1.0**
Critical?	Yes

Atlantic and Coho salmon

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

Atlantic and Coho salmon

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

Atlantic and Coho salmon

Criterion 9X Wildlife Mortality parameters	**Data and Scores**
Single species wildlife mortality score	-4
System score if multiple species assessed together	n/a
C9X Wildlife Mortality Final Score	**-4**
Critical?	No

Atlantic salmon

Criterion 10X: Introduction of Secondary Species	**Data and Scores**
Production reliant on transwaterbody movements (%)	2
Factor 10Xa score	9
Biosecurity of the source of movements (0-10)	8
Biosecurity of the farm destination of movements (0-10)	2
Species-specific score 10X score	-0.200
Multi-species assessment score if applicable	-0.200
C10X Introduction of Secondary Species Final Score	**-0.200**
Critical?	n/a

Coho salmon

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

Species-specific score 10X score	0.000
Multi-species assessment score if applicable	-0.000
C10X Introduction of Secondary Species Final Score	**-0.000**
Critical?	n/a