Monterey Bay Aquarium
Seafood Watch®

Rainbow trout

Oncorhynchus mykiss

Chile

Marine net pens

December 5, 2022
Seafood Watch Consulting Researchers

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: Buy first, they're well managed and caught or farmed in ways that cause little harm to habitats or other wildlife.

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

Avoid/Red: Don't buy, they're overfished or caught or farmed in ways that harm other marine life or the environment.

Final Seafood Recommendation

Rainbow Trout
Oncorhynchus mykiss
Chile
Marine net pens

Criterion	Scores			Critical?
	Region X	Region XI	Region XII	
C1 Data	6.59	6.59	6.59	
C2 Effluent	4.00	4.00	2.00	NO
C3 Habitat	6.40	6.40	6.40	NO
C4 Chemicals	2.00	2.00	6.00	NO
C5 Feed	4.59	4.59	4.59	NO
C6 Escapes	3.00	3.00	2.00	NO
C7 Disease	4.00	4.00	4.00	NO
C8X Source	0.00	0.00	0.00	NO
C9X Wildlife mortalities	–4.00	–4.00	–4.00	NO
C10X Secondary species escape	0.00	0.00	0.00	
Total	**26.58**	**26.58**	**27.58**	
Final score (0–10)	**3.80**	**3.80**	**3.94**	

OVERALL RANKING	Rainbow Trout		
	Region X	Region XI	Region XII
Final Score	**3.80**	**3.80**	**3.94**
Initial rank	YELLOW	YELLOW	YELLOW
Red criteria	2	2	2
Interim rank	RED	RED	RED
Critical Criteria?	0	0	0
Final Rating	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.

In Regions X and XI, the final numerical score for farmed rainbow trout from Chile is 3.80 out of 10, including two Red scores: Criterion 4—Chemicals and Criterion 6—Escapes. This leads to a final rating of Red and a recommendation of Avoid.

In Region XII, the final numerical score for farmed rainbow trout from Chile is 3.94 out of 10, including two Red scores: Criterion 2—Effluent and Criterion 6—Escapes. This leads to a final rating of Red and a recommendation of Avoid.

Executive Summary

Chile is currently the world's second-largest producer of farmed salmonids, with harvests of 725,280 metric tons (mt) of Atlantic salmon, 213,199 mt of coho salmon, and 56,656 mt of rainbow trout in 2021. Salmonid farming also is Chile's second-largest export product (after copper); in 2021, roughly two-thirds of rainbow trout production was exported and valued at over USD 335 million. Rainbow trout production is centered in Aysén (Region XI), with lower production levels in Los Lagos and Magallanes (Regions X and XII). Although trout production is small compared to that of Atlantic salmon (rainbow trout constitutes 6% of total Chilean salmonid production), it remains an important industry for the country.

The principal production systems are marine net pens, and this report focuses on several key aspects of this production, including effluents, habitats, chemical use, feed, escapes, diseases and parasites, source of stocks, wildlife and predator effects, escape of unintentionally introduced species, and the overall quality and availability of data. As noted below, the data availability in Chile is improving, with some data available at the site level and many datasets now differentiated by species and production region. Each region of Chile has complex environmental and industry variables. Still, the improved data availability now allows this Seafood Watch assessment to consider many criteria in each of the three primary production regions (Regions X, XI, and XII).

Data collection and availability, particularly from the government, have improved in Chile, but the access and availability from outside Chile continue to lag behind other major salmonid-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 stakeholder 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 concerning the latter, the limited number of companies means that it must be used with caution as an indicator of Chile's average performance. There is generally a greater focus on Atlantic salmon in the data and studies in Chile than on coho and trout. Still, there are sufficient similarities in the available data to be representative of the three species. The same score of 6.59 out of 10 is assigned to all regions for Criterion 1—Data.

Because of the open nature of net pen production systems, virtually all waste produced from an operation, including dissolved and particulate effluents, discharges directly to the surrounding environment with little or no intervention. In addition, some important gaps exist in understanding the carrying capacity of Chile's fjords and channels and the corresponding impact of nutrient discharge from salmonid sites cumulatively. But, 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 that substantial impacts in the water column from salmonid 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 the three salmonid species. The long-term data show that these results are all improving over time, and while still uncertain, the available research shows that the impacts are likely to be limited primarily to the immediate farm area. Still, more than half the sites in Region XII must undertake 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 water-body 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 anaerobic 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 water-body scale, and the final score for Criterion 2—Effluent for Regions X and XI 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 water-body scale. The final score for Criterion 2—Effluent in Region XII is 2 out of 10.

Salmonid 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 salmonid farm contains 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 nonnative species and/or pathogens and parasites. Salmonid farms also attract a variety of wild animals as fish aggregation devices or artificial reefs; or repel other wild animals through disturbances such as noise, lights, or increased boat traffic. Because of 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 whale. Changes in the behavior of wild fish around fish farms and even of their flesh quality due to the consumption of waste feed have been reported. Key aspects 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). But, 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 affect 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 maintain 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 industry's ongoing expansion into largely pristine habitats in Region XII is of particular concern, which raises questions about the content of management measures. The scores for Factor 3.1 (8 out of 10) and Factor 3.2 (3.2 out of 10) combine to result in a final Criterion 3—Habitat score of 6.4 out of 10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations). This score applies to all regions.

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. The total Chilean antimicrobial use on salmonid farms declined from 2015 to 2018 but has since increased through 2021. The average country-level use reported by Sernapesca of 350 g/mt hides considerable variability by production region in total and relative terms; for example, the relative use on rainbow trout in Regions X, XI, and XII in 2020 was calculated to be 138 g/mt, 142 g/mt, and 25 g/mt, respectively. Rainbow trout's approximated treatment frequency per site in Region X and XI was 0.8 per production cycle, and 0.15 per production cycle in Region XII.

Almost all antimicrobial use (96.8% by weight in 2020) is currently of florfenicol to treat piscirickettsiosis (or salmonid rickettsial syndrome, SRS), although oxytetracycline has been important until recently. The direct ecological impacts of antimicrobials to the receiving environments remain unclear, but of high general concern are the potential development of antimicrobial resistance (in the treated bacterial pathogen as well as in the surrounding nontarget 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 challenges, 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 human and terrestrial sources.

Some recent studies indicate that 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. But, the government's resistance surveillance program shows that approximately 50% of the isolates of *P. salmonis* tested in 2020 displayed reduced susceptibility to florfenicol (and approximately 17% to oxytetracycline) in in-vitro laboratory trials. Values were low for other pathogens except *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 salmonid farms (particularly Atlantic salmon farms) has resulted in bacterial populations evolving and adapting to the two most commonly used drugs.

Pesticide use for salmonids in Chile is also high (mainly driven by use on Atlantic salmon), although reports showed a substantial decrease from 2019 to 2020. Still, the overall high and fluctuating trend over time reflects the ongoing struggle to control parasitic sea lice. Over 8 mt of pesticide active ingredients were used in 2020, plus over 4,119 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. Rainbow trout production was only responsible for 3.6% and 2.6% of the total salmonid pesticide use in 2019 and 2020, respectively, and the relative pesticide use for rainbow trout (2.4–4.5 g/mt) is considerably lower than that of Atlantic salmon (8–10 g/mt). Despite this, the impact of these pharmaceuticals on the marine environment remains largely uncertain, particularly regarding repetitive treatments at a single site or coordinated treatments in a single water body. Widespread resistance has previously developed in Chile and is likely to recur with the repeated use of a limited number of available treatments.

Overall, there is no specific evidence indicating that antimicrobial use in Chilean salmonid farms has led to the development of clinical resistance (i.e., the loss of efficacy of treatments) for the primarily treated pathogens. It must also be noted that bacterial resistance genes in marine environments may have originated from human and terrestrial sources. Although the Chilean rainbow trout industry's use of antimicrobial treatments per site per year remains high compared to international use, the trend since 2018 has been decreasing. Florfenicol is noted for its "floR" resistance gene associated with mobile elements (such as plasmids and transposons) and the potential contribution to the pool of resistant genes in the environment, so it remains a critical conservation concern in Chile. For rainbow trout, the average frequency of florfenicol (a highly important antimicrobial for human medicine) use between 2017 and 2020 was slightly higher than one treatment per site per year in Regions X and XI (1.17 and 1.27 treatments per year, respectively). Pesticide use is also significant (e.g., azamethiphos, emamectin benzoate), with multiple treatments per site per year in all regions where production takes place. Therefore, with chemicals known to be used on multiple occasions each productive cycle (including significant use of highly important antimicrobials), plus a treatment method that allows their release into the environment, the final score for Criterion 4—Chemical use is 2 out of 10 for Regions X and XI. Based on a demonstrably lower need and lower frequency of antibiotic treatments used in Region XII (0.29 treatments per year), the final score for Criterion 4—Chemical use is 6 out of 10 for Region XII. 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, although 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, feed composition data were obtained from the literature and from sustainability reports published by the three major feed companies (Biomar, Ewos-Cargill, and Skretting). Although not precisely accurate, the key aspects of this assessment were considered sufficiently robust. In addition, the performance indicators such as the Feed Conversion Ratio may vary by region, but there is currently insufficient regional data to assess them separately.

Overall, rainbow trout feed in Chile uses fishmeal and fish oil made from whole wild fish and by-product sources with an eFCR of 1.3. The fishmeal inclusion level is moderate (9.8%); over one-third of it (35%) is sourced from fishery and/or aquaculture by-products, and the rest (65%) from whole-fish reduction processes. The fish oil inclusion level is also moderate at 8.6%, and 34% comes from by-product sources. The resulting score for Factor 5.1a—Forage Fish Efficiency Ratio (FFER) is low (1.52), meaning that, from first principles, 1.52 mt of wild fish are needed to produce the fishmeal required for 1 mt of farmed rainbow trout. Most of the marine ingredients used by Chilean feed suppliers are sourced from MSC, IFFO-RS certified, or managed fisheries, resulting in a score for Factor 5.1b—Source fishery sustainability of 5 out of 10. The inclusion levels of these wild fish ingredients in Chilean rainbow trout feeds combined with the sustainability of raw materials result in a Factor 5.1—Wild fish use score of 4.17 out of 10. Factor 5.2—Net protein gain or loss scores 3 out of 10 and is driven by a moderate to high net protein loss of –65.77%. Factor 5.3—Feed footprint scores 7 out of 10 due to a low to moderate feed footprint of 12.63 kg CO_2-eq. per kg of harvested protein. Altogether, Factor 5.1, 4.17 out of 10; Factor 5.2, 3 out of 10; and Factor 5.3, 7 out of 10 combine for a final score of 4.59 out of 10, which results in a Yellow rating for Criterion 5—Feed.

Large escape events of farmed salmonids continue to occur in Chile. Escape events totaling 410,000 escaped fish were reported in 2020, including a single escape event of 51,000 rainbow trout in the ecoregion of Magallanes. 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, 3.8 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 escaped salmonids on average in Regions X and XI (noting that some, e.g., by local fishers, may not be reported), but due to the lack of artisanal fishers and lower predation pressure by native predators such as sea lions, recaptures in Region XII are considered insignificant. Large numbers of salmonids still enter the environment every year, and the production system remains vulnerable in all regions.

Escaped rainbow trout pose a significant threat to native Chilean ecosystems because of the species' unique potential to establish naturalized populations. Decades of intentional stocking for recreational fishing have established populations throughout southern Chile and, although rainbow trout is known to predate upon the Galaxiid spp., it appears to have reached a balance that allows the species to cohabit. The contradictions in the literature make it challenging to score this criterion with a high level of confidence, which is why it is pertinent to use the precautionary approach in this case. Regions X and XI are not considered pristine habitats, and significant aquaculture production of rainbow trout has been occurring in these regions for decades. This is not the case for Region XII, where industry expansion is ongoing and which is considered a pristine ecoregion, providing habitat to three endemic and endangered species. Rainbow trout (nonnative) was established in this region for sport fishing well before aquaculture began, and it only accounted for 2.4% of the samples captured during a study carried by IFOP; nonetheless, the potential increase in escapees of trout bred for farming (as opposed to stocking), as a result of the ongoing industry expansion, increases the risk of escapees affecting the population status of wild species.

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). With a production system vulnerable to large escape events and trickle losses, and a small adjustment for recaptures (in Regions X and XI), the net pen systems' vulnerability to escape results in Factor 6.1 scores of 3 out of 10 for Regions X and XI and 2 out of 10 for Region XII. Regarding Factor 6.2, competition, predation, and impacts to wild species, habitats, or ecosystems may occur, but are not considered likely to affect the population status of wild species in Regions X and XI; therefore, they score 4 out of 10, resulting in a Criterion 6—Escapes final score of 3 out of 10. But, Factor 6.2 in Region XII was scored 2 out of 10, because rainbow trout has a high potential to affect the population status of wild species, and because of its possible further expansion within this range. As a result, the Criterion 6—Escapes final score is 2 out of 10.

Disease-related losses and increased production costs have been a defining characteristic of the development of salmonid farming in Chile, but with control improving, the mortality due to disease is relatively low (15.9% for rainbow trout in 2020). Of 54 active rainbow trout production sites in 2020, 7 were classified as centers of high pathogen dissemination (CAD, its Spanish acronym) for SRS in 2020 (all sites under surveillance) and 12 for sea lice in 2021. The IFOP monitoring of wild-caught fish for the presence of pathogens of concern to salmonid 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 dominate farmed Atlantic salmon production). Though 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 infectious pathogens and parasites that 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). Still, 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 do or do not affect wild fish, the Risk-Based Assessment method is used. Ultimately, despite the widespread employment of biosecurity protocols, Chilean salmonid farms are challenged with diseases, and the openness of the net pen production system directly connects farmed rainbow trout to wild populations. Although diseases are more commonly detected in Regions X and XI mainly due to higher production levels, the new detections of parasitic sea lice in Region XII make the overall risks applicable to all regions. The final score for Criterion 7—Disease is 4 out of 10.

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

The presence of cultivated salmonids 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 salmonid farms in Chile is limited and has been shown to be of questionable validity, particularly considering the remote areas in which the industry operates. Thus, without a robust understanding of the impact on 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 the southern sea lion and birds are considered to interact with farms regularly. There are records of accidental cases of mortalities of sea lions, dolphins, humpback whale, and recently a single sei whale. Although 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 salmonid and shellfish industries) is large and has a significant potential for interactions with blue whale. The potential disturbance is addressed in Criterion 3—Habitat, and the risk of mortality to cetaceans from collisions with aquaculture vessels appears low. Overall, regulations and management practices for nonharmful exclusion and control are in place. Still, accidental mortalities (such as those resulting from entanglement) cannot be prevented, and mortality numbers are unknown. There is no evidence with which to differentiate impacts by salmonid species, and the final score for Criterion 9X—Wildlife Mortalities is –4 out of –10 for rainbow trout.

The biosecurity of animal movements within Chile is understood to be high, with strict controls in place to prevent the spread of nontarget organisms, including pathogens. Concerning broodstock and fingerling biosecurity, broodstock are generally housed in tank-based recirculation systems with high biosecurity, while fingerlings are grown in lakes, introducing some possibility, albeit remote, of biosecurity breaches. Nonetheless, the utilization of health management zones and the fact that trans-water-body movements are between fresh and saltwater dramatically reduce this risk. In addition, rainbow trout farming has not relied on imported eggs since 2016. Concluding that there is minimal risk for the escape of secondary species, this results in a final score for Criterion 10x—Escape of Secondary Species of 0 out of –10.

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Introduction

Scope of the analysis and ensuing recommendation

Species

Rainbow trout: *Oncorhynchus mykiss* (Walbaum, 1792) also previously known as *Salmo gairdneri* (Richardson, 1836) as reported in Billard (1989).

Geographic Coverage

Chile

Production Method

Marine net pens

Species Overview

Rainbow trout is native to the western seaboard of North America from Alaska to Baja California, Mexico, as well as the upper Mackenzie River drainage (Arctic basin), Alberta, and British Columbia in Canada. It has been intentionally introduced as a sport fish worldwide and is now naturalized on all continents except Antarctica. It is highly adaptable and capable of inhabiting many different habitats, from an anadromous lifestyle in coastal waterways to permanent residence in freshwater lakes. From an aquaculture perspective, it is easy to spawn, fast-growing, and tolerant of a wide range of environments and handling; the fry are also easily weaned onto artificial diets. Although it is nonnative to Chile, it was introduced between 1850 and 1920 and is now widely distributed, and it has established viable populations in the wild (FAO 2005)(Carrera 2020)(Luna and Torres 2011)(Monzón-Argüello et al., 2014).

Production Statistics

The majority of farmed salmonids in Chile are produced in floating net pens in coastal and fjordic inshore environments, typical to the industry worldwide. (Although Seafood Watch [henceforth, SFW] is aware of a sizable amount of rainbow trout [roughly 2,000 mt per year] produced through raceways in Chile, this production is outside the scope of this report.) The hatchery phase is conducted primarily in freshwater tanks in indoor flow-through or recirculation systems on land, after which smolts are transferred to seawater net pens when they achieve weights of around 100 to 200 g. Trout are grown to between 2.3 and 3 kg (5 and 6.6 lb), at which point they are harvested and processed for sale. Pens routinely used are floating steel (Figure 1) or circular plastic structures, both of which are considered “open” in that they allow full water exchange with the surrounding environment.

Figure 1. An example of salmonid net pens as used in Chile.

There are approximately 450 salmonid sites in Chile, but not all are active at the same time; according to Sernapesca,[1 2] in 2021 there were a maximum of 354 active sites, and approximately 73% were producing Atlantic salmon, 21% coho, and 6% rainbow trout. The sites (typically called "concessions") are managed in production neighborhoods or *barrios* (the formal name is Agrupación de Concesiones para la Salmonicultura, ACS), and marine production sites for salmonids are located in Chile's southernmost Regions X (Los Lagos), XI (Aysén del General Carlos Ibáñez del Campo) and XII (The Magallanes y la Antártica Chilena) (Figure 2).

Chile is the world's second foremost producer of rainbow trout, harvesting 56,656 metric tons (henceforth, "tons" or mt) in 2021, making it the third most-produced salmonid in Chile (after Atlantic salmon and coho salmon) and making up 6% of the country's salmonid production (Sernapesca, 2021a). In 2021, Los Lagos (Region X), Aysén (Region XI), and Magallanes (Region XII) were the main regions producing rainbow trout (Figure 2), with 15,710 mt, 25,957 mt, and 12,418 mt, respectively (Sernapesca, 2021). These amounts show a reduction of 206,018 mt (78%) from the peak production of 262,674 mt of rainbow trout in 2012. The most recent statistics indicate that Chile represented 40.7% of global total marine rainbow trout production (net pens) in 2019, with 81,714 mt of production. It was not until 2019 that Norway took first place as the largest producer of rainbow trout by only 1,576 mt (83,290 total tons) more than Chile's production (FAO, 2022).

[1] http://www.sernapesca.cl/sites/default/files/informe_sanitario_con_informacion_sanitaria_de_agua_dulce_y_mar_ano_2021_enero-noviembre_202112209.pdf
[2] http://www.sernapesca.cl/informacion-utilidad/anuarios-estadisticos-de-pesca-y-acuicultura

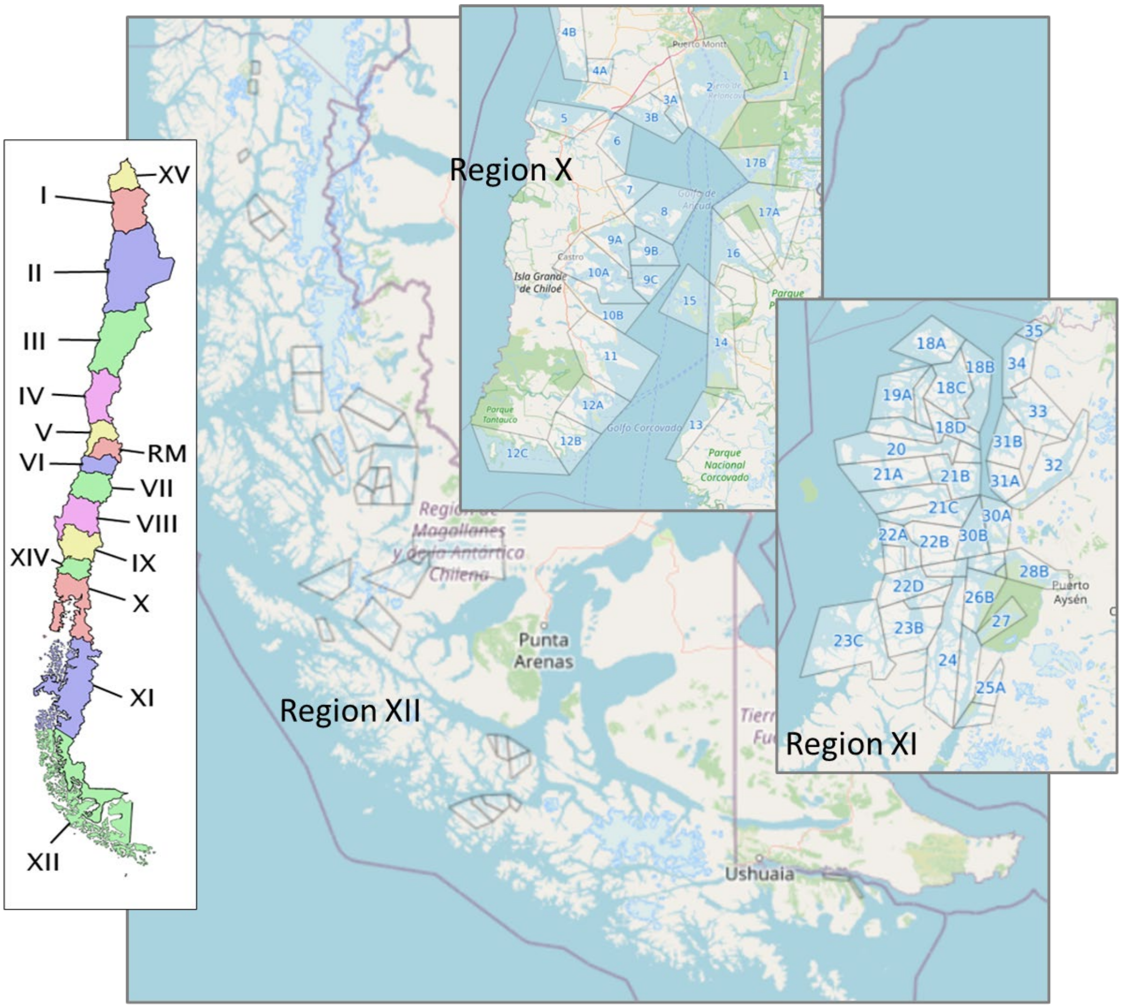

Figure 2. Map of aquaculture neighborhoods (ACS) in Region X (Los Lagos), Region XI (Aysen), and Region XII (Magallanes). The scale of the Region XII map is larger, and the ACSs are not numbered. Maps were created from SalmonChile/Intesal's map tool.[3] Inset of all Chilean regions copied from Wikipedia.com.

The salmonid industry in Chile went through a reallocation of production between 2009 and 2013, as shown in Figure 3. During this period, the increase in trout production was in response to the collapse of salmon production between 2009 and 2011, caused by the Infectious Salmon Anaemia (ISA) outbreak that happened between 2007 and 2008. Since the end of the crisis, producers switched back to salmon, causing trout prices to drop and trout production to return to pre-crisis levels for the next 2 consecutive years (2013–2014). While Atlantic and coho salmon production experienced an average growth rate of 7% and 8.3%, respectively, since 2013, rainbow trout production decreased on average by 8.1% per year (Sernapesca, 2021b). Another explanation for the sudden drop in Chilean rainbow trout production is a 21.81% increase in mortality from diseases (piscirickettsiosis, SRS; idiopathic trout syndrome, SIT; and caligus) in 2012 (Aqua, 2015)(Pérez-Mallea, 2015)(Tallaksen, 2013). It is worth noting that SIT created much uncertainty around disease control in trout production, given its unknown etiology and mortality. In addition, veterinarians from different salmonid farms believe that SIT

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

predisposes the fish to SRS outbreaks (Pérez-Mallea, 2015). Following these events, trout price recovery started in 2014, but it was not until 2016 that its production stabilized at 75,000 to 90,000 tons per year (FAO, 2021)(Villegas, 2014).

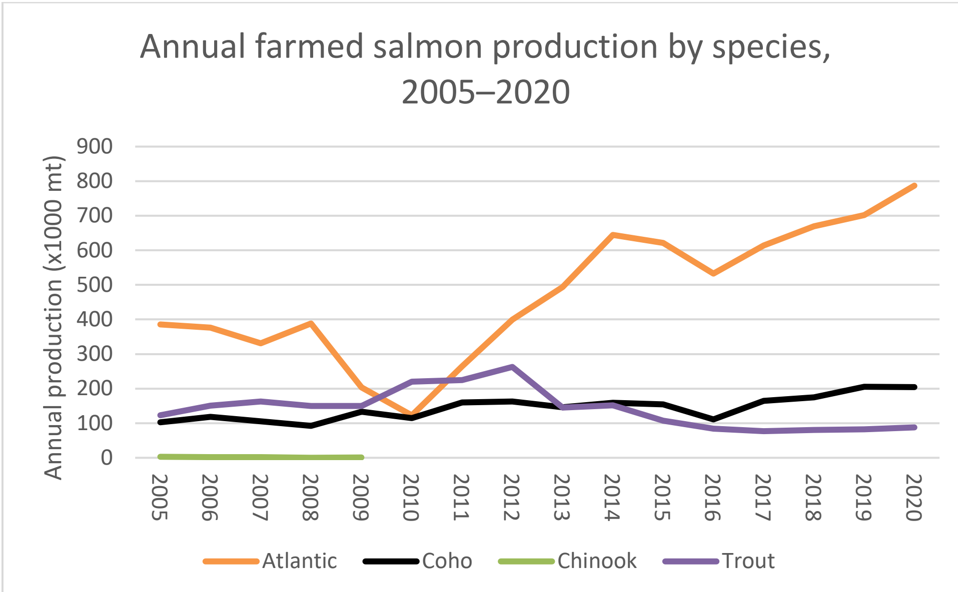

Figure 3. Annual salmonid production in Chile. Data from Sernapesca (2020).

The total biomass of farmed salmonids varies from a minimum production of 450,000 mt in 2010 to a maximum of 1.079 million mt in 2020, experiencing an annual average growth rate of 10.25% during these 10 years (Sernapesca, 2021b). In greater detail, monthly harvests of rainbow trout occur throughout the year, with summer and spring (Southern Hemisphere seasonality) the most important production seasons (Figure 4) (Sernapesca, 2021b).

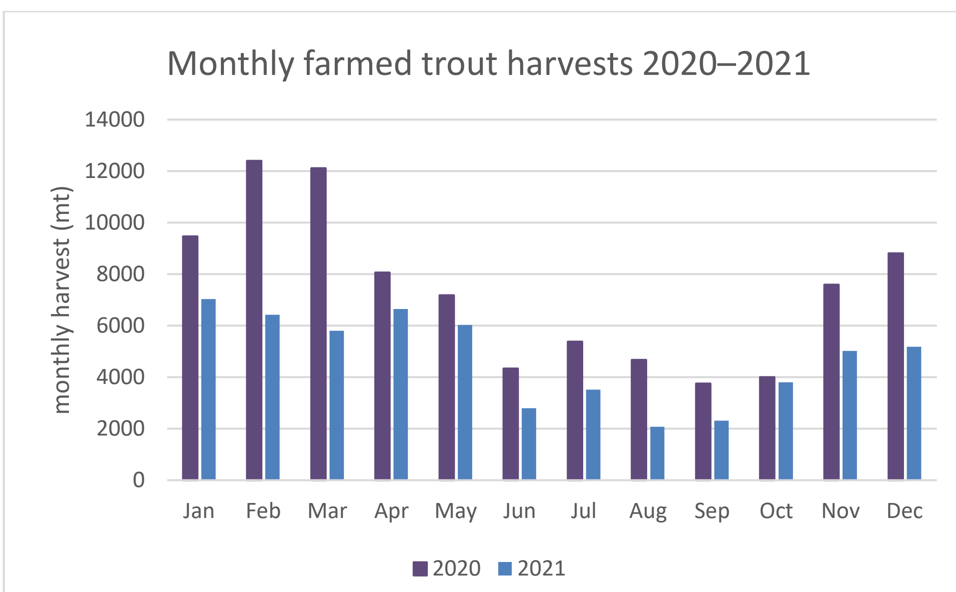

Figure 4. Monthly harvests of rainbow trout in 2020 and 2021. Data from Sernapesca, 2022.

In 2021, the annual output of salmonids in Region X (363,234 mt) was lower than in Region XI (482,644 mt) but more than double that of Region XII (146,498 mt) (Figure 5). Rainbow trout production is concentrated in Region XI, with 48% of the annual total output, followed by Region X (29%) and Region XII (23%) (Sernapesca, 2021b). Trout production per region shifted considerably from 2019 to 2021. Region XI was leading trout production in 2019 with almost 50% (39,844 mt) but was reduced to nearly 0.3% by 2020 (39,588 mt reduction); however, it increased again to 48% in 2021 (Sernapesca, 2021b). Although significant fluctuations in trout production between regions can be observed in Figure 5, Region X has maintained an important production level, and Region XII shows an increasing trend during this 3-year period. Shifting trout production to the more remote Region XII presents challenges to producers, given the limited smolt supply and the lack of hatchery infrastructure in the region. Therefore, it can be speculated that production shifted back to Region XI in 2021 for these reasons (pers. comm., Roxanna Peña, Australis Seafoods, December 2021). Other reasons for these fluctuations could be intrinsic to the management system in place (e.g., extended fallowing periods in certain areas) or to the farms' harvest cycles (pers. comm., Rolando Ibarra, Seafood Watch, August 2022).

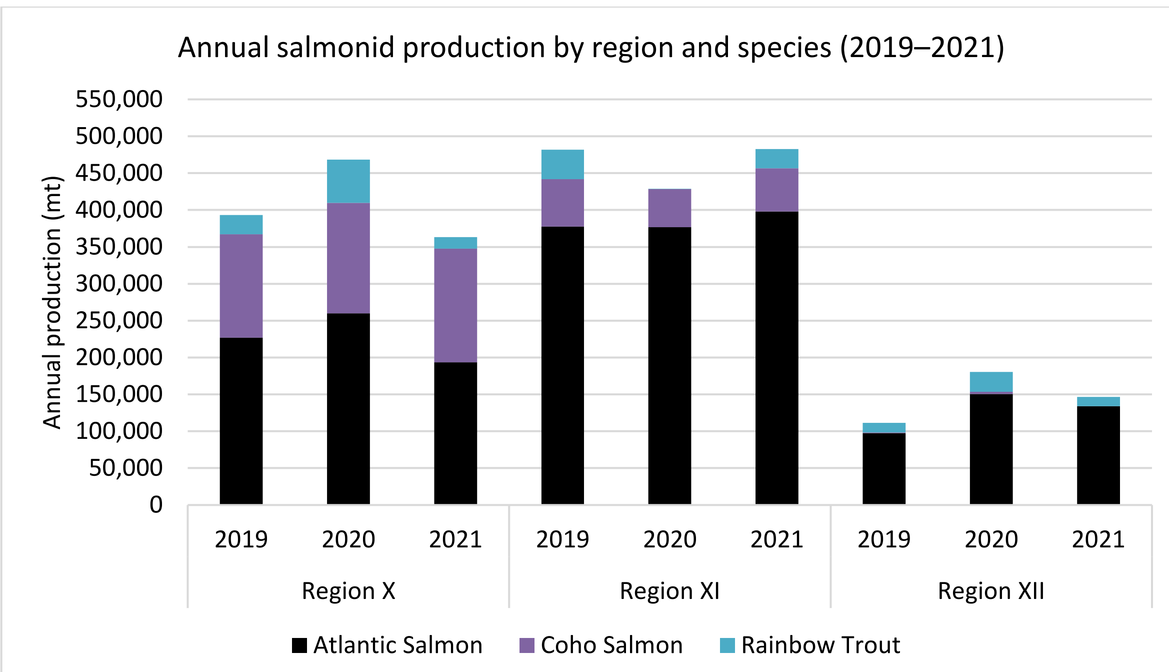

Figure 5. Regional salmonid production in Chile from 2019 to 2021. Data from Sernapesca (2021b).

Production is increasing in all regions, but 65% of the increase from 2019 to 2020 was due to the expansion of Atlantic salmon in the southernmost Region XII (Magallanes y la Antártica Chilena). Figure 6 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

[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.

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.). But, 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 (× 0.94) over the same 3 years (Figure 6).

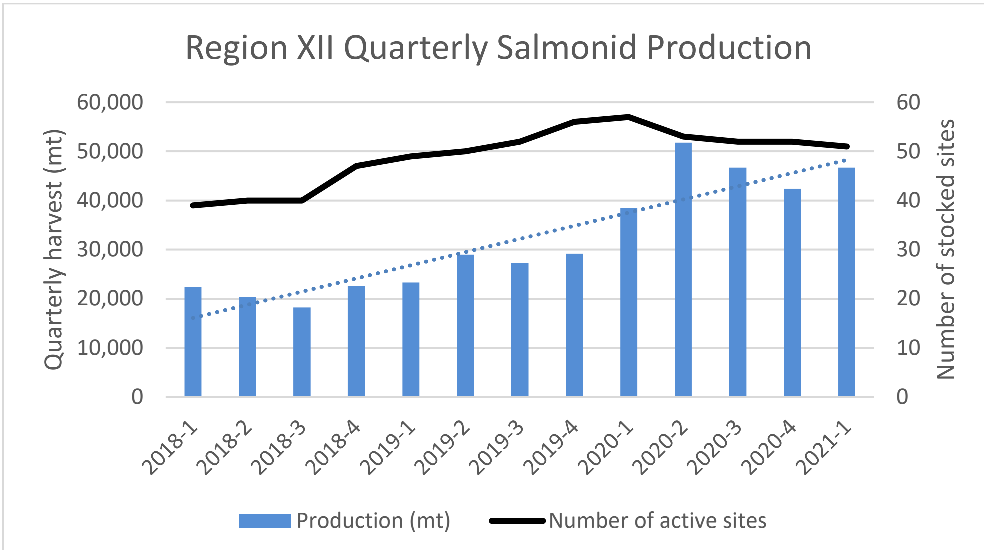

Figure 6. Quarterly farmed salmonid production (mt, including rainbow trout) in Region XII from 2018 to the first quarter of 2021 (blue bars, primary y-axis) and the number of active sites (black line, secondary y-axis, including rainbow trout sites). The dotted blue line shows a simple linear regression 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 7 from Vila et al. (2016) with Figure 8 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, labeled in Figure 8 as 3, 6, and 8.

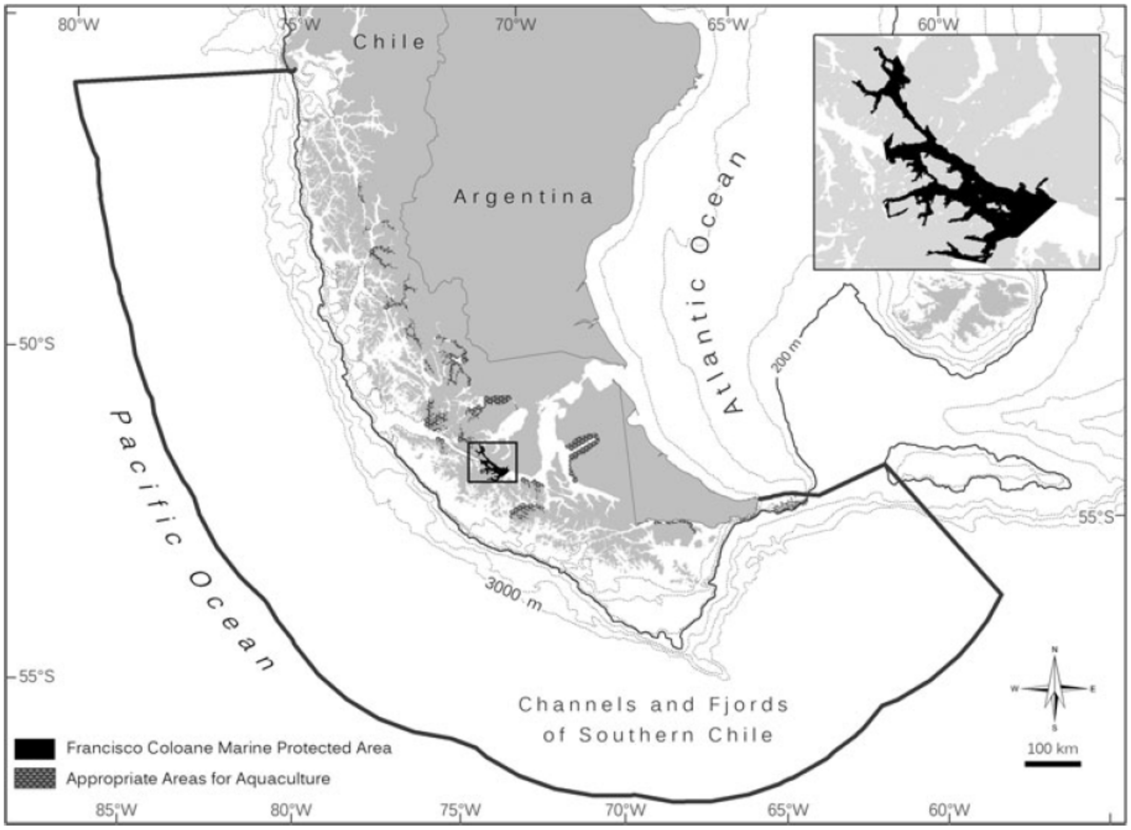

Figure 7. Areas appropriate for aquaculture in Region XII. Image copied from Vila et al. (2016).

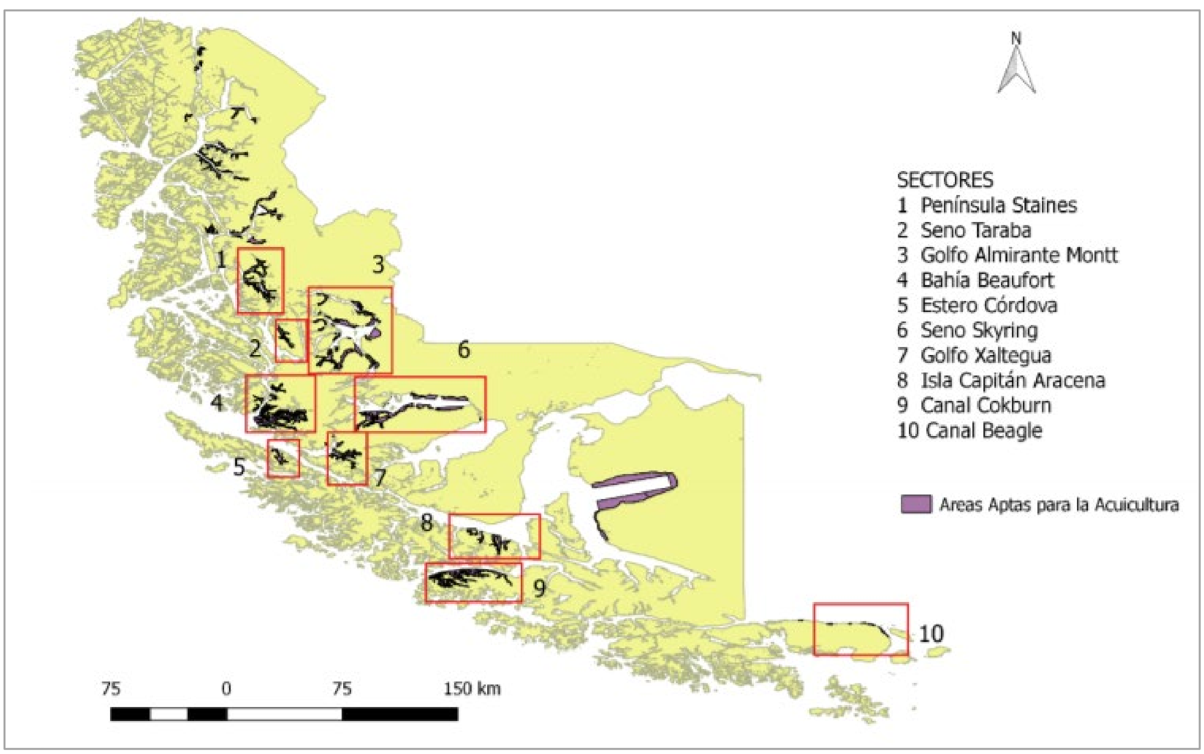

Figure 8. Map of Region XII with 10 production sectors (red boxes) and Appropriate Areas for Aquaculture (black and purple). Image copied from Sernapesca.

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, there were 367 active salmon sites in Chile in 2020, with approximately 50 active sites in Region XII.

Table 1. Number of aquaculture active sites (all salmonids) in Chile's three southernmost regions in 2021. 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	100.0

Currently, the Aquaculture Stewardship Council (ASC) certifies approximately 77 Atlantic salmon, 42 coho, and 6 trout sites in Chile to their Salmon Standard (as of February 22, 2022[6]). 247 salmonid 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[7]) (note some sites are certified to both schemes).

Import and Export Sources and Statistics

Salmonids are Chile's second-largest export product (631,309 total mt) after copper. In 2018, 27% of exported salmonids were destined for the United States market (170,058 mt), followed by 23% to Japan (142,921 mt), and 14% to Brazil (87,082 mt) (SalmonChile website,[8] accessed July 2021). Chile exported 52,578 mt of rainbow trout in 2019, with a value of USD 471 million, increasing at an annual average rate of 3% by volume and 5.6% in value since 2016 (FAO, 2021). Chilean exports of rainbow trout peaked in both volume and value in 2012, with 141,092 tons worth USD 892.9 million. Rainbow trout currently represents the third most valuable Chilean aquaculture export after Atlantic and coho salmon (Figure 9) (SalmonChile website, accessed December 2021).

For the first quarter of 2022, the main buyers of Chile's exported salmonids were the United States, Japan, and Brazil, accounting for 39.6%, 22.7%, and 11.6%, respectively, of exported whole fish equivalent (Intesal[9] accessed in August 2022). With respect to frozen aquaculture products (almost exclusively salmonids) in 2020, Japan, the United States, and Russia imported 29.8%, 16.1%, and 9.1% from Chile, respectively (Table 2) (DAS/SPA, 2020). Chile's major recipients of fresh aquaculture exported products are the United States and Brazil, representing 69.3% and 21.2%, respectively (Table 3) (DAS/SPA, 2020). Although these statistics do not differentiate by aquaculture species, Japan is the primary importer of Chile's rainbow trout,

[6] https://www.asc-aqua.org/find-a-farm/
[7] https://www.bapcertification.org/Producers
[8] https://www.salmonchile.cl/en/exports/
[9] https://www.infosalmonchile.cl/

importing over 50% (more than 30,000 mt) of total production in 2021 (pers. comm., Rolando Ibarra, August 2022). During that same year, the United States only imported about 17% of Chile's total rainbow trout production (NOAA Fisheries, 2022)(EUMOFA, 2021). The total exported rainbow trout value and quantity fell by 13% and 12.2%, respectively, from 2019 to 2020 (DAS/SPA, 2020).

Table 2. Export value "Valor" (USD 1000) and quantity "Cantidad" (tons) for frozen Chilean aquaculture products through December 2019 and 2020. Data from Subpesca (2020).

País/Ítem	Valor Miles US$		Cantidad Toneladas	
	2019	2020	2019	2020
Japón	1.172.964	1.101.707	151.499	176.482
Estados Unidos	610.196	596.360	60.996	66.203
Rusia	398.357	336.437	68.513	69.662
China	205.280	135.761	35.632	24.850
España	118.551	126.218	28.440	32.159
México	102.196	91.772	11.273	12.005
Tailandia	86.843	78.952	15.588	18.461
Taiwán	63.688	73.331	10.885	18.555
Corea del Sur	73.990	73.128	19.629	23.524
Otros	866.986	803.646	303.944	321.562
Total	3.699.053	3.417.313	706.398	763.463

Table 3. Export value (USD 1000) and quantity (tons) for fresh Chilean aquaculture products through December 2019 and 2020. Data from Subpesca (2020).

País / Ítem	Valor FOB (miles US$)		Cantidad (toneladas)	
	2015	2016	2015	2016
Estados Unidos	756.193	884.147	98.624	93.025
Brasil	377.880	397.802	74.089	61.042
China	31.872	87.429	6.152	12.308
Argentina	39.479	44.011	7.218	6.662
México	10.248	11.505	1.287	1.223
Colombia	10.120	10.975	1.391	1.241
Uruguay	3.426	3.919	404	421
Perú	2.108	2.861	342	362
España	1.850	2.533	230	285
Otros	5.484	7.023	762	859
Total	1.238.660	1.452.206	190.499	177.427

Figure 9 shows the division of export value by species, indicating that rainbow trout's export value was USD 412 million in 2020, compared to approximately USD 3,275 million for Atlantic salmon. Rainbow trout is the third most significant salmonid export, by value, from Chile.

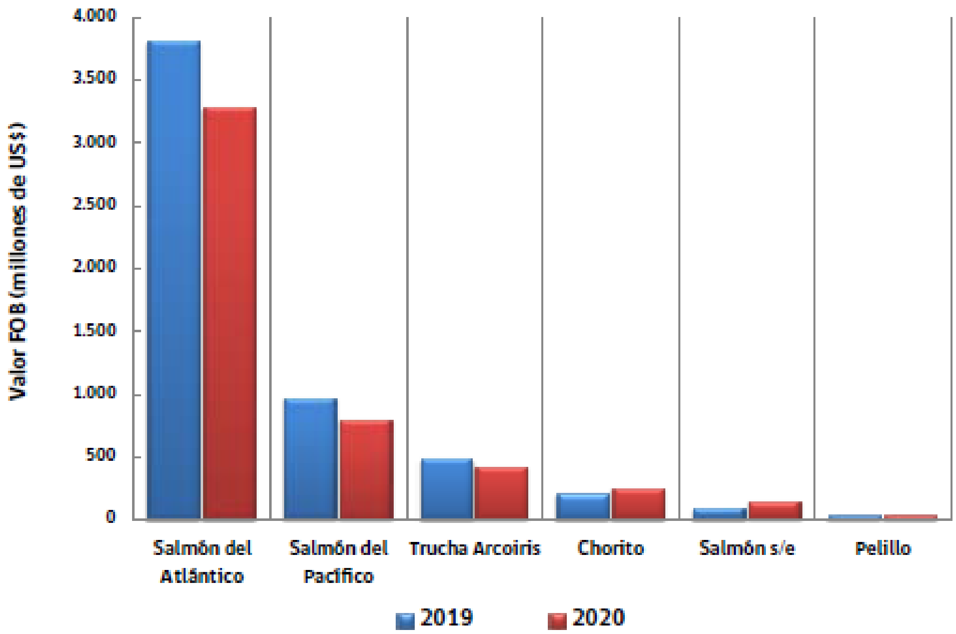

Figure 9. Value of exports of salmonids from Chile in 2019 and 2020, subdivided into species (DAS/SPA, 2020). Relevant translations: Salmon del Atlántico (Atlantic salmon); Trucha arcoiris (rainbow trout); salmon del Pacifico (Pacific salmon).

Common and Market Names

Table 4. Rainbow trout names.

Scientific Name	*Oncorhynchus mykiss*
Common Name	Rainbow trout, steelhead
Spanish	Trucha arcoiris
French	Truite arcenciel
Japanese	虹鱒 (Torauto)

Product Forms

As shown in Table 5, rainbow trout takes the following product forms (percentages based on quantity exported in 2019, in mt):

- Frozen (88.8%)
- Fresh (9.6%)
- Smoked (1.5%)
- Canned (0.03%)

Table 5: Export value (USD 1000) and quantity (mt) for the different product forms of rainbow trout in Chile between 2016 and 2019 (FAO, 2021).

Rainbow Trout Exports in Chile								
	2016		2017		2018		2019	
Commodity	**Value**	**Quantity**	**Value**	**Quantity**	**Value**	**Quantity**	**Value**	**Quantity**
Fresh	34,880	3,525	53,495	4,336	55,495	4,877	52,116	5,093
Frozen	351,066	44,287	395,062	37,820	358,408	39,507	402,924	46,667
Smoked	19,344	1,249	18,788	1,019	14,693	752	15,757	803
Canned	7	3	113	5	266	13	318	15
Total	405,297	49,064	467,458	43,180	428,862	45,149	471,114	52,578

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

Rainbow trout in all regions

C1 Data Category	Data Quality
Production	10
Management	7.5
Effluent	7.5
Habitat	5.0
Chemical Use	7.5
Feed	2.5
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)	**6.591**
Final Ranking	Yellow

Brief Summary

Data collection and availability, particularly from the government, have improved in Chile, but the access and availability from outside Chile continue to lag behind other major salmonid-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 stakeholder 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 concerning the latter, the limited number of companies means it must be used with caution as an indicator of Chile's average performance. There is generally a greater focus on Atlantic salmon in the data and studies in Chile compared to coho and trout. Still, there are sufficient similarities in the available data to be representative of the three species. The same score of 6.591 out of 10 is assigned to all regions for Criterion 1—Data.

Justification of Ranking

Although culture sites do not usually switch between species over multiple cycles (e.g., producing Atlantic salmon one cycle, rainbow trout the next), the general production system employed (marine net pen) is the same, and all three species produced in Chile may be produced simultaneously in a given area (Agrupación de Concesiones, ACS). Therefore, many of the diseases, culture methods, effluent characteristics, regulations, and other factors are common between the three species. Therefore, much of the information available for evaluation in this assessment relates to salmonid farming activities in general; in many areas, it does not differentiate between salmon and rainbow trout farming. Thus, significant sections of this report are reproduced from the Seafood Watch report on Atlantic and coho salmon aquaculture in Chile (Bridson, 2021).

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), companies, and 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[10] (undersecretary of fisheries and aquaculture) known as Subpesca and the Servicio Nacional de Pesca y Acuicultura[11] (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 salmonid farm site locations with details of basic company ownership and surface area,[12] as does Intesal[13] (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), such as the approved site attributes (e.g., authorized biomass density per cage). Export/import figures are available from Sernapesca, SalmonChile,[14] and the U.S. 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 10 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 bodies Consejo del Salmón and SalmonChile (and SalmonChile's technical organization Intesal[16]), which collectively represent

[10] Subpesca: http://www.subpesca.cl/institucional/602/w3-channel.html
[11] Sernapesca: http://www.sernapesca.cl/index.php.
[12] http://mapas.subpesca.cl/ideviewer/
[13] http://mapas.intesal.cl/publico/
[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

about 90% of the industry. 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] Because of 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.

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 (before 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 between species-specific sites) no longer appear to be publicly available. There is also a growing body of literature specific to Chile that 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; Tett et al., 2018). There is a substantial volume of information available from Sernapesca in terms of regulations, management, farm registration and environmental monitoring requirements, site locations, and the grouping of concessions. But, there is still a limited understanding of the potential cumulative effluent impacts of salmonid farming in Chile (e.g., waterbodies' carrying capacity), particularly while the industry continues to move into pristine habitats in Region XII in the far south of Chilean Patagonia (Soto et al., 2020)(Soto, 2022). Still, these knowledge limitations have been increasingly addressed, and the overall understanding of effluent impact continues to improve. Thus, 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. But, there is little specific data on the impacts of the infrastructure or its operation (besides the discharge of nutrient wastes addressed in Criterion 2—Effluent). McKindsey's (2011) review provides a useful list of potential impacts associated with the infrastructure. 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. These potential impacts have been poorly studied and are challenging 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

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

de Calificacion Ambiente, RCA) are available online in the SEIA database. With a limited understanding of the 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

Although SEPA collects detailed antimicrobial use data through the Aquaculture Inspection Information System (Sistema de Información para la Fiscalización de Acuicultura, SIFA[22]), only 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[23]) and from the first annual report[24] 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 that 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 it aggregates species (including coho, for which pesticides are not considered to be used). But, Sernapesca's representative provided a data set that broke down the antiparasitic treatments used by species from 2017 to 2020 for each aquaculture concession, after a data request was submitted directly to Sernapesca's platform SIAC (Sistema Integral de Informacion y Atencion Ciudadana). Collectively, these give a good impression of pesticide use in Chile. Like for antimicrobials, there is a large body of literature on the development of pesticide resistance, plus a similar surveillance program and annual report from IFOP (e.g., IFOP, 2020b), but again, there are limited data on specific impacts. Overall, there are 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 remain 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)

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

23 http://www.sernapesca.cl/sites/default/files/informe_sobre_el_uso_de_antimicrobianos_en_la_salmonicultura_nacional_-_primer_semestre_-_ano_2022_v20221026.pdf

24 https://www.csarp.cl/csarp-report

was obtained from the literature and from sustainability reports published by the three major feed companies (Biomar, Ewos-Cargill, and Skretting) (Aas et al., 2019; Skretting, 2020; Cargill, 2020; Ghamkhar and Hicks, 2020; Mowi, 2021; Naylor, 2021; Tacon et al. 2021; Biomar, 2021). Thus, a best-fit feed composition was created and 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 trout feeds, the global data for three major feed companies (Biomar, Ewos-Cargill, and Skretting) that report through the Ocean Disclosure Project were used.[25] The Global Feed Lifecycle Initiative (GFLI) database was used for the feed footprint calculations. Although enough data were gathered to create an approximation of the feed used to produce trout in Chile, there were substantial limitations in country-specific and species-specific information; therefore, the confidence level to evaluate this criterion is low to moderate. The data score for Feed is 2.5 out of 10.

Escapes

Sernapesca provides basic data on reported escape events and total numbers of escapes aggregated by region from 2010 to 2020.[26] The data are not separated by species, but a representative from the organization provided some species-specific information. 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 data sets. 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,[27] and a large body of recent literature details the impact of escaped and intentionally introduced rainbow trout in Chilean ecosystems (Arismendi et al. 2014)(Monzón-Argüello et al. 2014a/b)(Di Prinzio et al. 2013)(Garcia de Leaniz et al. 2013)(Figueroa-Munoz et al. 2021)(Marr et al. 2013)(Monzón-Argüello et al. 2013)(Sepulveda et al. 2013)(Arismendi et al. 2012)(Schröder and Garcia de Leaniz 2011)(Garcia de Leaniz et al. 2010). Chile's Fisheries Development Institute[28] (Instituto de Fomento Pesquero, IFOP) has conducted research fishing since 2010 for wild and feral fish in 29 zones of Chile (in lakes, estuaries, and the sea). Though IFOP research is primarily to monitor the presence of pathogens of concern in Chile, it also carries genetic analysis to determine the presence of wild rainbow trout versus farm escapees in the wild. Soto et al. (2022) performed a thorough environmental risk assessment looking at biodiversity impacts due to escapes of the three salmonid species, which helped further the understanding of these impacts while underscoring the knowledge gaps that need attention. Data gaps remain in understanding key information, such as the scale of escapees (e.g., trickle losses) and the impact of salmonid escapees on pristine regions in Chile, so the data score for Escapes is 5 out of 10.

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[25] https://oceandisclosureproject.org/
[26] http://www.sernapesca.cl/informacion-utilidad/escape-de-peces-de-la-salmonicultura
[27] https://centroincar.cl/
[28] http://biblioteca.ifop.cl/exlibris/aleph/u23_1/adam_objects/ifp01/view/4/000035225.pdf

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: Arriagada 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). 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 a high concern in salmonid farms (IFOP, 2019). Although these programs aim to detect and prevent the dissemination of pathogens and disease, there are some limitations to the scope of surveillance and the ability to sample moribund fish and/or detect unknown viruses (or viruses outside of the programs' surveillance scope). Research in other regions (e.g., the Strategic Salmon Health Initiative in British Columbia) highlights the potential presence of previously unknown pathogens on salmonid 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

There is a large body of literature and public information regarding domesticated broodstocks and selective breeding programs globally, inclusive of Chile (Janssen et al. 2015)(Cárcamo et al. 2015). Government data indicating the sourcing of imported rainbow trout eggs were well detailed (which applies to Criterion 10X as well). Therefore, the data score for Source of Stock is 10 out of 10.

Wildlife and Predator Mortalities

Regulations that confirm marine mammal mortalities must be reported to Sernapesca and 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 the 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."[29] Regulations on live fish movements and authorizations in Chile are also available from Sernapesca's website. The fish health certificate from the only approved egg importer (the Icelandic company Benchmark Genetics Iceland) and additional details are available on the company's website. Nevertheless, information on the movement of smolts between hatcheries and grow-out sites is unavailable. 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, have improved in Chile, but the access and availability from outside Chile continue to lag behind other major salmonid-producing countries, particularly for site-specific information. Many impact areas are ongoing areas of data collection and study, and published peer-reviewed papers are increasing, in addition to many stakeholder 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 concerning the latter, the limited number of companies means that the data must be used with caution as an indicator of Chile's average performance. There is generally a greater focus on Atlantic salmon in the data and studies in Chile than on coho and trout. Still, there are sufficient similarities in the available data to be representative of the three species. The same score is assigned to all regions for Criterion 1—Data of 6.591 out of 10.

[29] 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

Rainbow trout; Regions X, XI

Effluent Evidence-Based Assessment

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

Rainbow trout; Region XII

Effluent Evidence-Based Assessment

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

Brief Summary

Because of the open nature of net pen production systems, virtually all waste produced from an operation, including dissolved and particulate effluents, discharges directly to the surrounding environment with little or no intervention. In addition, some important gaps exist in understanding the carrying capacity of Chile's fjords and channels and the corresponding impact of nutrient discharge from salmonid sites cumulatively. But, 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 that substantial impacts in the water column from salmonid 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 the three salmonid species. The long-term data show that these results are all improving over time and, although still uncertain, the available research shows that the impacts are likely to be limited primarily to the immediate farm area. Nonetheless, more than half the sites in Region XII must undertake 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 water-body 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 anaerobic 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 water-body scale, and the final score for Criterion 2—Effluent for Regions X and XI 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 scale and likely the water-body scale. The final score for Criterion 2—Effluent in Region XII is 2 out of 10.

Justification of Ranking

The Effluent Criterion considers the 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. Thus, the Evidence-Based Assessment method in the Seafood Watch Aquaculture Standard has been used. Salmonids excrete both soluble and particulate wastes primarily due to incomplete digestion and absorption of their feeds. Hence, salmonid net-pen aquaculture represents a substantial release of nutrients and particulate matter into the environment where 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 salmonid industry's nutrient-related impacts is separated into the impacts of soluble effluents in the water column and into particulate wastes on the seabed. But, 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 return nutrients to the water column and/or result in resettlement in distant locations (Grefsrud et al., 2021a,b). Because of the similarities in production characteristics and data with which to assess production impacts, the assessment of this criterion applies to all salmonids produced in Chile.

There is a substantial body of literature on the fate and impact of nutrient wastes from net-pen fish farms, including salmonid farms, and key recent reviews such as Price et al. (2015) provide a useful summary. Price et al. (2015) conclude that modern operating conditions have minimized impacts of individual fish farms on marine water quality; effects on dissolved oxygen and turbidity have been largely eliminated through better management, and near-field nutrient enrichment of the water column is usually not detectable beyond 100 m of the farm (when formulated feeds are used, feed waste is minimized, and farms are properly sited in deep waters with flushing currents). But, 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 and how these can potentially lead to increased primary production, harmful algal blooms, eutrophication, and increased sea lion populations (Soto et al., 2020)(Price et al., 2015).

Soluble nutrients in the water column

The total nutrient discharges from the salmonid farms in Chile appear large; for example, in Chile's Region XI alone, Niklitschek et al. (2013) estimated that the nutrient discharges from salmonid farms were equivalent to 12,300 mt of nitrogen (N) and 1,600 mt of phosphorous (P) in 2010. But, many studies in Chile and elsewhere indicate that the increases in nutrient concentration in the water column near salmonid farms can generally be considered minor in comparison to natural flows 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-Santosa 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 salmonid 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 salmonid farming. In Norway, Grefsrud et al. (2019) note that even in the densest farming areas, the on-site measurements of phytoplankton show "Very good" to "Good" environmental conditions at all monitoring stations, and the authors state with high confidence (due to the combination of their modeling 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 salmonid farm effluent, including changes to the natural nutrient ratios in salmonid farming areas (e.g., Soto, 2022; Iriarte et al., 2010, 2013; Rebolledo et al., 2011), and the effects on the microbial communities, food webs, and algal bloom events (e.g., Soto et al., 2020; Navarro et al., 2008; 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 salmonid 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. Olsen et al. (2017) suggested that 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.

Although some uncertainty and a potential for localized impacts in some areas remain (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 salmonid farms to generally have less of an impact than the benthic impacts of particulate effluents.

Particulate effluents on the seabed

Where feces and uneaten feed settle on the seabed is 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 salmonid 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 quite rich and diverse and of high ecological value (Quiroga et al., 2013). They have been shown to possess a unique benthic fauna that comprises 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 (2005) found two to five times 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. Although this study is somewhat dated and production practices in Chile have substantially improved since the early 2000s, offshore aquaculture still increases nutrient input to the adjacent water body (50 kg of nitrogen for each harvested ton of Chilean salmonid—Soto, 2022), and it is an additional anthropogenic factor to consider when assessing environmental impacts. Kowalewski (2011) documented a catastrophic decline in local benthic productivity triggered by salmonid 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.

Similar to 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.[30] The specific monitoring requirements and methodologies for the INFA are laid out in Resolution No. 3612 (2009). For salmonid farms, monitoring must take place every cycle, 2 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 at 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 at greater than 60 m depth, the requirements are limited to dissolved oxygen, temperature, and salinity. Sernapesca's data from 2012 to 2019 show that the presence of bacterial mats is the dominant factor used to determine the aerobic status of sites, accounting for 39%, 55%, and 34% in Regions X, XI, and XII, respectively, of all the determining factors considered by INFAs. Benthic oxygen levels and redox make up the majority of the remaining determinations in each region.

Figure 10 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. Though an aerobic INFA result suggests a healthy environmental condition (in proximity to the ACS), it does not indicate that the organic matter and nutrients released by the farms have disappeared, and there are no guarantees that it has not simply moved to another place and is contributing to cumulative effects (Soto, 2022).

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

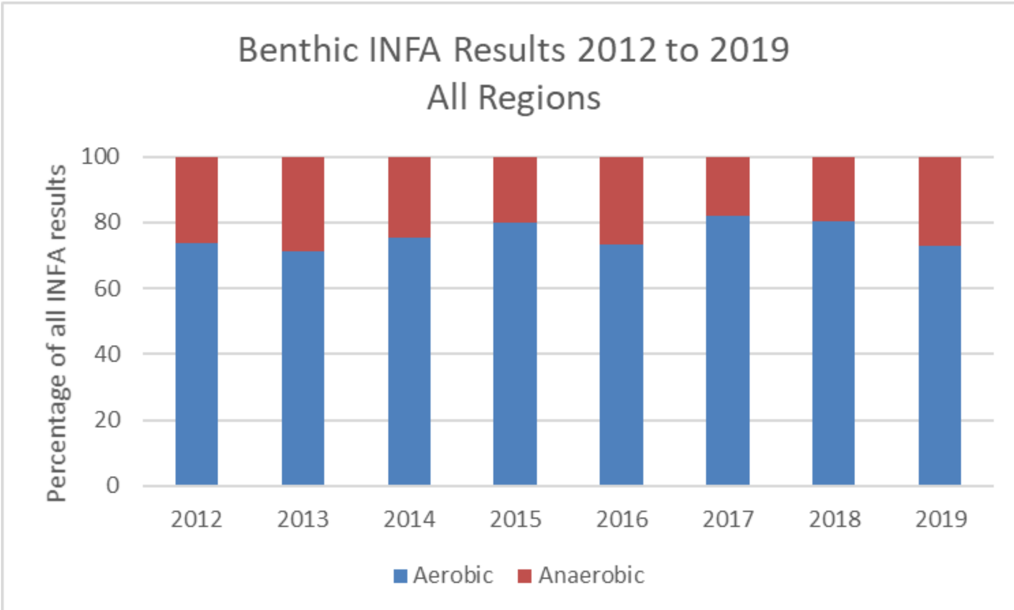

Figure 10. Annual average percent of Chilean salmon farms achieving "Aerobic" status in INFA assessments. Data from Sernapesca.

With regard to species, Sernapesca published separate site-level data from 2016 to 2018 for Atlantic salmon, coho, and trout, which show similar results. The percentage of aerobic coho sites was 4.7% higher than Atlantic salmon sites and only 2.1% higher than rainbow trout sites. It is worth noting that, during this period, no rainbow trout sites in Region XII were classified as anaerobic. But, after 2018, a considerable number of active sites for rainbow trout were relocated to aquaculture concessions in Region XII that had not produced trout in the past (i.e., ACS 47A, 51, and 52). The similar INFA results between species in the other two regions, the shifting of active sites in Region XII, and the lack of species-specific information after 2018 make it challenging to determine species-specific regional differences. As a result, the three species are deemed similar and the INFA results are considered representative of all salmonid species.

In contrast, the INFA results vary considerably by region. Figure 11 shows that the annual percentage of aerobic INFA results is consistently high in Region X and progressively lower in Regions XI and XII. In 2020, all aerobic INFA results in Regions X, XI, and XII were 84.0%, 59.6%, and 47.3%, respectively. The average values over the 2012 to 2020 period show 87% and 69.5% of INFA results were aerobic in Regions X and XI, respectively, but less than half (49%) were aerobic in Region XII. The simple trendlines in Figure 11 show that, despite poor results in 2020, the percentage of aerobic sites increases 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 reasons for these regional differences are not clear; although 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,[31] Sernapesca noted that some sites in Region XII are located in deep areas with poor water circulation, such as the Puerto Natales sector, which causes the dissolved oxygen content of deep waters to decrease to below-standard values.

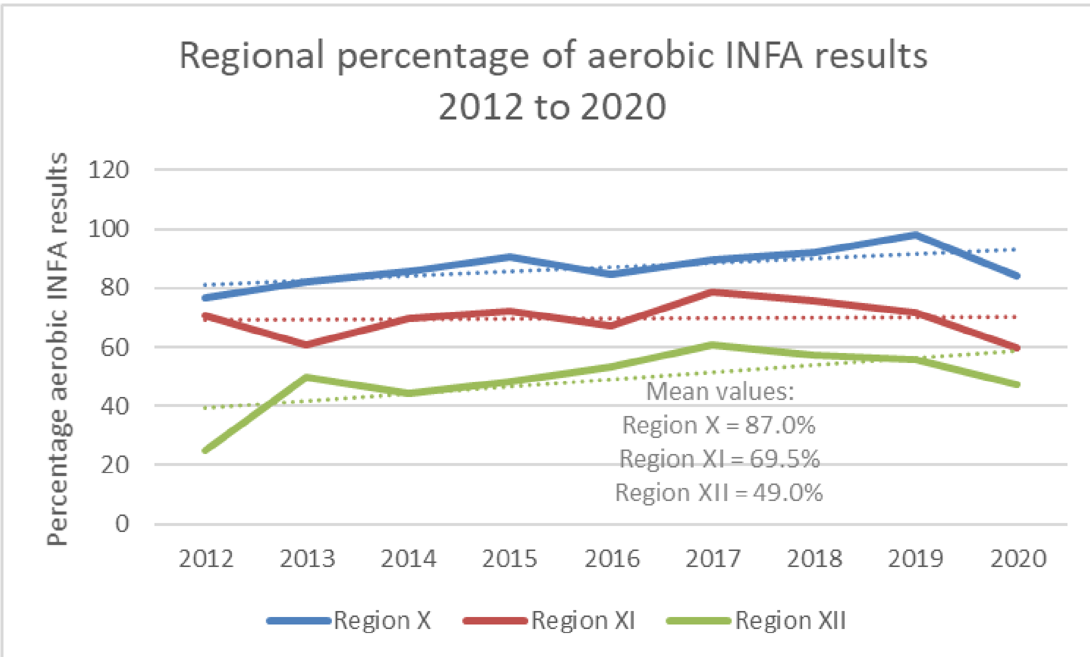

Figure 11. Percentage of all INFA results by region that were aerobic from 2012 to 2020. Dotted lines for each region show simple trendlines fitted by Excel. Data from Sernapesca.

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 3-month fallow period, or longer if necessary). Anaerobic INFA reports, particularly when repetitive, lead to reduced biomass permissions and also affect the stocking of the ACS as a whole.

Although a return to aerobic status does not imply a full recovery, benthic impacts of this nature are considered to be relatively rapidly reversed with the cessation of production or with fallowing (Keeley et al., 2015). The INFA data from Sernapesca show that recovery times between an anaerobic sample and subsequent aerobic sample vary 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

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

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 water body 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 2 in the Introduction, or Figure 18 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 after the ISA virus crisis; Alvial, 2012; Soto, 2020).

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 that 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 that the primary productivity dynamics varied 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 time scale.
- 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 (described above) regarding the impacts of organic wastes (Quiñones et al., 2019). Because many of the studies referred to above (or reviewed by Quiñones et al., 2019) occurred before 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 a number of Appropriate Areas for Aquaculture in Region XII, based on the identification of High Conservation Value Areas using 39 conservation features (Figure 8). 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 salmonid 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.). But, production appears to be increasing more rapidly, and annual harvests in Region XII (including trout) more than doubled from 2018 to 2020 (noting that the simple linear regression in Figure 5 shows a steeper increase, with production nearly doubling each year [$\times$ 0.94] over the same three years). The industry is therefore expanding in regions where the potential impacts of effluent at the site and water-body scale are not fully understood.

Conclusions and Final Score

Because of the open nature of net pen production systems, virtually all waste produced from an operation, including dissolved and particulate effluents, discharges directly to the surrounding environment with little or no intervention. In addition, some important gaps exist in understanding the carrying capacity of Chile's fjords and channels and the corresponding impact of nutrient discharge from salmonid sites cumulatively. But, 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 that substantial impacts in the water column from salmonid farm effluents are unlikely. Time series data 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 the three salmonid species. The long-term data show that these results are all improving over time and, although still uncertain, the available research shows that the impacts are likely to be limited primarily to the immediate farm area. Nonetheless, more than half the sites in Region XII must undertake 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 water-body 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 anaerobic 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 water-body scale, and the final score for Criterion 2—Effluent for Region X and XI 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 scale and likely the water-body scale. The final score for Criterion 2—Effluent in Region XII is 2 out of 10.

Criterion 3: Habitat

Impact, unit of sustainability and principle

- Impact: Aquaculture farms can be located in a wide variety of aquatic and terrestrial habitat types and have greatly varying levels of impact to both pristine and previously modified habitats and to the critical "ecosystem services" they provide.
- 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

Rainbow trout in all regions

C3 Habitat parameters	Value	Score
F3.1 Habitat conversion and function (0–10)		8
F3.2a Content of habitat regulations (0–5)	2	
F3.2b Enforcement of habitat regulations (0–5)	4	
F3.2 Regulatory or management effectiveness score (0–10)		3.2
C3 Habitat Final Score (0–10)		**6.4**
Critical?	No	Yellow

Brief Summary

Salmonid 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 salmonid farm contains 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 nonnative species and/or pathogens and parasites. Salmonid farms also attract a variety of wild animals as fish aggregation devices or artificial reefs, or repel other wild animals through disturbances such as noise, lights, or increased boat traffic. Because of 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 whale. Changes in the 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). But, 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 affect 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 maintain 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 industry's ongoing expansion into largely pristine habitats in Region XII is of particular concern, which raises questions about the content of management measures. The scores for Factor 3.1 (8 out of 10) and Factor 3.2 (3.2 out of 10) combine to result in a final Criterion 3—Habitat score of 6.4 out of 10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations). This score applies to all regions.

Justification of Rating

Note that the operational impacts to benthic habitats beneath salmonid farms resulting from settling particulate wastes are addressed in Criterion 2—Effluent. In Chile, trout is farmed in production systems where the same technology is used independently of the species under cultivation. Consequently, this section was reproduced almost in its entirety from the Atlantic and coho salmon report.

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 among those with the highest conservation priority worldwide because of 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 a clear demonstration that they are quite rich, diverse, and of high ecological value (Quiroga et al., 2013). They have been shown to possess a unique benthic fauna that comprises 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 because of their land-ocean exchange of energy and matter (Elizondo-Patrone et al., 2015, and references therein). These ecosystems provide important services to humans that, according to Iriarte et al. (2010), have not been adequately measured and valued, and as a consequence, fjords' ecosystem services are commonly ignored in public policy design and in the evaluation of development projects.

The location, size, and company information of every salmonid farm concession is available in the mapped database of Subpesca.[32] Options for the database map layering allow the concessions to be overlaid on satellite images (examples shown in Figures 12 and 13), from which it is apparent that the floating net pen containment system does not result in any gross

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

functional conversion of surface habitats compared to (for example) the construction of ponds—but that is not to say there are no habitat impacts.

Figure 12. Location of salmonid 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 13. Screenshot from Subpesca's Map Viewer database.

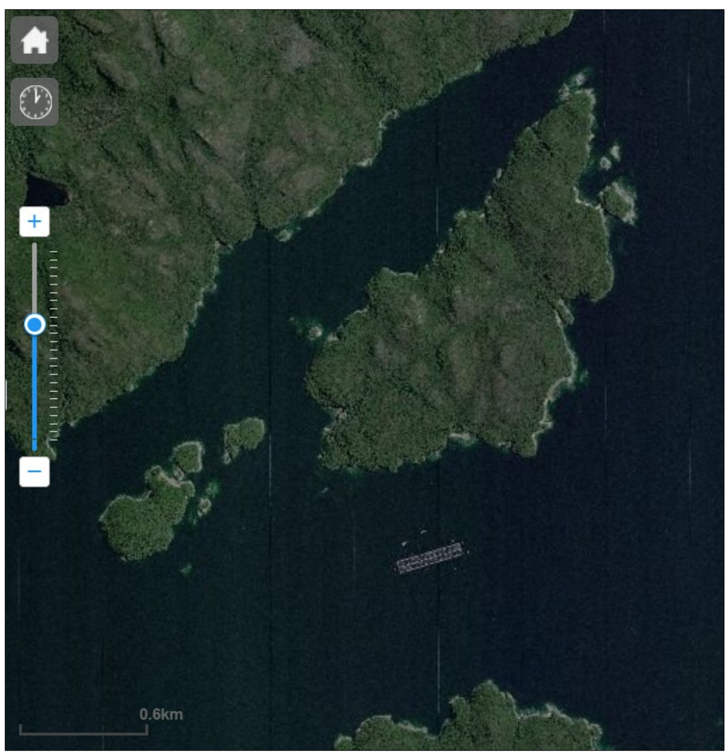

Figure 13. Closer image of the white square in Figure 12, showing that one of the two concessions in the area had net pens in position. Screenshot from Subpesca's Map Viewer database.

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 developing rich biotic assemblages that may further increase the complexity of the habitat (McKindsey, 2011). An average salmon farm (using a Norwegian example) contains 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 14 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 the southeast end of the net pen array in this example) shows the extent of the physical structures.

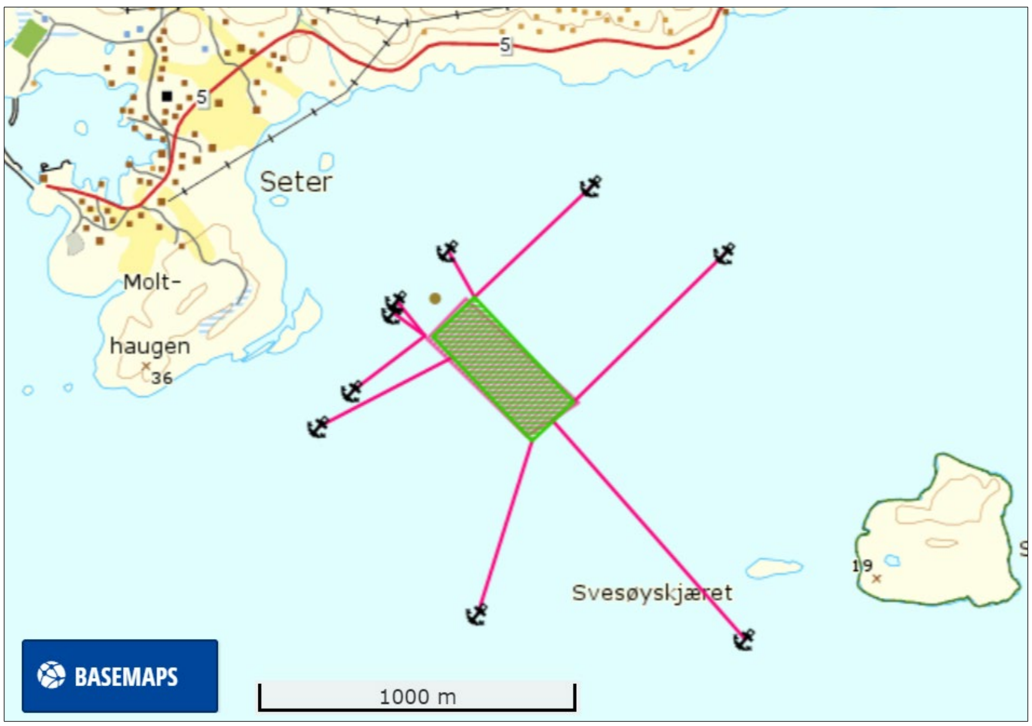

Figure 14. Illustration of the anchoring array of a Norwegian salmon farm (selected at random). Image copied from the Directorate of Fisheries' mapped database (https://kart.fiskeridir.no/)

McKindsey (2011) provided a detailed review of "Aquaculture-related physical alterations of habitat structure as ecosystem stressors,"[33] 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

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

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 that an overriding issue in all discussions of these potential stressors is that most proposed effects from 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 noticeable impacts may be due, at least in part, to this factor. McKindsey also noted that the effects related to the addition or modification of physical structure are not well studied, most effects have not been quantified, and the discussion of effects in the scientific literature is largely based on extrapolations from other systems. Noting the publication date of 2011, McKindsey also noted that major recent reviews on aquaculture-environment interactions (at that time) did not discuss the implications of these structures or did so only in a limited way.

A search for relevant literature since 2011 adds additional potential impacts; for example, the Canadian Department of Fisheries and Oceans (DFO, in a 2017 information webpage on the Alteration of Habitats[34]) also notes that the use of underwater lights may influence the behavior of wild fish by attracting them to (or causing them to avoid) farm sites. It also notes that the lights do not penetrate more than a few meters beyond marine nets, suggesting that their use has a minimal effect on the surrounding environment. Floerl et al. (2016) note that a large number of fish (and mussel) farms in North America, Europe, and New Zealand support extensive populations of biofouling invasive species, and the on-site cleaning of fouled net pens may inadvertently support the persistence and distribution of such species within aquaculture regions by the localized dispersal of nonindigenous 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) could 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 on 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

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

(e.g., increased boat activity and cleaning). Callier et al. noted that 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 noted that salmon farms attract large amounts of wild fish, which consume uneaten feed pellets. For specific examples, Otterå et al. (2014) and Skilbrei et al. (2016) note that saithe (*Pollachius virens*) is by far the most numerous fish visitor to fish farms on the Norwegian coast and shows evidence of establishing core residence areas close to fish farms, such that the aquaculture industry is influencing the local saithe distribution. Again, Otterå et al. (2014) conclude that large-scale population effects are difficult to prove, but note that 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 noted that 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, thus influencing the local fisheries (although they noted that the changes in flesh quality were small).

Regarding the 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, by 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. But, 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.

Although 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 that aquaculture operations might negatively affect the movement, distribution, and behavioral patterns of Chilean dolphin (*Cephalorhynchus eutropia*), a local species listed on the International Union for the Conservation of Nature (IUCN) Red List as "Near Threatened" with a decreasing population trend.[35] Viddi et al. (2015) noted that the preference for coastal, shallow waters and river-influenced habitats by Chilean dolphin puts it in direct conflict with a growing aquaculture

[35] 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.

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 (including 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 (MPA) within the Corcovado Gulf, an area identified as a high-value conservation area by WWF[36] (pers. comm., Intesal, 2017). Nonetheless, a recent publication by WWF Chile (2022) indicates that 191 approved farm concessions are within MPAs across Chile, and while SERNAPESCA is no longer accepting requests for new farm sites, 53 additional concessions are already waiting for approval to operate within MPAs. It is also worth noting that 46 out of these 53 concessions would operate within MPAs in Region XII. In addition, WWF asserts that there is excessive flexibility from the Ministry of the Environment (*Ministerio del Medio Ambiente*) to accepting environmental impact assessments (EIAs) when farms request modifications or new concessions, which has resulted in negative consequences in the past. WWF (2022) explains that salmon farming is incompatible with the conservation objectives pursued by MPAs, which are officially established to maintain the ecosystem's biodiversity. WWF states that farm concessions overlap with feeding, reproductive, and migration areas of marine mammals and birds, causing negative interactions (e.g., entanglements, collisions, noise pollution), which is an example of their incompatibility (WWF, 2022). Overall, WWF suggests that the current management system is not adequately accounting for the risk of impacts when authorizing farms to operate in these protected areas.

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-Gaete et 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) modeled the predicted overlap between vessel traffic and blue whale habitat use in the NCP. Although 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 of other industries (artisanal fishery, industrial fishery, and transportation), the modeled probability of a vessel encountering a blue whale was the 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 salmonid industry and the number of its vessels operating in the study area do present some concern for seasonal whale disturbance. Sernapesca has information sheets[37] for many aquatic

[36] https://wwf.panda.org/?216893/Blue-whale-conservation-gets-a-boost
[37] http://www.sernapesca.cl/informacion-utilidad/fichas-de-especies-protegidas-urcep

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 gillnets to 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. But overall, the floating net pen salmon farm containment system is unusual among 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. Thus, the habitats are considered to be maintaining functionality with minor to 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)[38] 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.[39] 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 (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.[40]

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 quite 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 before the ACS system. As described in this report's

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

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

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

Introduction (Production System), the ACS system divides the farming regions into groups of farm sites (each site called a concession) sharing a similar water body, 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 impacts described in Factor 3.1 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 precise estimations of the carrying capacity of the fjord systems for aquaculture activities and the possible impacts of changes in the carrying capacity on ecosystems services are major scientific challenges 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). Though 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 regarding 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 for the defined "appropriate areas for aquaculture," but the potential for unforeseen challenges remains (for example, see Criterion 2—Effluent).

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 are required for new sites). But, these systems do not account for potential cumulative habitat impacts described in Factor 3.1 (e.g., habitat conversion and functionality) associated with the combined expansion of aquaculture infrastructure at the scale of the industry in all regions. In addition, the management system does not prevent the siting of farms within MPAs (as is the case in Regions X and XI), and there are no precedents indicating that it will be different in Region XII, where 43 concessions within MPAs are waiting for approval. Considering the uncertainties in carrying capacities and in the scale of the impacts described in Factor 3.1, the score for Factor 3.2a is 2 out of 5 for all regions.

Factor 3.2b: Enforcement of habitat management measures

It is clear that there is substantial enforcement of the aquaculture regulations in Chile, and regarding 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 management and ACS-level management can be seen through Sernapesca and readily available monitoring results, such as the INFAs.

GSI provides data on environmental noncompliance and shows that most of the eight companies represented have had one or more fines for noncompliance with environmental regulations. This further indicates that enforcement is active to some extent, although it is not known if these extend to noncompliance related to farm infrastructure and habitat impacts.

Overall, the enforcement organizations are identifiable and active in all regions, but concerning the potential impacts outlined in Factor 3.1, the activities are perhaps limited in their effectiveness and/or have some gaps in transparency, particularly in relation to any potential cumulative impacts. The enforcement of the site licensing process is robust, but there is concern about its effectiveness when it allows the industry to expand to high-value conservation areas, where fundamental factors such as carrying capacity are still not well understood. Therefore, the score for Factor 3.2b—Enforcement of habitat management measures is 4 out of 5 for all regions.

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 3.2 out of 10 for all regions.

Conclusions and Final Score

Salmonid 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 contains 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 nonnative species and/or pathogens and parasites. Salmonid farms also attract a variety of wild animals as fish aggregation devices or artificial reefs; or repel other wild animals through disturbances such as noise, lights, or increased boat traffic. Because of 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 whale. Changes in the 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). But, 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 affect 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 maintain 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 is managed, including from a cumulative perspective. The industry's ongoing expansion into largely pristine habitats in Region XII is of particular concern, which raises questions about the content of management measures. The scores for Factor 3.1 (8 out of 10) and Factor 3.2 (3.2 out of 10) combine to result in a final Criterion 3—Habitat score of 6.4 out of 10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations). This score applies to all regions.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

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

Criterion 4 Summary

Rainbow trout; Regions X, XI

C4 Chemical Use Final Score (0–10)	**2**	Red

Rainbow trout; Region XII

C4 Chemical Use Score (0–10)	**6**	Yellow

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. The total Chilean antimicrobial use on salmonid farms declined from 2015 to 2018 but has since increased through 2021. The average country-level use reported by Sernapesca of 350 g/mt hides considerable variability by production region in total and relative terms; for example, the relative use on rainbow trout in Regions X, XI, and XII in 2020 was calculated to be 138 g/mt, 142 g/mt, and 25 g/mt, respectively. Rainbow trout's approximated treatment frequency per site in Region X and XI was 0.8 per production cycle, and 0.15 per production cycle in Region XII.

Almost all antimicrobial use (96.8% by weight in 2020) is currently of florfenicol to treat piscirickettsiosis (or salmonid rickettsial syndrome, SRS), although oxytetracycline has been important until recently. The direct ecological impacts of antimicrobials to the receiving environments remain unclear, but of high general concern are the potential development of antimicrobial resistance (in the treated bacterial pathogen as well as in the surrounding nontarget 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 challenges, 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 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. But, the government's resistance surveillance program shows that approximately 50% of the isolates of *P. salmonis* tested in 2020 displayed reduced susceptibility to florfenicol (and approximately 17% to oxytetracycline) in in-vitro laboratory trials. Values were low for other pathogens except for *Flavobacterium psychrophilum*, which showed that 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 salmonid farms (particularly Atlantic salmon farms) has resulted in bacterial populations evolving and adapting to the two most commonly used drugs.

Pesticide use for salmonids in Chile is also high (mainly driven by use on Atlantic salmon), although reports showed a substantial decrease from 2019 to 2020. Still, the overall high and fluctuating trend over time reflects the ongoing struggle to control parasitic sea lice. Over 8 mt of pesticide active ingredients were used in 2020, plus over 4,119 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. Rainbow trout production was only responsible for 3.6% and 2.6% of the total salmonid pesticide use in 2019 and 2020, respectively, and the relative pesticide use for rainbow trout (2.4–4.5 g/mt) is considerably lower than that of Atlantic salmon (8–10 g/mt). Despite this, the impact of these pharmaceuticals on the marine environment remains largely uncertain, particularly regarding repetitive treatments at a single site or coordinated treatments in a single water body. Widespread resistance has previously developed in Chile and is likely to recur with the repeated use of a limited number of available treatments.

Overall, there is no specific evidence indicating that antimicrobial use in Chilean salmonid farms has led to the development of clinical resistance (i.e., the loss of efficacy of treatments) for the primarily treated pathogens. It must also be noted that bacterial resistance genes in marine environments may have originated from human and terrestrial sources. Although the rainbow trout industry's use of antimicrobial treatments per site per year remains high when compared internationally, the trend since 2018 has been decreasing. Florfenicol is noted for its "floR" resistance gene associated with mobile elements (such as plasmids and transposons) and the potential contribution to the pool of resistant genes in the environment, and it remains a critical conservation concern in Chile. For rainbow trout, the average frequency of florfenicol (a highly important antimicrobial for human medicine) use between 2017 and 2020 was slightly higher than one treatment per site per year in Regions X and XI (1.17 and 1.27 treatments per year, respectively). Pesticide use is also significant (e.g., azamethiphos, emamectin benzoate), with multiple treatments per site per year in all regions where production takes place.

Therefore, with chemicals known to be used on multiple occasions each productive cycle (including significant use of highly important antimicrobials), plus a treatment method that allows their release into the environment, the final score for Criterion 4—Chemical use is 2 out of 10 for Regions X and XI. Based on a demonstrably lower need and lower frequency of antibiotic treatments used in Region XII (0.29 treatments per year), the final score for Criterion 4—Chemical use is 6 out of 10 for Region XII. It is noted here that, although 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, although 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. Though other types of chemicals may be used in salmon aquaculture (e.g., antifoulants, anesthetics), the risk of impact to the ecosystems that receive them is acknowledged to be less than that for antimicrobials and pesticides.

The primary chemicals of concern used in aquaculture are mainly divided into antibiotics and antiparasite treatments. The use of such chemicals in aquaculture is widespread in reducing the impacts of pathogens and parasites on production. In open systems, such as net pens, controlling the release of chemicals into the environment is virtually impossible. Antibiotics are typically administered orally through feed, and once they are in water, there is ample opportunity for active compounds to leach from feeds (Cabello et al. 2013). In addition, some antibiotics such as oxytetracycline are poorly absorbed by fish, and Cabello, Godfrey et al. (2013) estimate that up to 80% of applied treatments can pass through the fish into the environment, where they will accumulate under and around net pens or be carried to distant sites.

Regulations/Governance

In May 2021, Sernapesca established a program to surveil the susceptibility of pathogens to antimicrobials used in salmonid aquaculture (Programa Sanitario General de Vigilancia de la Suceptibilidad a Antimicrobianos en la Salmonicultura). This program authorizes Sernapesca to take the necessary measures in keeping track of the susceptibility of pathogens (mainly SRS), with the goal of maintaining the efficacy of the main antimicrobials used in the Chilean salmonid industry (Resolution number: DN - 00386/2021[41]). It also established the preliminary methods and guidelines to monitor the industry and to analyze the information generated through the process. In addition, governance programs (such as CSARP), public pressure, and

[41] http://www.sernapesca.cl/sites/default/files/res.ex.386-2021.pdf

voluntary industry practices have led to initiatives and commitments to reduce antimicrobial usage in the Chilean salmon industry.

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 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[42] (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, so 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 the proportion used per species, and when combined with the total annual harvest data, the simple relative use (in grams of active ingredient per mt of harvested salmon) per year can be calculated (Figure 15).

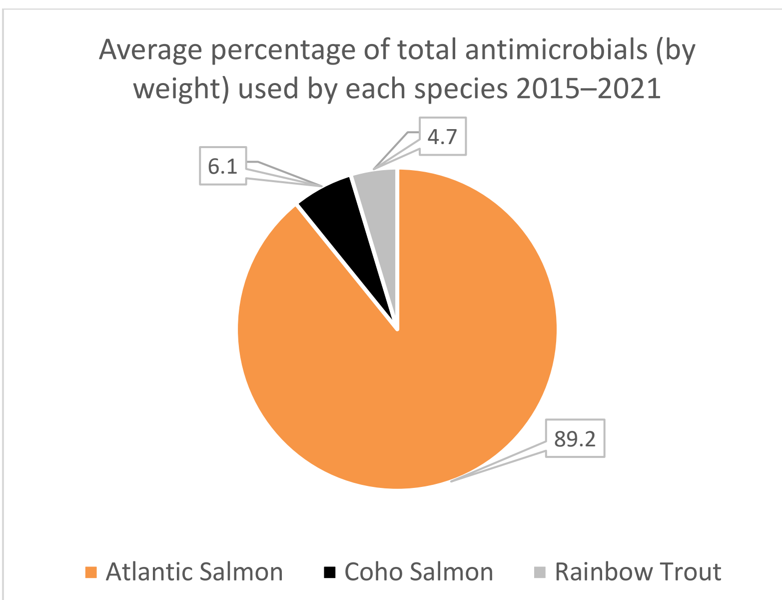

Figure 15. Proportion of antimicrobials used by each species as a percentage of the total use, averaged from 2015 to 2021. Data from Sernapesca.

[42] 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.

The total (mt) and relative (g/mt) antimicrobial use calculated for trout using Sernapesca data are plotted in Figure 16 and show an overall decreasing trend. From 2005 until 2015, the use of antibiotics for trout production ranged from 50 to 105 mt per year (338–708 g/ton), whereas from 2016 on, it went from 9 to 22 mt per year (133–278 g/ton). Rainbow trout was responsible for only 2.05% of the total antimicrobials used in 2021 for all salmonids, totaling 9.5 mt (compared to 19.6 mt in 2019 and 50.1 mt in 2015); the relative use was 167.7 g/mt (compared to 238 g/mt in 2019 and 468.2 g/mt in 2015). Note that these figures of relative use are averaged across the three production regions, which present considerable variation between them—see the regional analysis below.

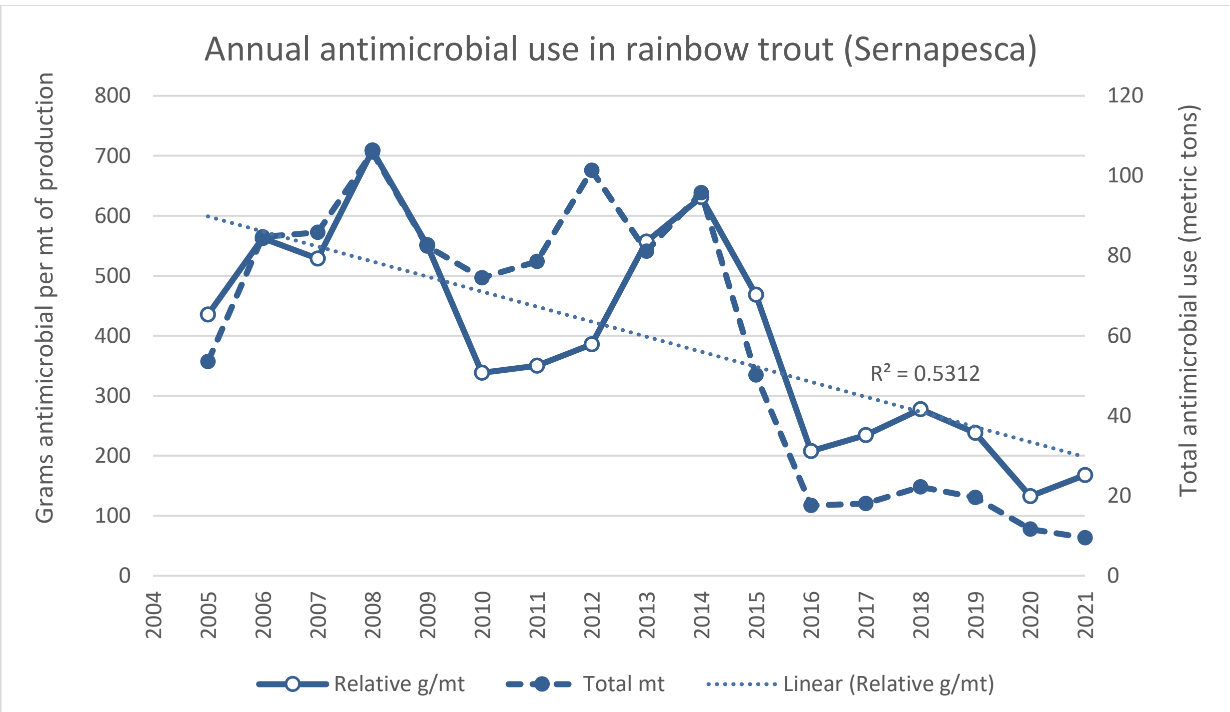

Figure 16. Solid blue line shows antimicrobial use in rainbow trout aquaculture in Chile in grams per ton of production (primary y-axis). The dashed blue line shows total antimicrobial use for rainbow trout in tons (secondary y-axis). A simple linear trendline (dotted blue line) was adjusted to relative g/mt. Data from Sernapesca.

The CSARP primarily recognizes that production cycles commonly span 1 or even 3 calendar years; therefore, a single batch of harvested fish, particularly Atlantic salmon with a 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, which represent 70% of the rainbow trout production in Chile and 100% of Atlantic and coho salmon production, are therefore more closely aligned because they relate directly to completed production cycles but will differ in any one year from Sernapesca figures. Even rainbow trout, which presents 1-year production cycles (11–13 months), still shows data differences between Sernapesca and CSARP. For instance, the relative antibiotic use during 2017–19 reported by Sernapesca for trout is 22.6% higher than what CSARP reports, on average. Most likely, such difference is because not all trout producers in Chile are affiliated with CSARP. In addition, because of the nature of the complete cycle indicators used by CSARP, it is to be expected that there would be a delay before these indicators show the annual increases shown in the Sernapesca data.

The 3-year data set from CSARP (plotted in Figure 17) shows that, for all salmonids, the relative antibiotic use declined during this period, dropping to 375.4 g/mt, 141.1 g/mt, and 38.5 g/mt in 2019 for Atlantic salmon, rainbow trout, and coho salmon, respectively. In the case of the total antibiotic use, the same decreasing trend for 2017–19 was observed in Atlantic salmon (263.5 mt) and coho salmon (7.9 mt), but not for rainbow trout, which shows a slight increase from 2018 at 11.0 mt to 2019 at 11.2 mt. These data also confirm that the antimicrobial use in coho salmon and rainbow trout production is substantially lower than in Atlantic salmon.

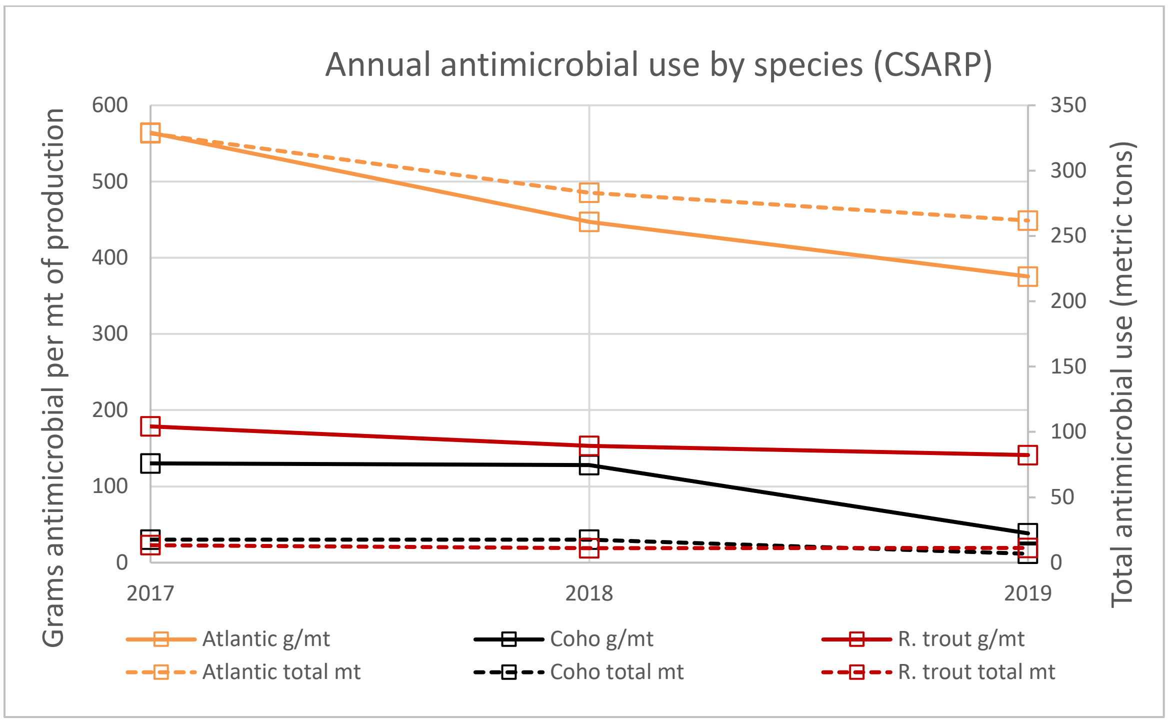

Figure 17. Solid lines show relative antimicrobial use in Atlantic (orange) and coho (black) salmon, and rainbow trout (red) aquaculture in Chile in grams per ton of production. Dashed lines show total antimicrobial use in metric tons for each species. Data from CSARP.

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[43] (and therefore, the amount used in each "treatment"), as well as changes in the use of different antimicrobials over time. But, florfenicol has remained the dominant antimicrobial used in the seawater phase of salmonid production in Chile for the past

[43] For example, oxytetracycline has a much larger treatment dose 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).

10 years (>95% of applied antimicrobials by weight), so variation in g/mt due to changes in antimicrobial used are negligible (Sernapesca, 2022).

At the country level, nearly all antimicrobial use in Chile (97.6%) occurs during the marine stage of production, out of which 92.2% of that marine use is to treat the bacterial pathogen *Piscirickettsia salmonis,* the causative agent of piscirickettsiosis (salmon rickettsial septicemia/syndrome, SRS), which, as for Atlantic salmon, also drives most of the trout disease mortality (67.3%; see Criterion 7) (Sernapesca, 2021b). Numerous vaccines for SRS are currently registered for use in Chile, but because the occurrence of SRS is influenced by multiple factors, there is little evidence of the vaccines' 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 (see also the regional variability information below).

<u>Regional antimicrobial use</u>

The total antimicrobial use by weight (in mt) is highly variable by region. Figure 18 from CSARP shows the 2017–19 use in each ACS relative to the national average for all species combined. This initially highlights the lower use in Region XII.

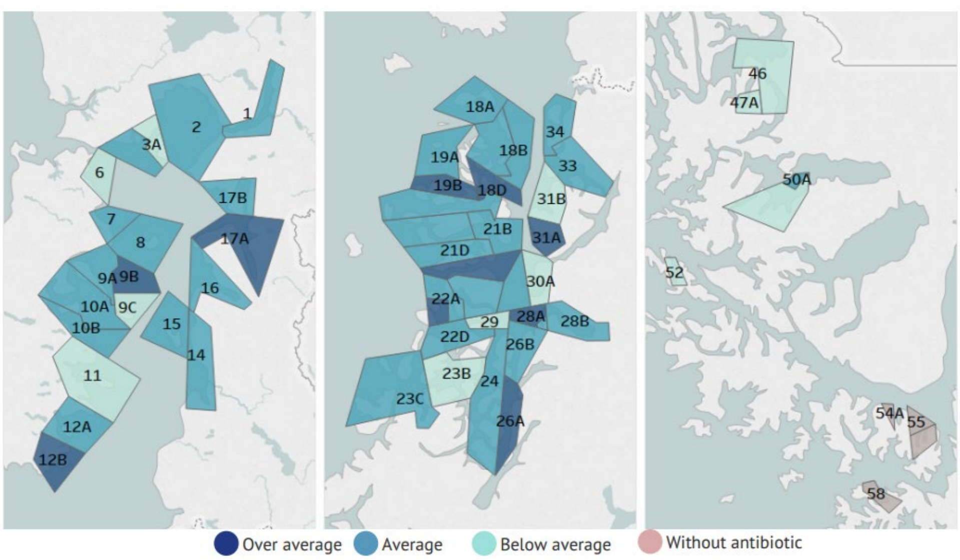

Figure 18. Antimicrobial use (combined for all salmonids) relative to the national average in each ACS neighborhood in Regions X, XI, and XII, using the same annual indicators as Sernapesca (2017–19). Alphanumeric codes indicate each ACS. Image copied from CSARP (2020).

Using Sernapesca data, Figure 19 shows the regional antimicrobial use by weight (combined use of all salmonids); for example, showing over 249 mt of antimicrobials used in Region XI in 2021 compared to 9 mt in Region XII. The total regional use is correlated with regional production (see Figure 5), but it is also affected by the mix of species produced and the bacterial disease characteristics of 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%); this differs substantially from Regions X and XII, which are dominated by treatments for *P. salmonis* (data provided by Asociación Salmonicultres de Magallanes, 2019).

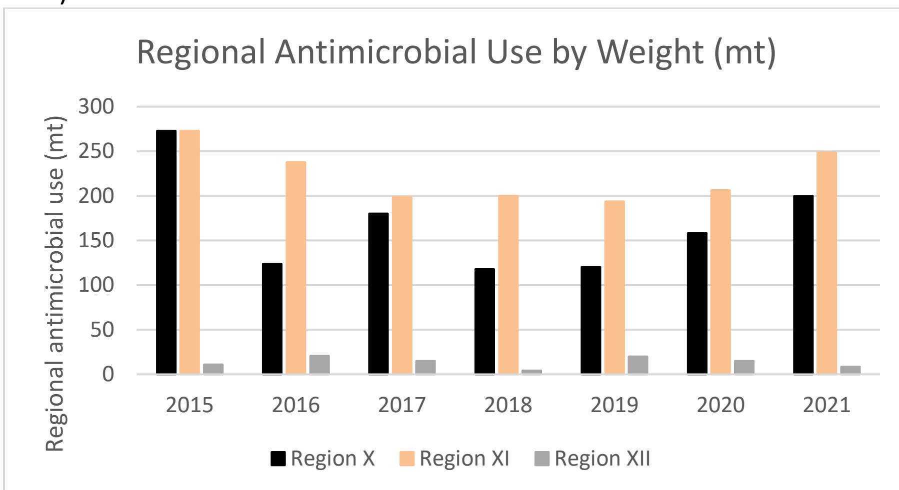

Figure 19. Regional antimicrobial use in Chile, combined for salmonids, from 2015 to 2021. Data from Sernapesca (2022).

Sernapesca also provides figures for the proportion of the annual total used by each species (2015 to 2021 average shown in Figure 20); for example, in 2021, 92.8% of the total antimicrobial use in Chile was for Atlantic salmon, 5.11% for coho, and 2.05% 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 20 shows the regional differences of the relative use of antimicrobials for rainbow trout from 2015 to 2021. The relative use in Region XII is substantially lower than in the other two regions; that is, for every 1 mt of rainbow trout produced in Region XII, there is less antimicrobial used compared to producing the same 1 mt of salmonids in either Region X or XI. These data (Figure 20) also indicate that the antimicrobial use for rainbow trout has not exceeded the levels of 2015. Yet, it remains highly variable because no region shows a clear trend during this period.

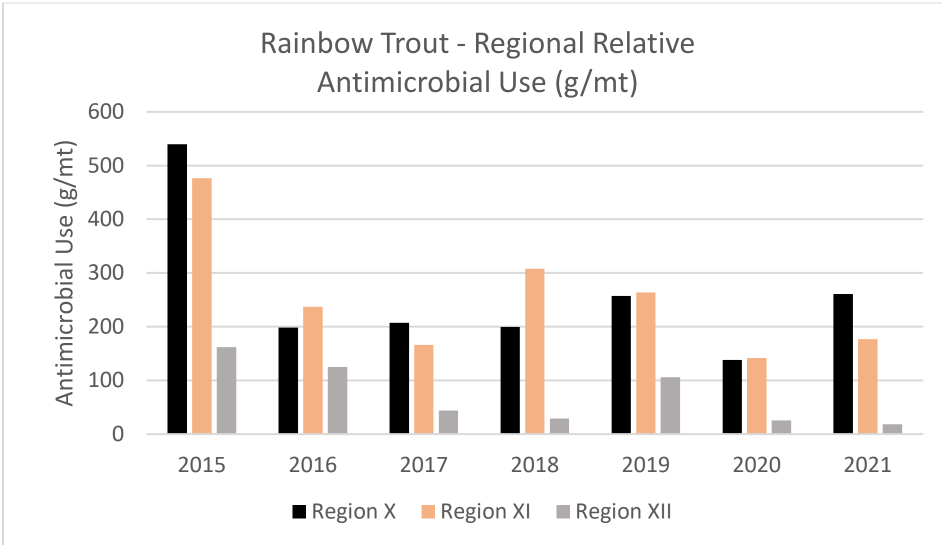

Figure 20. Regional relative antimicrobial use (in g/mt of production) for rainbow trout from 2015 to 2021. Values calculated from Sernapesca data.

Although Region X and Region XI share the first and second place with respect to the relative antimicrobial use during the period covered in Figure 20, further insight can be gathered when analyzing the relative use for the number of active sites producing trout in each region (Figure 21). For instance, Region XI shows the highest rate of relative antibiotic use per site in 4 of the 5 years assessed in Figure 21 because of the combination of the low number of sites and high antibiotic use levels. The antibiotic use per site in Region XI was more than double that of the other two regions in 2018 and 2019. Note that the antibiotic use per site of Region XII was higher than the two other regions in 2016 and higher than Region X in 2019, which seemed unlikely when the number of active sites was not considered, as shown in Figure 20.

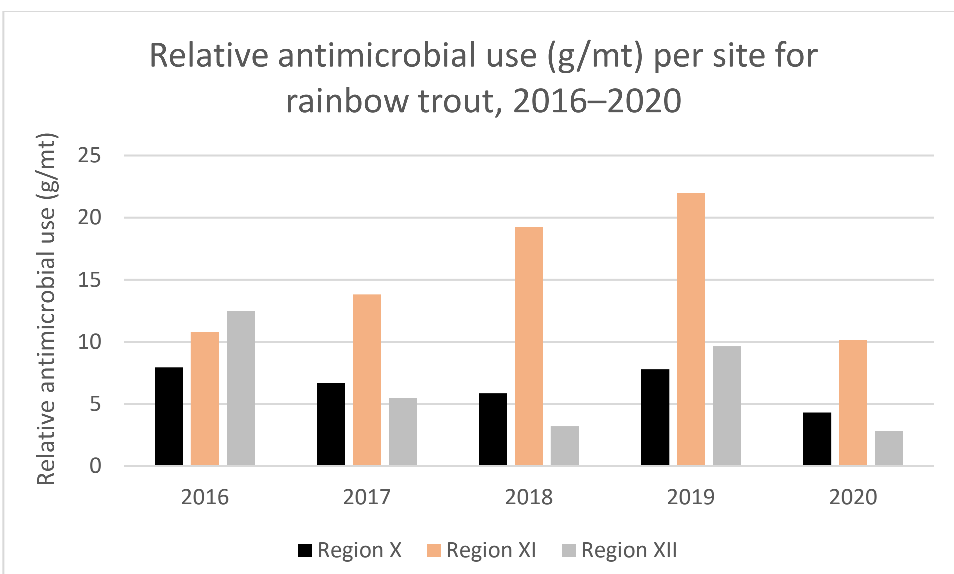

Figure 21. Relative antimicrobial use (in g/mt of production) per site for rainbow trout from 2015 to 2021, across regions. Values calculated from Sernapesca data.

In 2016, Sernapesca initiated a program to establish antimicrobials limits (as shown in Table 6) and recognize sites that do not exceed the limits during a production cycle. 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.[44]

Table 6. PROA Salmon maximum number of oral treatments and maximum weight (kg) per production cycle per site.

Species	Maximum number of oral treatments	Maximum weight (kg) of active ingredient
Atlantic salmon	2	1,200
Coho salmon	1	600
Rainbow trout	1	600

Since 2016, 236 sites have been certified by PROA Salmon. From the 58 total certified sites by PROA Salmon in 2021 (Figure 22), 45% were in Region X, 21% in Region XI, and 19% in Region XII. By species, 60% of the certified sites produced coho salmon, 29% Atlantic salmon, and 10% trout.

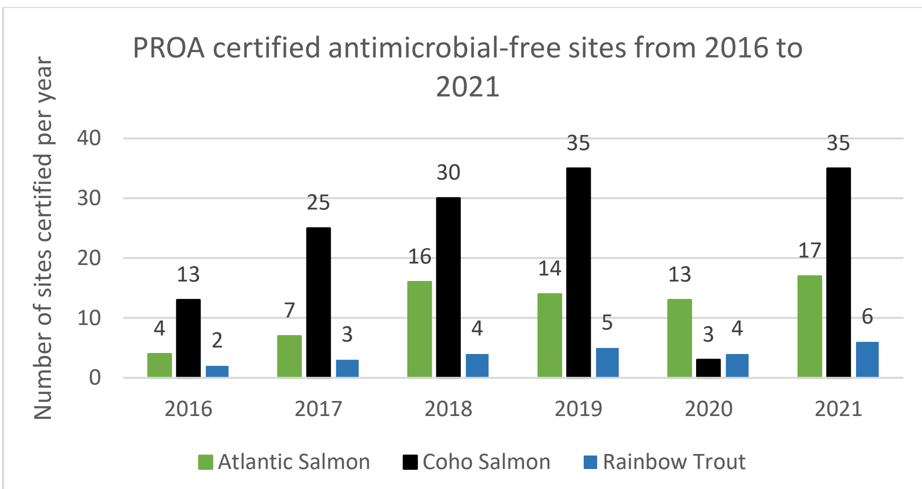

Figure 22: Number of sites certified as antimicrobial-free by the PROA each year from 2016 to 2021 by species. Data from Sernapesca.

Looking within each species revealed that, on average since 2016, 21% of coho salmon active sites were certified by PROA Salmon each year, while only 7% of rainbow trout sites and 3% of Atlantic salmon sites, respectively, were certified each year. In 2021, over 10% of active rainbow trout sites were certified, representing the highest number of certified trout sites over the 2016–21 period. This is detailed in Table 7.

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

Table 7. Proportion of PROA sites from total active sites per species (%), 2016–2021. Data from Sernapesca, 2021 and 2022.

Year	Atlantic salmon	Coho salmon	Rainbow trout
2016	1.20	16.25	3.23
2017	2.04	27.47	5.26
2018	4.46	27.52	6.06
2019	3.22	27.13	7.94
2020	2.93	1.99	6.90
2021	4.07	23.97	10.34

These data also reflect the discussion above regarding the antimicrobial use for each species and reflect the evolution of the program since 2016. The stagnant number of trout sites certified since 2016 may reflect a practical limit on the number of potential sites that can achieve the antimicrobial-free status.

International comparison

Antimicrobial use in Chile has typically been quite high in comparison to other salmonid farming countries globally; in 2020, the average use was 0.17 g/mt in Norway,[45] and in 2019 was 10.94 g/mt in Scotland[46] and 94.0 g/mt in British Columbia,[47] compared to the Chilean use of 444.0 g/mt for Atlantic salmon, 132 g/mt for trout, and 92 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 (e.g., 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 rainbow trout in Chile is 780 times higher than the country's average in Norway.

Frequency of antimicrobial use

CSARP reports the 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 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 23) are averaged over all three regions and show declines in antimicrobial use for

[45] Data from Sommerset et al. (2021)
[46] From a freedom of information request from the Scottish Environmental Protection Agency. Because of a data hack of SEPA, recent requests for updated data have not been addressed.
[47] From the Department of Fisheries and Oceans, Canada.

Atlantic and coho salmon, but rainbow trout remained constant over this 3-year period. It is worth noting that CSARP data represent approximately 70% of Chilean rainbow trout production but are the best estimate readily available.

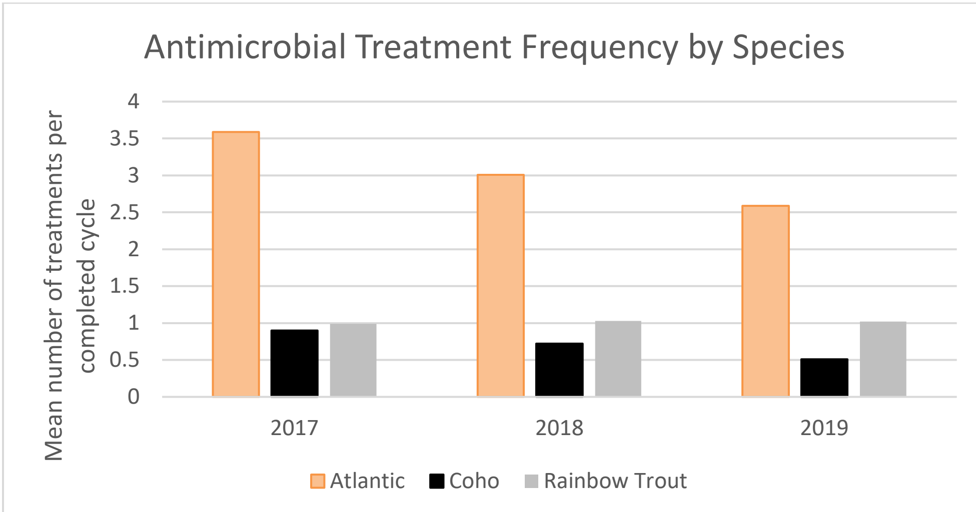

Figure 23. Antimicrobial treatment frequency, as the mean number of antimicrobial treatments administered to the fish harvested in completed production cycles each year. Data from CSARP (pers. comm., CSARP, 2021).

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,[48] 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 12 months (coincidentally aligned with the production period for rainbow trout).

[48] Because of 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.

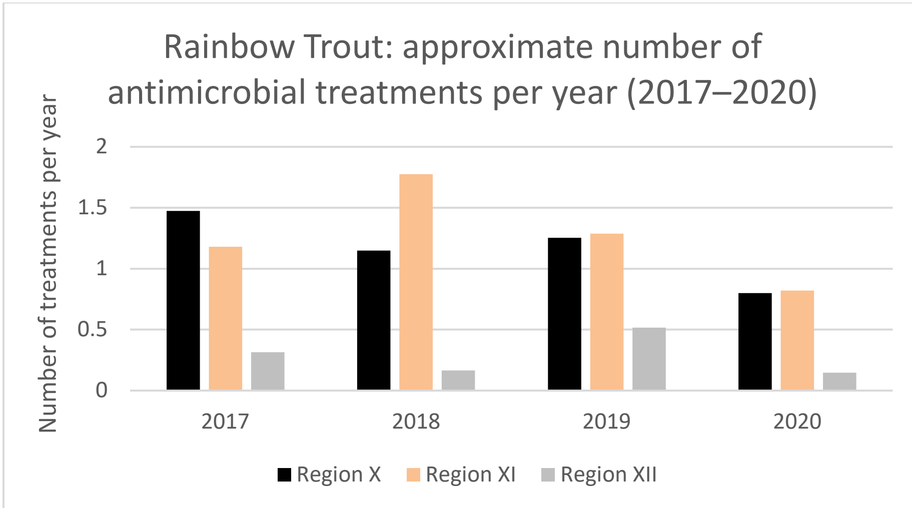

Figure 24. Approximate antimicrobial treatment frequency, in number of treatments per year for rainbow trout in each region, from 2017 to 2020. Calculated using data from Sernapesca and CSARP.

Figure 24 shows the calculated treatment frequency values per year and region for rainbow trout. These regional results provide further insight into the yearly averages shown in Figure 23. For instance, Figure 23 shows that the average of 1.02 treatments per year in 2019 actually comprised higher frequencies in Regions X and XI, with 1.25 and 1.29 treatments per year, respectively, and a lower frequency in Region XII, with 0.52 treatments per year. Figure 24 also shows the extrapolated treatments per year for rainbow trout in 2020, equivalent to 0.8 in Region X, 0.8 in Region XI, and 0.15 in Region XII. But, these extrapolated values do not reflect the production shifts of roughly 47.7% from Region XI (reduced to 0.3% of the total national production) to Regions X and XII that took place in 2020. Overall, during this period (2017–20) the average treatment frequency for Regions X and XI exceed one treatment per year (1.17 and 1.27 treatments per year, respectively), while Region XII's average falls well below the single treatment per year (0.29 treatments per year).

<u>Type and application of antimicrobial use</u>

Oral administration of antibiotics accounts for 99.45% of all antibiotic use in Chile, while 0.55% are administered through injection (Sernapesca, 2020). The types of antimicrobials used are reported for all salmonids (e.g., Atlantic salmon, coho salmon, rainbow trout) by the environment type (e.g., freshwater or marine waters) by Sernapesca. Florfenicol accounted for 98% of all antibiotic usage by weight. The other antibiotics used and the percentage, by weight, are oxytetracycline (0.53%), tiamulin (0.53%), and tilmicosin (0.02%).

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) because of the potential for human pathogens to acquire resistance genes from florfenicol-treated nonhuman 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 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 that antimicrobials may impose toxic effects in wild nontarget 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, water body, site), and particularly the contributions that salmonid farming’s antimicrobial use makes in relation to other key users (e.g., terrestrial agriculture and human health) (Lulijwa et al. 2020). Quiñones et al. (2019) also emphasize that there is an urgent need for more comprehensive ecosystem (beyond farm) studies on the impacts of antimicrobials.

Antimicrobial resistance

This section focuses on the 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; Lulijwa 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; thus, understanding the complex potential impacts to food safety, occupational health, and (marine and nonmarine) antimicrobial resistance continues to be challenging to fully comprehend (Lulijwa et al., 2020).

Because rainbow trout production is part of the broader salmonid net pen production industry in Chile, the literature regarding antimicrobial resistance for the industry is considered broadly applicable for this assessment.

As noted above, the concern is that the repeated use of antimicrobials in salmonid 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) considers the conclusion of Cabello and Godfrey to be highly debatable, stating that it "goes against the more widely accepted paradigm that antibiotic resistance genes enter aquatic environments from the human resistome (referencing Higuera-Llantén et al. 2018; Domínguez et al. 2019)."

Although 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 as a result of 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 a reduced appetite for antimicrobials administered in feeds (Happold et al., 2020; San Martin, 2019).

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 "nonwild type," which have reduced susceptibility (Contreras-Lynch et al., 2017). Various academic articles continue to use the term "resistance," and when referred to here, the same term is used.

A robust understanding of the status of reduced antimicrobial susceptibility in Chile remains elusive. A review by Lulijwa et al. (2020) of antimicrobial use in aquaculture indicates that 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 antibiotics, 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 salmonid farming."[49] 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 ("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 that 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 differing results for rainbow trout in Regions X and XI, with approximately 60% and 25% of isolates classified as NWT for florfenicol for each respective region. In terms of trends (for all salmonid species due to sample size), 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 that 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 nontarget bacterial populations (the IFOP program is to study antimicrobial susceptibility in nonpathogenic bacteria associated with salmonid farming beginning in 2021). Higuera-Llantén et al. (2018) demonstrated that the high use of florfenicol and oxytetracycline has, as a consequence, selected for multiresistant 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 because of the widely recognized phenomenon of horizontal gene transfer (HGT), florfenicol has the potential to co-select for a diversity of resistances (Kim and Aoki, 1996). For this reason, human health as well as animal health can potentially be affected by the use of antimicrobials in aquaculture (Fernandez-Alarcon et al., 2010). Several recent

[49] Vigilancia de la resistencia de los agentes patógenos a los antimicrobianos de uso habitual en la salmonicultura nacional.

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 health, human health, and environmental health (Dominiguez et al., 2019)(Cabello et al., 2020)(Cabello & Godfrey, 2019)(Quiñones et al., 2019). But, 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 (e.g., 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). Regarding 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 sublethal 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[50]). Eight Chilean companies report their pesticide use through the Global Salmon Initiative (GSI) from 2013 to 2020, and these data are separated into in-feed and bath treatments, and by species. Of the eight GSI

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

companies in Chile, half cultured rainbow trout at some point during 2013 to 2020: AquaChile, Australis Seafood S.A., Cermaq, and Multiexport Foods. The GSI data for rainbow trout and Atlantic salmon are shown in Figure 25 (not including hydrogen peroxide), and do not show a clear trend over time in the overall relative pesticide use (g/mt). It is important to consider that the results shown in Figure 25 reflect the eight GSI companies when it comes to Atlantic salmon, but only reflect the data of the four companies producing trout, when it comes to this species. Nonetheless, the relative pesticide use for trout is significantly lower than the use for Atlantic salmon.

The primary application method for trout is using bath treatments, and in-feed treatments were scarcely used, with only 0.003 g/mt and 0.008 g/mt in 2015 and 2020, respectively (these values are included but are too small to be observable in the graph). Although trout's averaged relative pesticide use remained lower than 2.17 g/mt during this period, when disaggregated, two companies reported a relative pesticide use of 8.08 and 6.5 g/mt (bath treatments) in 2016 and 2019, respectively. The four trout-producing companies reported no pesticide treatments used in 2013, 2014, and 2018, and no hydrogen peroxide trout treatments during the 8 years considered here. This data set shows a low application of pesticides in rainbow trout, although it is not possible to differentiate between regions.

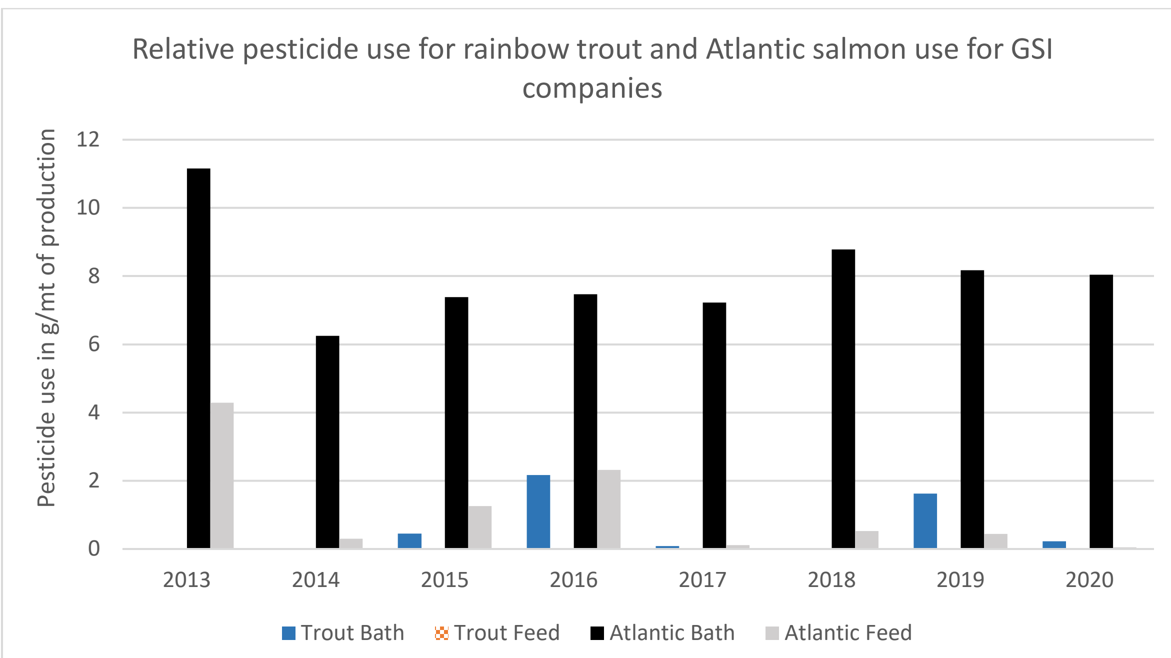

Figure 25. Relative pesticide use (not including hydrogen peroxide) in g/mt for rainbow trout and Atlantic salmon in Chile for companies reporting through the GSI (only four of the eight companies produce trout). Pesticides administered through bath treatments are shown in solid blue and black, and by in-feed treatments in pattern gray and orange. Data from GSI.

Sernapesca also collects data on the number of treatments, amount, and types of pesticide used for each species at each ACS, which was obtained through a formal request to

Sernapesca's platform SIAC[51] (Sistema Integral de Informacion y Atencion Ciudadana). Inclusive of all salmonids, the industry cut back its pesticide use by 2,035 kg (–19.6%) from 2019 to 2020 by reducing the use of e. benzoate, diflubenzuron, deltamethrin, azamethiphos, and lufenuron.[52] But, the use of cypermethrin, hexaflumuron[53], and hydrogen peroxide increased during this period (see Table 8) (Sernapesca, 2021). Azamethiphos has been the largest by weight (except for hydrogen peroxide) during this period. The use of hexaflumuron (trade name Alpha Flux) shows drastic increases each year since 2017, when only 90 kg were reported; by 2020, its use was already 1,484 kg. Like the other treatments, according to EU regulations, hexaflumuron is classed as Category 1: Hazardous to the aquatic environment and a long-term aquatic hazard, and highly toxic to aquatic life with long-lasting effects (Pharmaq, 2020). If hydrogen peroxide is considered as one of the active ingredients, the overall use of pesticide treatments has been increasing during these 4 years, which point to the continued pesticide problem faced by the industry.

Table 8. Pesticide use (in kg) in all salmonids from 2017 to 2020 listed by active ingredient. Data from Sernapesca (2021).

Total weight (kg) of treatments used in salmonids				
Active ingredient	**2017**	**2018**	**2019**	**2020**
Azamethiphos	4,727.95	6,728.03	8,751.77	6,354.62
Emamectin benzoate	59.00	50.98	39.17	33.64
Cypermethrin	9.01	—	2.45	11.25
Deltamethrin	32.65	42.72	90.92	62.53
Diflubenzuron	—	323.40	147.68	—
Hexaflumuron	90.00	—	763.07	1,484.06
Lufenuron*	199.80	220.50	587.17	400.82
Total active ingredient (excluding hydrogen peroxide)	5,118.41	7,365.63	10,382.23	8,346.93
Hydrogen peroxide†	—	195,057.36	3,215,540.90	4,119,187.50
Total active ingredient	5,118.41	202,422.99	3,225,923.13	4,127,534.43

* Lufenuron is used in salmon hatcheries to treat smolts before their transfer to sea. It is considered to have a lower ecological concern than the related diflubenzuron (and teflubenzuron) (Poley et al., 2018).
† 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.

When analyzing Sernapesca data for relative pesticide use per species, noticeable differences can be observed compared with the GSI analysis. Both Atlantic salmon and rainbow trout show a higher relative use and some differences in trends, especially for rainbow trout in 2018 (GSI = 0; and Sernapesca = 4.33 g/mt). Still, Atlantic salmon's relative pesticide use (≈8–14 g/mt) more than doubles that of trout (2.4–4.5 g/mt) for every year during this period. On average from 2017 to 2020, 3.5 grams of pesticide were used to produce 1 metric ton of rainbow trout (Figure 26) (Sernapesca, 2021).

[51] https://servicios3.sernapesca.cl/Siac/faces/jsp/formulario/ingresoFormularioUsuario.xhtml
[52] Lufenuron is used in salmon hatcheries to treat smolts before their transfer to sea. It is considered to have a lower ecological concern than the related diflubenzuron (and teflubenzuron) (Poley et al., 2018).
[53] Hexaflumuron (trade name Alpha Flux) was launched in Chile in late 2019 and its use has already increased by 50% (1 mt) in 2020 (https://thefishsite.com/articles/new-sea-lice-treatment-launched-in-chile).

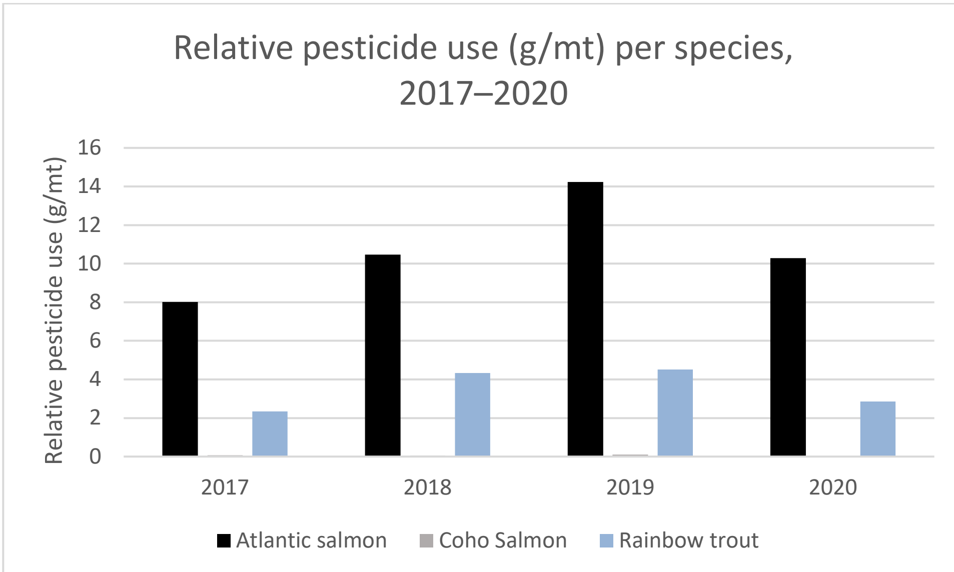

Figure 26. Relative pesticide use (not including hydrogen peroxide) in g/mt for Atlantic and coho salmon, and rainbow trout in Chile, 2017–2020. Data from Sernapesca, 2021.

Furthermore, Figure 27 (excludes hydrogen peroxide) shows the weight (kg) of each pesticide's active pharmaceutical ingredient (API) used to treat rainbow trout in all production regions from 2017 to 2020. In 2019, trout producers reported the highest use during this period, doubling the pesticides used of 2017. The change in API used for trout from 2019 to 2020 (–19.4%) aligns to the one described before when accounting for all salmonids (–19.6%), and it is almost entirely due to the reduction of azamethiphos. There was no use of cypermethrin, hexaflumuron, and lufenuron in trout during this period until 2019, when lufenuron was used, followed by a small use of cypermethin and hexaflumuron more recently in 2020 (Sernapesca 2021). Rainbow trout accounted for 8% of Chile's salmonid production in 2020 but was responsible for only 3.5% of the total pesticides used that year. From 2017 to 2019, rainbow trout was responsible for 4.9% to 7.3% of the total weight of pesticide use.

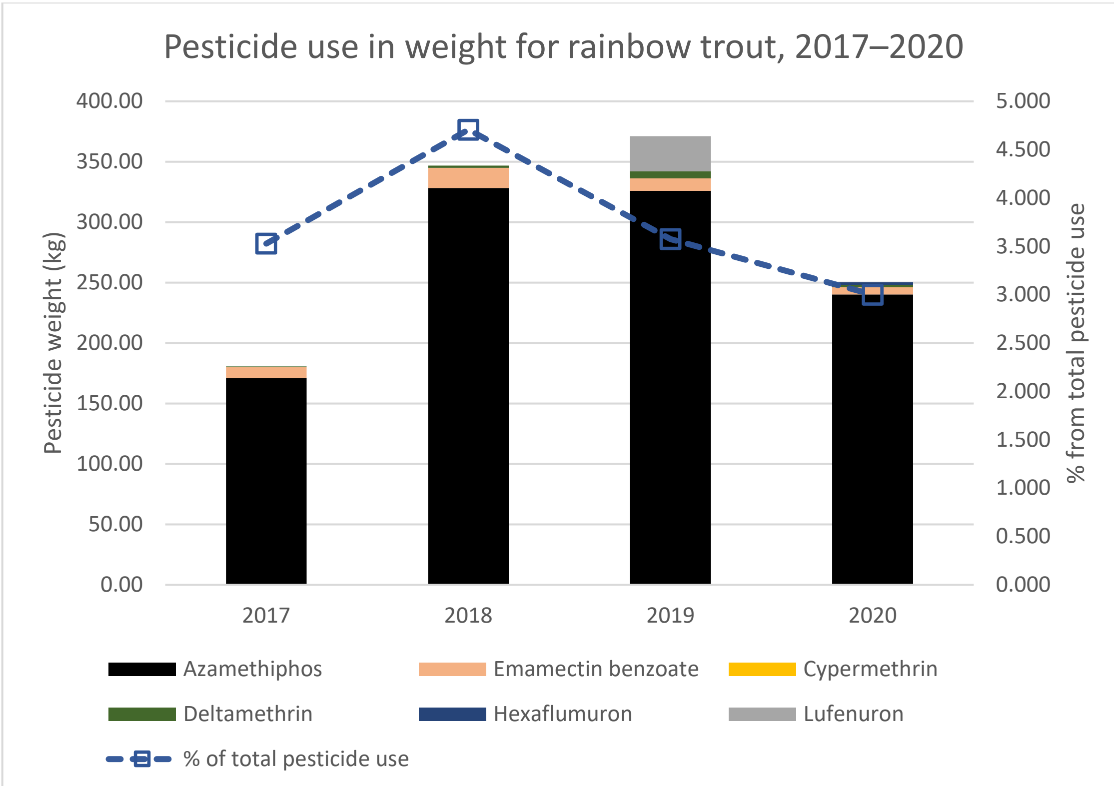

Figure 27. Pesticide use in weight by API for rainbow trout. Data from Sernapesca 2021.

Altogether, these datasets provide a good picture of the pesticides used for salmonids for the last 2 to 4 years in all production regions in Chile. Although there are discrepancies between the data sets, they all signal an increase in pesticide use from 2017 till 2019 and a reduction from 2019 to 2020 (Figures 25, 26, and 27). Both GSI and Sernapesca's data confirm the difference in pesticides used between Atlantic salmon and the lower level of pesticides used for rainbow trout since 2017.

Regional pesticide use

The frequency of treatments applied is a highly concerning environmental risk because it can contribute to the resistance of sea lice treatments and possibly cause other ecological impacts (addressed in the following sections). Although the weight of pesticides used to treat rainbow trout has been decreasing over the last 3 years, as shown in Figure 28, the total number of pesticide treatments has fluctuated around 150 treatments each year since 2016. In 2016, most treatments were applied in Region XI, but by 2020, this region presented no more use of pesticide treatments. This result is expected due to the transfer of rainbow trout production out of Region XI (39,844 mt in 2019 to 256 mt in 2020) to Region X (26,157 mt tons in 2019 to 58,468 mt in 2020) and to Region XII (7,581 mt in 2018 to 13,552 mt in 2020) (Sernapesca 2021). Following this same reasoning, the first treatments were reported for Region XII in 2020. But, the bulk of the total Chilean pesticide use is considered to be administered in Region X, because this region has the greatest number of sea lice per fish (SFW, 2021). Figure 28 is consistent with this statement, because Region X shows an increasing pesticide use trend in number of treatments, and the highest average during this period (102.8 treatments per year) from the three regions.

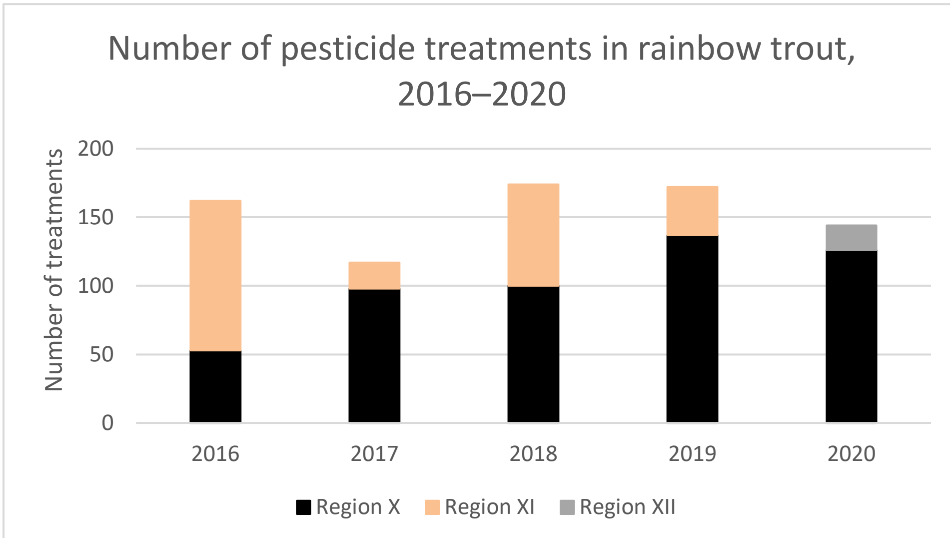

Figure 28. Number of pesticide treatments used for rainbow trout by production region. Data from Sernapesca 2021.

Similar behavior is observed in the following analysis, which reports the number of treatments used in active sites producing rainbow trout in each region. The highest rate of treatments per site (five treatments per site) was recorded in Region XI in 2016. An overall increasing trend is again observed in Region X; Region XII starts averaging two treatments per site in 2020 (Figure 29).

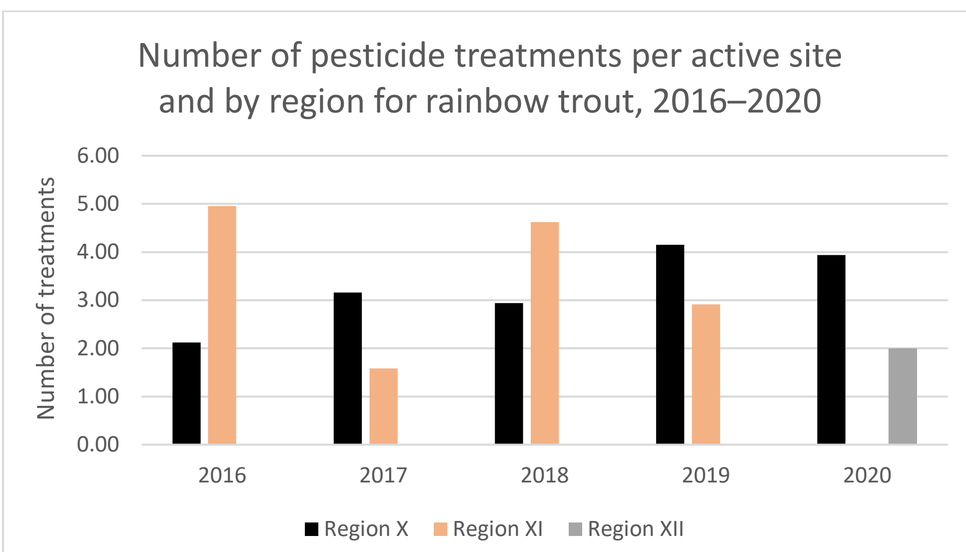

Figure 29. Number of pesticide treatments used per active site and by production region for rainbow trout. Data from Sernapesca 2021 and 2022.

Sernapesca's data also provide a breakdown of the APIs applied to rainbow trout and the total number of treatments by region, included in Table 9. Azamethiphos and emamectin benzoate are the primary compounds used across regions. The former was consistently the most common treatment in Region X during these 5 years and the second most common in Region XI. Though deltamethrin is only used in Region X, it presents an increasing trend. The two main APIs, azamethiphos and emamectin benzoate, are the first and only used in the most recent productive Region XII.

Table 9. Number of pesticide treatments by active pharmaceutical ingredients and by production region used for rainbow trout. Data from Sernapesca 2021.

	2016	2017	2018	2019	2020
Region X	**53**	**98**	**100**	**137**	**126**
Azamethiphos	26	54	46	64	80
Emamectin benzoate	17	32	43	38	17
Cypermethrin	3				1
Deltamethrin	7	12	11	35	27
Hexaflumuron					1
Region XI	**109**	**19**	**74**	**35**	
Azamethiphos	25	3	30	22	
Emamectin benzoate	79	16	39	4	
Cypermethrin	5		5	9	
Region XII					**18**
Azamethiphos					2
Emamectin benzoate					16
Grand Total	**162**	**117**	**174**	**172**	**144**

Another insightful indicator of regional pesticide use is the sea lice load by region. Figure 30 shows that weekly average sea lice numbers are much higher in Regions X and XI than in Region XII. As mentioned before, Region X and Region XI account for 48% and 29% of rainbow trout production in 2021, respectively (Sernapesca 2020). The first sea lice were reported on Atlantic salmon farms in Region XII in 2017, with eight farms detecting lice and three farms presenting epidemic behavior requiring treatment (Arriagada et al., 2019), and Figure 30 shows that lice levels currently continue to be low with a limited requirement for treatments. Thus, sea lice load is another indicator to the increased pesticide use for rainbow trout in Region X.

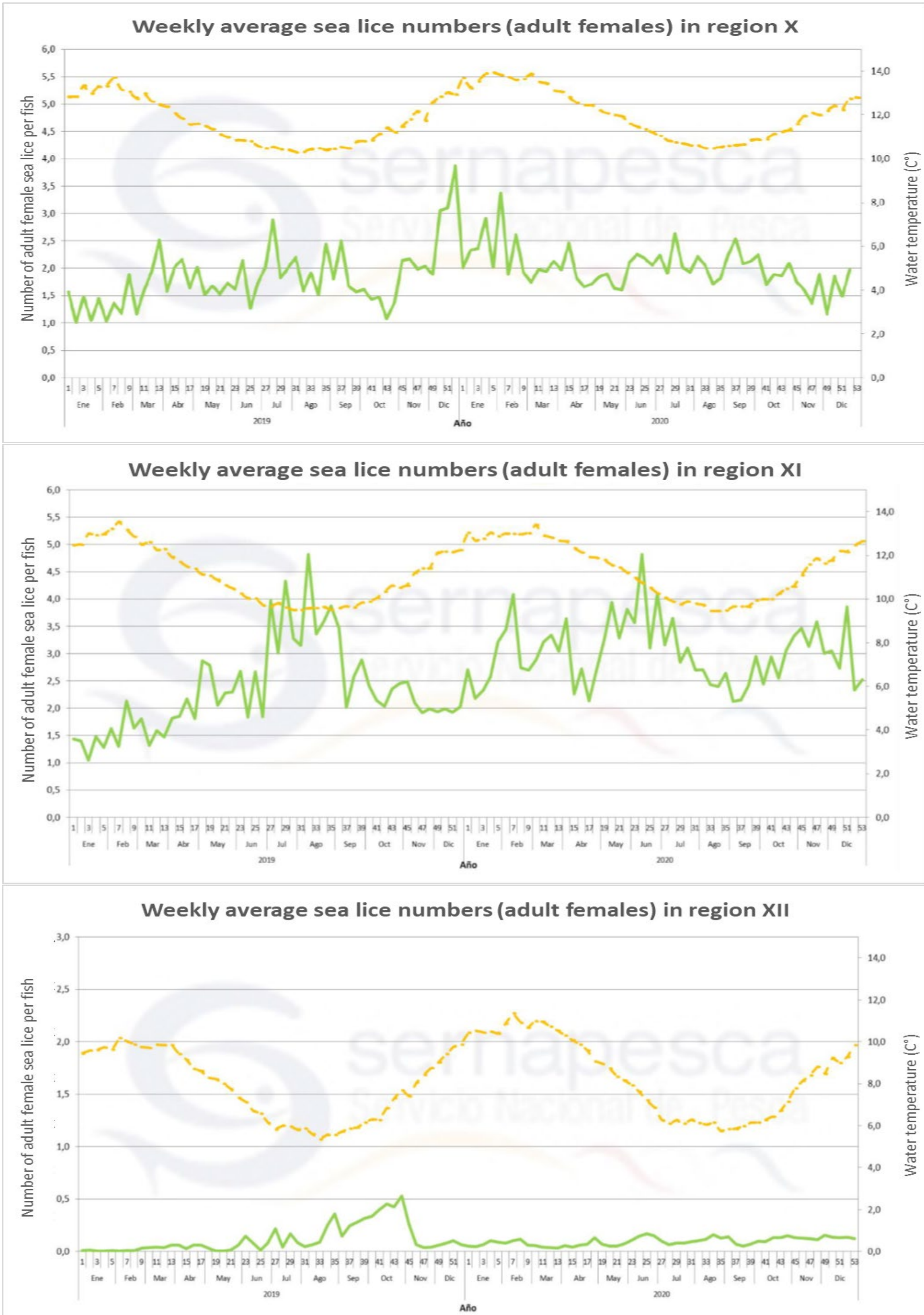

Figure 30. Weekly average sea lice (green line) and water temperature (yellow line and secondary y-axis) in Region X (top), Region XI (middle), and Region XII (bottom) in 2019 and 2020. Note the different scales of primary y-axis.

Resistance to sea lice treatments

Given Atlantic salmon's dominance in volumetric production and economic importance, the majority of literature studying sea lice and their control is focused on Atlantic salmon. Thus, considering the paucity of data specific to rainbow trout production, and given their similar susceptibilities to the parasite and treatment rates, information regarding the environmental impacts of chemical sea louse control is drawn from literature examining pesticide application in salmonid farming operations.

The extensive use of sea lice medicines has resulted in an inevitable drift toward resistance, which threatens 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, so resistance is 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). For instance, one of the strategies implemented by this program to prevent further reduction of sea lice susceptibility is to rotate active ingredients between treatments (Memo number: 00450/2022[54]). 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 have decreased over time,[55] probably due to the increasingly frequent appearance of parasites with reduced susceptibility.

Despite the different species of sea lice that are the primary target of pesticide use in Northern Hemisphere salmonid 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)

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[54] http://www.sernapesca.cl/sites/default/files/res.ex_.60-2022.pdf

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

state that 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 in Norway despite a large reduction in pesticide use, and they consider it likely to be the result of resistance genes now being 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 among 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 there will also develop resistance to this chemical—though there is currently no evidence, although limited data availability, that hydrogen peroxide is currently being used.

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.

<u>Environmental impacts of sea lice pesticides</u>

The pesticides used in Chile are nonspecific (i.e., their toxicity is not specific to the targeted sea lice), so they may affect nontarget organisms—particularly crustaceans—in the vicinity of treated net pens (Grefsrud et al., 2021). The fate and environmental impact of discharged sea lice treatments and their metabolites vary according to the chemical type and the treatment method, so understanding the impacts to the ecosystems that 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. (2021) 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 nontarget 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, although 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 into 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, because bath treatments such as azamethiphos, cypermethrin, and deltamethrin have a rapid release, dispersion, and dilution post-treatment, they primarily affect nontarget 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 that their use may affect nontarget 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 to 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 nontarget 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.

More than a decade 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." Although 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. The total Chilean antimicrobial use on salmonid farms declined from 2015 to 2018 but has since increased through 2021. The average country-level use reported by Sernapesca of 350 g/mt hides considerable variability by production region in total and relative terms; for example, the relative use of rainbow trout in Regions X, XI, and XII in 2020 was calculated to be 138 g/mt, 142 g/mt, and 25 g/mt, respectively. Rainbow trout's approximated treatment frequency per site in Regions X and XI was 0.8 per production cycle, and 0.15 per production cycle in Region XII.

Almost all antimicrobial use (96.8% by weight in 2020) is currently of florfenicol to treat piscirickettsiosis (or salmonid rickettsial syndrome, SRS), although oxytetracycline has been important until recently. The direct ecological impacts of antimicrobials to the receiving environments remain unclear, but of high general concern are the potential development of antimicrobial resistance (in the treated bacterial pathogen as well as in the surrounding nontarget 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 challenges, 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 human and terrestrial sources.

Some recent studies indicate that 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. But, the government's resistance surveillance program shows that approximately 50% of the isolates of *P. salmonis* tested in 2020 displayed reduced susceptibility to florfenicol (and approximately 17% to oxytetracycline) in in-vitro laboratory trials. Values were low for other pathogens except for *Flavobacterium psychrophilum*, which showed that 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 salmonid farms (particularly Atlantic salmon farms) has resulted in bacterial populations evolving and adapting to the two most commonly used drugs.

Pesticide use for salmonids in Chile is also high (mainly driven by Atlantic salmon), although reports showed a substantial decrease from 2019 to 2020. Still, the overall high and fluctuating trend over time reflects the ongoing struggle to control parasitic sea lice. Over 8 mt of pesticide active ingredients were used in 2020, plus over 4,119 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. Rainbow trout production was only responsible for 3.6% and 2.6% of the total salmonid pesticide use in 2019 and 2020, respectively, and the relative pesticide use for rainbow trout (2.4–4.5 g/mt) is considerably lower than that of Atlantic salmon (8–10 g/mt). Despite this, the impact of these pharmaceuticals on the marine environment remains largely uncertain, particularly regarding repetitive treatments at a single site or coordinated treatments in a single water body. Widespread resistance has previously developed in Chile and is likely to recur with the repeated use of a limited number of available treatments.

Overall, there is no specific evidence indicating that antimicrobial use in Chilean salmonid farms has led to the development of clinical resistance (i.e., the loss of efficacy of treatments) for the primarily treated pathogens. It must also be noted that bacterial resistance genes in marine environments may have originated from human and terrestrial sources. Although the rainbow trout industry's use of antimicrobial treatments per site per year remains high compared to internationally, the trend since 2018 has been decreasing. Florfenicol is noted for its "floR" resistance gene associated with mobile elements (such as plasmids and transposons) and the potential contribution to the pool of resistant genes in the environment, and this remains a critical conservation concern in Chile. For rainbow trout farms, the average frequency of florfenicol (a highly important antimicrobial for human medicine) use between 2017 and 2020 was slightly higher than one treatment per site per year in Regions X and XI (1.17 and 1.27 treatments per year, respectively). Pesticide use is also significant (i.e., azamethiphos, emamectin benzoate, and others), with multiple treatments per site per year in all regions where production takes place. Therefore, with chemicals known to be used on multiple occasions each productive cycle (including significant use of highly important antimicrobials), plus a treatment method that allows their release into the environment, the final score for Criterion 4—Chemical use is 2 out of 10 for Regions X and XI. Based on a demonstrably lower need and lower frequency of antibiotic treatments used in Region XII (0.29 treatments per year), the final score for Criterion 4—Chemical use is 6 out of 10 for Region XII. It is noted here that, although 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, although 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

Rainbow trout in all regions

C5 Feed parameters	Value	Score
F5.1a Forage Fish Efficiency Ratio	1.52	
F5.1b Source fishery sustainability score (0–10)		5
F5.1: Wild fish use score (0–10)		4.17
F5.2a Protein INPUT (kg/100 kg fish harvested)	52	
F5.2b Protein OUT (kg/100 kg fish harvested)	17.8	
F5.2: Net Protein Gain or Loss (%)	–65.77	3
F5.3: Species-specific kg CO_2-eq kg^{-1} farmed seafood protein	12.63	7
C5 Feed Final Score (0–10)		4.59
Critical?	**No**	Yellow

Brief Summary

In the absence of specific feed composition information from Chilean feed mills, feed composition data were obtained from the literature and from sustainability reports published by the three major feed companies (Biomar, Ewos-Cargill, and Skretting). Although not precisely accurate, the key aspects of this assessment were considered sufficiently robust. In addition, the performance indicators such as the Feed Conversion Ratio may vary by region, but there are currently insufficient regional data to assess them separately.

Overall, rainbow trout feed in Chile uses fishmeal and fish oil made from whole wild fish and by-product sources with an eFCR of 1.3. The fishmeal inclusion level is moderate (9.8%); over one-third of it (35%) is sourced from fishery and/or aquaculture by-products, and the rest (65%) from whole-fish reduction processes. The fish oil inclusion level is also moderate at 8.6%, and 34% comes from by-product sources. The resulting score for Factor 5.1a—Forage Fish Efficiency Ratio (FFER) is low (1.52), meaning that, from first principles, 1.52 mt of wild fish are needed to produce the fishmeal required for 1 mt of farmed rainbow trout. Most of the marine ingredients used by Chilean feed suppliers are sourced from MSC, IFFO-RS certified, or managed fisheries, resulting in a score for Factor 5.1b—Source fishery sustainability of 5 out of 10. The inclusion levels of these wild fish ingredients in Chilean rainbow trout feeds combined with the sustainability of raw materials result in a Factor 5.1—Wild fish use score of 4.17 out of 10. Factor 5.2—Net protein gain or loss scores 3 out of 10 and is driven by a moderate to high net protein loss of –65.77%. Factor 5.3—Feed footprint scores 7 out of 10 due to a low to moderate feed footprint of 12.63 kg CO_2-eq. per kg of harvested protein. Altogether, Factor 5.1, 4.17 out of 10; Factor 5.2, 3 out of 10; and Factor 5.3, 7 out of 10 combine for a final score of 4.59 out of 10, which results in a Yellow rating for Criterion 5—Feed.

Justification of Ranking

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 1 kilogram of farmed salmonid protein. See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations.

Feed composition

Because of the lack of data availability from feed manufacturers and trout producers, the feed composition data for this assessment were compiled mainly from the literature (Skretting, 2020; Cargill, 2020; Ghamkhar and Hicks, 2020; Mowi, 2021; Naylor, 2021; Tacon et al. 2021; Biomar, 2021). In some cases, parameters considered representative of feed used for Chilean salmonid production were the best data available, so they were used here to assess rainbow trout. A best-fit feed composition for Chilean rainbow trout is included in Table 10. Although 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 rainbow trout feed for this assessment.

Factor 5.1. Wild Fish Use

Factor 5.1 combines an estimate of the amount of wild fish used to produce farmed trout with a measure of the sustainability of the source fisheries. Table 10 shows the data used and the calculated Fish Feed Equivalency ratio (FFER) for fishmeal and fish oil.

Factor 5.1a—Feed Fish Efficiency Ratio (FFER)

The Feed Fish Efficiency Ratio (FFER) for aquaculture systems is driven by the feed conversion ratio (FCR), the amount of fish used in feeds, and the source of the marine ingredients (i.e., does the fishmeal and fish oil come from processing by-products or whole fish targeted by wild capture fisheries). FCR is the ratio of feed given to an animal per weight gained, measured in mass (e.g., FCR of 1.4:1 means that 1.4 kg of feed is required to produce 1 kg of fish). It can be reported as either biological FCR (bFCR), which is the straightforward comparison of feed given to weight gained, or economic FCR (eFCR), which is the amount of feed given per weight harvested (i.e., accounting for mortalities, escapes, and other losses of otherwise-gained harvestable fish). The Seafood Watch Aquaculture Standard utilizes the eFCR.

The calculated fishmeal (FM) and fish oil (FO) inclusions are 9.80% and 8.60%, respectively, and are consistent with the literature. For instance, more than a decade ago, commercial feeds included 20% to 25% of FM and 12% to 15% of FO (Tacon and Metian 2008)(Tacon et al., 2011). But, advances in feed formulation and new alternatives to replace FM and FO have successfully reduced these ranges to 1% to 15% and 6% to 11% inclusion, respectively (Skretting, 2020)(Cargill, 2020)(Ghamkhar and Hicks, 2020)(Mowi, 2021)(Naylor, 2021)(Tacon et al. 2021)(Biomar, 2021).

The level of by-products used here to represent Chilean rainbow trout feeds is an average of the by-product levels reported in the sustainability reports by the three Chilean feed suppliers. As a result, 35% and 34% of fishmeal and fish oil inclusions, respectively, come from by-products. The whole fish inclusion levels were determined by calculating the difference between the by-product percentages described above and 100%.

The following equation (Eq. 1) calculates the fishmeal and fish oil feed fish efficiency ratio ($FFER_{FM}$ and $FFER_{FO}$). The FFER is a measure of the dependency on wild fisheries for feed ingredients, using the ratio of the amount of wild fish used in feeds to the harvested farmed fish. Each variable used in these calculations, as detailed below, is also summarized in Table 10. The whole fish inclusion levels for fishmeal and fish oil are used and can be found in Table 10 as variables *a* and *c*, respectively. Only 5% of the inclusion levels for fish oil and fishmeal from by-products are considered and are also noted in Table 10 as variables *b* and *d*. In addition, the eFCR (*g*) and the fish oil (*f*) and fishmeal yield (*e*) values are also identified in Table 10 and used in Equation 1. Note that fishmeal and fish oil yield values were not available, so global averages provided by Tacon and Metian (2008) were utilized.

(Eq. 1)

$$FFER_{FM} = [(a + b) \times g]/e$$

$$FFER_{FO} = [(c + d) \times g]/f$$

The resulting FFER for fishmeal is 0.38, and the FFER for fish oil is 1.52.

Table 10. Best-fit feed composition values from the available data.

Eq. variable	Parameter	Data
	Fishmeal inclusion level (total)	**9.80%**
a	Fishmeal inclusion level (whole fish)	6.40%
	Fishmeal inclusion level (by-product)	3.40%
b	Assessed fishmeal inclusion level (by-product)[56]	0.17%
e	Fishmeal yield	22.50%
	Fish oil inclusion level (total)	**8.60%**
c	Fish oil inclusion level (whole fish)	5.70 %
	Fish oil inclusion level (by-product)	2.90%
d	Assessed fish oil inclusion level (by-product)	0.15%
f	Fish oil yield	5.00%
g	Economic Feed Conversion Ratio (eFCR)	1.3
Calculated values		
Fish meal feed fish efficiency ratio (FFERfm)		0.38
Fish oil feed fish efficiency ratio (FFERfo)		1.52
Assessed FFER		**1.52**

Using the data in Table 10, 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 0.38 for fishmeal and 1.52 for fish oil. This means that, from first principles, 1.52 mt of wild fish would need to be caught to supply the fish oil needed to produce 1.00 mt of farmed rainbow trout.

Factor 5.1b—Sustainability of the source of wild fish

Without specific data for source fisheries supplying fishmeal and fish oil to Chilean rainbow trout, this section (Factor 5.1b) was reproduced almost in its entirety from the Atlantic and Coho salmon report (2021), which considered the global data for three major feed companies (Biomar, Ewos-Cargill, and Skretting) reporting through the Ocean Disclosure Project.[57] Although 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 3 companies and include the management status of the fishery (certified, well-managed, managed, needs improvement, and not rated[58]) (Table 11). 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

[56] The byproduct inclusion level data point utilized in this equation is the reported inclusion level multiplied by 0.05. See the Seafood Watch Aquaculture Standard page 38 for more information. https://www.seafoodwatch.org/globalassets/sfw/pdf/standards/aquaculture/seafood-watch-aquaculture-standard-version-a4.pdf

[57] https://oceandisclosureproject.org/

[58] Additional subcategories 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.

and used here for Chile. Again, this may not reflect the exact fishery sources used in Chilean salmon feeds but is considered to be acceptably representative and the best estimate available.

Table 11: 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 1.52, results in a final score for Factor 5.1—Wild Fish Use of 4.17 out of 10.

Factor 5.2. Net Protein Gain or Loss

Values for the total protein content of typical rainbow trout feeds range from 35% to 45%, and the averaged value used in the calculations is 40% (Ghamakhar et al., 2020)(Souza et al., 2015)(Hernandez and Roman, 2016)(Hernandez et al., 2013). The protein content of whole rainbow trout is estimated to range between 15% and 20% in a study conducted in Brazil, with a reported average of 17.8%, which is the value used here (Dumas et al. 2007)(Souza et al., 2015). Therefore, 1 ton of feed contains 400 kg of protein; 1.3 tons of feed are used to produce 1.00 ton of farmed rainbow trout (eFCR), and the net protein input per ton of farmed rainbow trout production is 520 kg. With only 178 kg of protein in 1 ton of harvested whole rainbow trout, there is a net loss of 65.77% 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 1 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[59] to estimate the CCI of 1 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 encourage data transparency and provision. The detailed calculation methodology can be found in Appendix 3 of the Seafood Watch Aquaculture Standard. Note that the inclusion level of vitamin/minerals/other averaged 13.9% (Seafish, 2018)(Skretting, 2020)(Cargill, 2020)(Mowi, 2021), but for ease of the calculations here, it was adjusted to 12.6% (see Table 12), thus allowing the overall ingredient percentage to total 100%.

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

Table 12: Source fishery sustainability categories from the Ocean Disclosure Project.

Feed Ingredient	Inclusion (% of total feed)	GFLI value
Fishmeal	6.4	70.09
Fishmeal by-products	3.4	37.74
Fish oil	5.7	42.09
Fish oil by-products	2.9	21.69
Wheat gluten	10	74.18
Soy protein concentrate	19	503.03
Corn gluten	4	103.91
Pea protein concentrate	4	54.35
Rapeseed (canola) oil	18	499.75
Poultry meal	14	173.30
Vitamin/minerals/other	12.6	149.13
Total	100	**1729.27**

Calculations based on the GFLI values presented in Table 12 above and following the methodology in the Seafood Watch Aquaculture Standard indicate that the CCI is 12.63 kg CO_2-eq per kg of farmed rainbow trout protein. This results in a score of 7 out of 10 for Factor 5.3.

Conclusions and Final Score

In the absence of specific feed composition information from Chilean feed mills, feed composition data were obtained from the literature and from sustainability reports published by the three major feed companies (Biomar, Ewos-Cargill, and Skretting). Although not precisely accurate, the key aspects of this assessment were considered sufficiently robust. In addition, the performance indicators such as the Feed Conversion Ratio may vary by region, but there are currently insufficient regional data to assess them separately.

Overall, rainbow trout feed in Chile uses fishmeal and fish oil made from whole wild fish and by-product sources with an eFCR of 1.3. The fishmeal inclusion level is moderate (9.8%); over one-third of it (35%) is sourced from fishery and/or aquaculture by-products, and the rest (65%) from whole-fish reduction processes. The fish oil inclusion level is also moderate at 8.6%, and 34% comes from by-product sources. The resulting score for Factor 5.1a—Forage Fish Efficiency Ratio (FFER) is low (1.52), meaning that, from first principles, 1.52 mt of wild fish are needed to produce the fishmeal required for 1 mt of farmed rainbow trout. Most of the marine ingredients used by Chilean feed suppliers are sourced from MSC, IFFO-RS certified, or managed fisheries, resulting in a score for Factor 5.1b—Source fishery sustainability of 5 out of 10. The inclusion levels of these wild fish ingredients in Chilean rainbow trout feeds combined with the sustainability of raw materials result in a Factor 5.1—Wild fish use score of 4.17 out of 10. Factor 5.2—Net protein gain or loss scores 3 out of 10 and is driven by a moderate to high net protein loss of –65.77%. Factor 5.3—Feed footprint scores 7 out of 10 due to a low to moderate feed footprint of 12.63 kg CO_2-eq. per kg of harvested protein. Altogether, Factor 5.1, 4.17 out of 10; Factor 5.2, 3 out of 10; and Factor 5.3, 7 out of 10 combine for a final score of 4.59 out of 10, which results in a Yellow rating for Criterion 5—Feed.

Criterion 6: Escapes

Impact, unit of sustainability and principle

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

Criterion 6 Summary

Rainbow trout; Regions X and XI

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)			4
C6 Escape Final Score (0–10)			**3**
	Critical?	No	Red

Rainbow trout; Region XII

C6 Escape parameters		Value	Score
F6.1 System escape risk (0–10)		2	
F6.1 Recapture adjustment (0–10)		0	
F6.1 Final escape risk score (0–10)			2
F6.2 Invasiveness score (0–10)			2
C6 Escape Final Score (0–10)			**2**
	Critical?	No	Red

Brief Summary

Large escape events of farmed salmonids continue to occur in Chile. Escape events totaling 410,000 escaped fish were reported in 2020, including a single escape event of 51,000 rainbow trout in the ecoregion of Magallanes. 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, 3.8 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 escaped salmonids on average in Regions X and XI (noting that some, e.g., by local fishers, may not be reported), but because of the lack of artisanal fishers and lower predation pressure by native predators such as sea lions, recaptures in Region XII are considered insignificant. Large numbers of salmonids still enter the environment every year, and the production system remains vulnerable in all regions.

Escaped rainbow trout poses a significant threat to native Chilean ecosystems because of the species' unique potential to establish naturalized populations. Decades of intentional stocking for recreational fishing have established populations throughout southern Chile, and although rainbow trout is known to predate upon the Galaxiid spp., it appears to have reached a balance that allows the species to cohabit. The contradictions in the literature make it challenging to score this criterion with a high level of confidence, which is why it is pertinent to use the precautionary approach in this case. Regions X and XI are not considered pristine habitats, and significant aquaculture production of rainbow trout has been occurring in these regions for decades. This is not the case for Region XII, where industry expansion is ongoing and which is considered a pristine ecoregion, providing habitat to three endemic and endangered species. Rainbow trout (nonnative) was established in this region for sport fishing well before aquaculture began, and it only accounted for 2.4% of the samples captured during a study carried by IFOP; nonetheless, the potential increase in escapees of trout bred for farming (as opposed to stocking), as a result of the ongoing industry expansion, increases the risk of escapees affecting the population status of wild species.

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). With a production system vulnerable to large escape events and trickle losses, and a small adjustment for recaptures (in Regions X and XI), the net pen systems' vulnerability to escape results in Factor 6.1 scores of 3 out of 10 for Regions X and XI and 2 out of 10 for Region XII. Regarding Factor 6.2, competition, predation, and impacts to wild species, habitats, or ecosystems may occur, but are not considered likely to affect the population status of wild species in Regions X and XI; therefore, those regions scored 4 out of 10, resulting in a Criterion 6—Escapes final score of 3 out of 10. But, Factor 6.2 in Region XII was scored 2 out of 10, because rainbow trout has a high potential to affect the population status of wild species and because of its possible further expansion within this range. Thus, it results in a Criterion 6—Escapes final score of 2 out of 10.

Justification of Ranking

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

In total, there are 23 introduced or exotic fish species living in Chilean waters (Marr, Olden et al. 2013), of which 12 are introduced salmonids (Soto et al., 2001 and 2006)(Arismendi et al. 2014). Rainbow trout was one of the first species introduced to Chile to support a new sport fishery at the beginning of the 1900s and was reintroduced at the end of the 20th century, establishing viable populations before aquaculture production began in this region (Basulto, 2003)(Arismendi et al. 2014). But, rainbow trout's extensive adoption in aquaculture production through continental waters in the 1980s, which consequently meant frequent escapes, allowed its expansion throughout the country, and it became one of the most successful invasive species in Chile (Sepulveda, Arismendi et al. 2013)(Gozlan et al., 2010). As a result, rainbow trout populations are self-sustained (feral), with a strong genetic structure that can be attributed to the difference in species varieties introduced through time (Benavente et al. 2015)(Carcamo et al. 2015).

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 salmonid farming offer the greatest opportunity for escapes because there is only a net barrier between the fish and the wild (Glover et al., 2017)(Atalah and Sanchez-Jerez, 2020). The latest effort to reduce escape risk taken by Chile's governmental body, Subpesca, is to require farms to certify their net pens annually (Resolution number: 1821-2020[60]), which entails on-site inspections every semester by a third party.

Sernapesca publishes escape data aggregated across salmonid species for total reported escaped fish and the number of reported escape events.[61] 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 31 from 2010 to 2020.

Figure 31. Reported total salmonid escapes (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 that the number of reported escape events each year is low (five in 2019 and eight in 2020), and they affect a quite small percentage of active sites. But, the numbers of escaped fish can be extremely high. Over 1.2 million fish were reported to have

[60] https://www.subpesca.cl/portal/615/articles-108479_documento.pdf

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

escaped in the last 4 years (2017 to 2020), and in the last decade, over 3.8 million escaped fish were reported (Soto et al., 2022). Though media sources have indicated that the 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 all salmonids, and the escape events are primarily a reflection of the much greater production and number of Atlantic salmon sites in Chile.

The mature salmonid farming industry in Chile (as elsewhere) is considered to operate best management practices for the design, construction, and management of farms, but according to Sernapesca's escape report, the causes of escapes include predator attacks on the nets, theft/vandalism[62] (between 2004 and 2009, theft constituted 21% of reported escapes), adverse weather conditions (29%), loss during handling and failure of net pens (18%), and accidental boat collisions (Sepulveda, Arismendi et al. 2013)(Soto et al. 2022). Except perhaps for 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. In addition to the reported escapes, undetected or unreported trickle losses may also be significant; escape statistics are usually based on reports by the farmers themselves and are likely to underestimate (significantly, in some circumstances) the actual number of fish escaping from farms (Glover et al. 2017).

From a regional perspective, Figure 32 shows that Region X has the highest reported total escapes from 2010 to 2020 and Region XII has low reported total escapes, but this is likely the result of the much lower scale of production in the far south (as opposed to an inherently lower escape risk). Although 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 its 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 in Region XII. In March 2020, Sernapesca[63] reported an escape event of rainbow trout in Region XII (considered a pristine and ecologically relevant ecosystem) but did not indicate the number of fish escaped. But, Sernapesca's escape report, updated in February 2021, indicates a single event in Region XII of 51,358 fish for 2020; in the absence of any further information, it is safe to assume that this escape event was rainbow trout.

[62] 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."
[63] http://www.sernapesca.cl/noticias/escape-de-salmones-en-magallanes

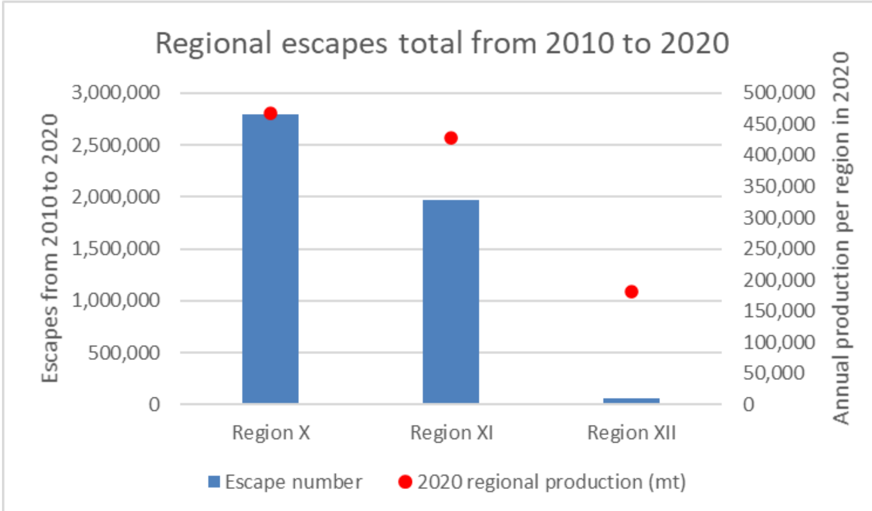

Figure 32. Total escapes per region from 2010 to 2020 (blue bars and primary y-axis) and annual production per region in 2020 (red dots and secondary y-axis). All salmonid species are aggregated (Atlantic and coho salmon, and rainbow trout). Data from Sernapesca.

From a species perspective, Sernapesca escapes data from 2016 to 2020, separated by Atlantic and coho salmon and rainbow trout, were provided (pers. comm., Pablo Cajtak, 2021). After analysis, these data show that 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 33). 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.

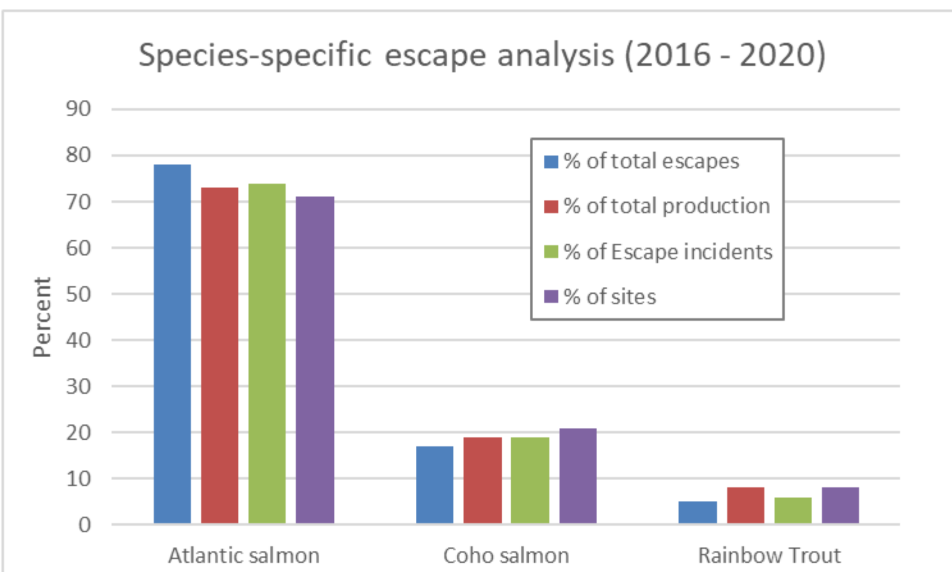

Figure 33. Analysis of Sernapesca escapes data from 2016 to 2020 separated by species. Data from Sernapesca, provided by pers. comm., P. Cajtak, 2021.

Large-scale catastrophic escape events are clearly limited to a quite 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 that 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 that 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 times 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 minority of farms in Chile. Yet, high numbers of farmed salmonid 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 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. Although the number of fish escaped and the number of escape events for rainbow trout is low compared to those for Atlantic and coho salmon, the escape risk is the same across all species. Thus, the initial score for Factor 6.1—Escape Risk is 2 out of 10 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% of the escaped fish or face a fine or even the withdrawal of its license.

Vivanco (2020) reports the number of fish escaped and each event's recapture percentage from 2016 to 2020 for Region X (Table 13). The average recapture percentage per event is 22% (Vivanco, 2020). But, this averaged percentage does not accurately reflect the fraction of fish recaptured from the total fish escaped during this period. For instance, out of the 1.22 million escapees, only 93,517 fish were recaptured, corresponding to a much lower 7.6%.

Table 13: Salmonid escapes from 2016 to 2020 in Los Lagos - Region X (Vivanco, 2020).

Year	No. Escaped Fish	% Recaptured	No. Recaptured Fish
2016	47,000	10.13	4,761.1
2017	567	38.62	219.0
2017	63,156	3.04	1,919.9
2017	213,973	0.02	42.8

2018	373	10.00	37.3
2018	690,277	6.00	41,416.6
2018	28,660	12.00	3,439.2
2019	518	87.00	450.7
2019	26,511	24.12	6,394.5
2019	22,943	30.00	6,882.9
2020	37,150	27.00	10,030.5
2020	92,863	19.30	17,922.6
Total	**1,223,991**	**22.27 (Avg)**	**93,517.0**

Additional research 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 shows an average of 14.6% recapture (range of 1% to 30%). These data illustrate that recaptures do occur, but the data 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 fishers for local sale); for example, in response to a record fine relating to a large escape in 2018, the company (Mowi[64]) 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." Part of the CLP 5.3 billion fine (USD 6.7 million) related to an insufficient recapture rate (i.e., at approximately 5.7%, it was less than the regulated 10%).[65] There may also be some case to argue that the high aggregation of predatory birds around net pens (Jimenez, Arriagada et al. 2013) along with other predatory animals might cause some mortality after an escape event, or during trickle escapes, but this cannot be quantified. It is worth noting that the lack of artisanal fishers and lower predation pressure by native predators such as sea lions in Region XII compared to Regions X and XI present a higher risk for environmental impact, due to potentially lower escapees' mortality and lower mitigation/recapture capacity in the region (Soto et al. 2022).

Overall, recaptures do occur and may be substantial in some escape events, especially in areas that are close to human settlements and fishery coves. Using the limited data available, the recapture adjustment is 1 out of 10 for Regions X and XI and 0 out of 10 for Region XII. The final score for Factor 6.1—Escape Risk is 3 out of 10 for Regions X and XI and 2 out of 10 for Region XII.

Factor 6.2. Competitive and Genetic Interactions

Salmonid escapes in areas where farming intensity, suitable habitats to support reproduction and juvenile salmonid rearing, and low capacity of mitigating escapes have been identified as those with the highest environmental risks (Soto et al. 2022). After fish escape, their

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

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

potential for impact depends 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 salmonids in Chile, mortality is likely to be high because of a limited feeding ability in the wild and predation (e.g., Arismendi et al., 2014). For example, in contrast to the South American sea lion (*Otaria byronia*) sampled in the north of Chile, Guererro et al. (2020) noted that 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 that is commonly found in terrestrial environments, suggesting consumption of farmed salmonids whose diet is usually based on terrestrial sources. Similarly, Sepulveda et al. (2015) showed that 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.

Since the beginning of the 20th century, 10 salmonid species, including rainbow trout, have been intentionally introduced throughout Chile and Argentinian Patagonia as a consequence of governmental and private efforts. Three species of trout (brown, rainbow, and brook) rapidly established and are present throughout Patagonia, which happened well before aquaculture in the region began (Di Prinzio et al., 2009)(Pascual et al., 2007). Rainbow trout is known to be one of the most successful salmonid invaders in Chile and the most widely distributed nonnative species in the region. A possible factor for its success is its facultative anadromous lifestyle, which allows it to disperse into streams via the sea (Di Prinzio, Casaux et al., 2009)(Young, Dunham et al., 2010). Hence, escaped rainbow trout poses a significant threat to native Chilean ecosystems because it has the greatest potential to establish naturalized populations as a result of its high plasticity (Monzón-Argüello et al., 2014). Although Chalde et al. (2019) note that established nonnative trout species have interacted with native species for a long period of time and have likely reached a balance that allows them to cohabitate stably, it is also important to consider the genetic differences between trout raised for the stocking of wild waterbodies versus those raised to be grown in net pens. Though genetic diversification would be a priority in the former to maintain a healthy feral population that could more likely cohabit with native species, the latter would be selected for faster growth and resiliency (e.g., disease resistance). Therefore, trout escapes would present a higher environmental risk than those purposefully introduced into wild habitats (Soto et al., 2022).

Soto et al. (2022) further explain that rainbow trout presents a higher risk of affecting biodiversity and ecosystem services than the other salmonids (i.e., Atlantic and coho salmon), and it receives the highest risk scores for the three assessed criteria: species hazard, habitat sensitivity, and habitat exposure. Rainbow trout's risk scores were mainly driven by its survival, trophic impacts, reproductive capacity, availability of suitable food, stream reproductive potential, and presence of native or endangered species that trout compete with. These risks become even more relevant in Region XII (considered a pristine and ecologically relevant ecosystem), where the introduction of sturdier and faster-growing rainbow trout strains through escapes has not occurred until the recent expansion of aquaculture to this region. As mentioned previously, Region XII is more sensitive to disturbance from escapes because natural predators such as sea lion are much less abundant than in Regions X and XI, and artisanal and sport fishing pressure is also much lower (Soto et al., 2022).

Although a long residence time would be expected to be a driving factor for genetic, phenotypic, and adaptative (growth-related traits) divergence, it was not the case, according to a study by Monzón-Argüello et al. (2014). Instead, the youngest populations were as genetically diverse as the older populations. Furthermore, hybridization between escapees and naturalized rainbow and brown trout was the most significant factor in increasing phenotypic variation, which results in heterosis (individuals with superior qualities due to crossbreeding) (Monzón-Argüello et al., 2014).

Chile’s Fisheries Development Institute (Instituto de Fomento Pesquero, IFOP) has conducted research fishing since 2014 for wild and feral fish in 29 zones of 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; rainbow trout made up 15.9% of the salmonids portion. Rainbow trout was the third most captured species, surpassed only by bass and sea silverside fish when considering all water bodies. But, it was the most caught species in freshwater bodies, accounting for 28.7% of the total sample. The regional stratification of captured samples showed that rainbow trout was most abundant in Los Rios (Region XIV), La Araucania (Region IX), and Aysen (Region XI), with 37.1%, 14.7%, and 14.4%, respectively. Though rainbow trout only accounted for 2.4% of the sample captured in Magallanes (Region XII), the IFOP’s study does not reflect the recent expansion of aquaculture in this region. Trout’s production level in Region XII has fluctuated over the period shown in Figure 4 (2019–21), but it still shows an increasing trend for all salmonids. This trend is expected to continue as more of the 53 concessions waiting for approval get authorized and as the industry continues to develop the currently lacking infrastructure in this region (e.g., hatcheries). Thus, it will be important to increase monitoring (including freshwater ecosystems) to better understand the fate of escaped salmonids and be able to detect any changes in the population structure of Region XII (Soto et al., 2022).

The scope of this assessment typically excludes the hatchery stage of rainbow trout production, but evidence indicates that the smolt escapees cultured in freshwater bodies can establish wild populations in rivers and lakes. For instance, since the 1980s, many lakes and their adjacent rivers in Chile have been used as the primary media for salmonid smolt production (León-Muñoz, 2007). Until 1991, 70% of aquaculture concessions in lakes belonged to the country’s five major salmonid producers. From 1998 to 2005, almost 1 billion smolts were produced in Chilean freshwater sites, and a little over 600 million in estuaries (León-Muñoz, 2007). In 2014, 500,000 rainbow trout smolts were produced in Lake Llanquihue alone—the lake with the largest smolt production in Chile (Benavente, 2015). Hence, the close relationship between the smolts produced in freshwater bodies and supplied to marine grow-outs, paired with the IFOP 2019 analyses described below, are discussed in this evaluation.

The IFOP 2019 also used genetic profiles to assign freshwater rainbow trout caught in the wild as wild-spawned or a direct farm escape. The first genetic analysis determined that, from the

879 individuals caught at 40 different locations, the majority (67.11%) were genetically designated to the "Lago Llanquihue" reference group, and 22.96% were farm escapes. These two groups are genetically different, but the trout populations established in Lago Llanquihue and assigned to this reference group are highly influenced by many farms in the area presenting high heterozygosity levels, which possibly results in an overestimation (IFOP 2019).

A second genetic analysis reported in IFOP 2019 clearly shows that the two southern lakes (Lago Villarrica and Lago Calafquen) in Figure 34 have more farms in their vicinity (blue dots) and higher genetically identified percentages as escaped individuals compared to the two northern lakes. Of the analyzed individuals in Lago Villarrica, 92% were farm escapes and only 8% were feral (Araucania group). Similarly, for Lago Calafquen, 88% were farm escapes and only the remaining 12% were feral. With fewer farms in their vicinity, the two northern lakes, Lago Colico and Lago Caburga, showed considerably lower proportions of escaped individuals (but still over half), with 75 and 64%, respectively.

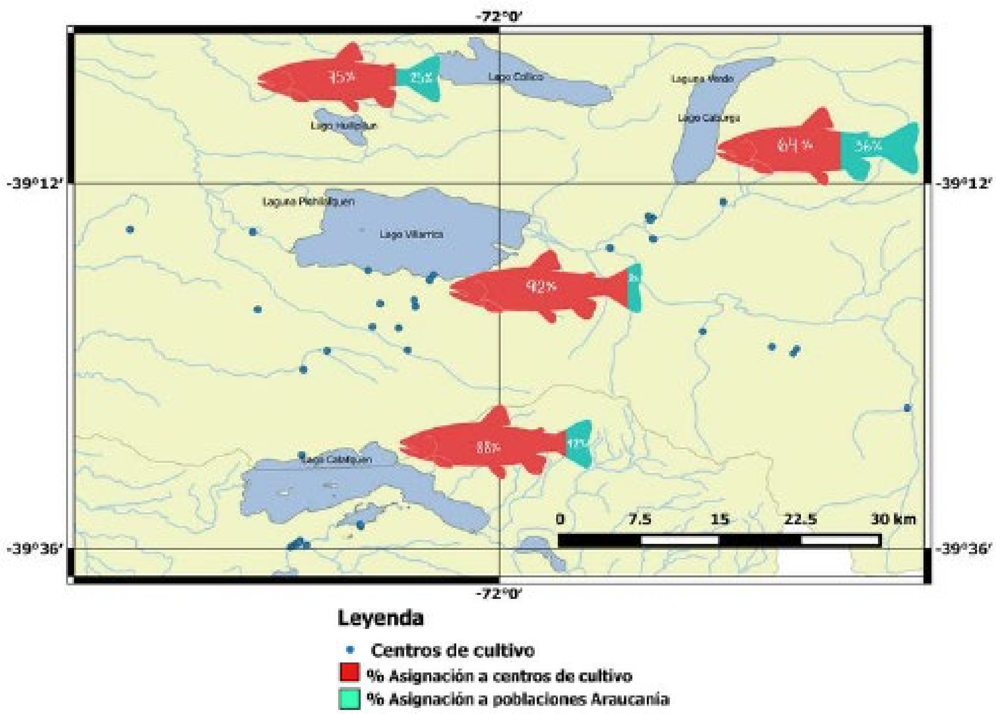

Figure 34. Genetic identification using branchial tissue of rainbow trout from four lakes in La Araucania (Region IX). Blue dots represent the geographic location of rainbow trout farms. Analyzed individuals assigned to two reference groups: "centros de cultivo (Red)" = farm escape group and "poblaciones Araucania (green)" = feral from Araucania. Map copied from IFOP (2019).

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. Figueroa-Munoz et al. (2021) suggest a synergistic interaction between rainbow trout and other invasive salmonids because of the adjustment of trout's diet to the salmonid spawning season. During Chinook salmon's spawning season, its eggs represented the primary food source for rainbow trout, thus increasing growth and condition to further rainbow trout's establishment in the system.

Although it does not necessarily explain causation, dated literature demonstrated a clear correlation between high salmonid abundance and low numbers of native species such as jack mackerel and hake (Soto and Jara, 1995)(Soto et al., 2001). These native species are threatened in Chile, mainly due to overfishing, but are also considered major competitors with salmonids. Moreover, rainbow trout's diet within a year of escaping into the inner seas consists primarily of pelagic crustacean species (32.3% frequency of diet item occurrence), followed by fish species (15% frequency). Predation pressure imposed by exotic salmonids, particularly on schooling fish, is thought to be high (Niklitschek, Soto et al. 2013), though it is known that predation on native fish species is more commonly associated with brown trout (*Salmo trutta*) than rainbow trout due to the former's greater ability to hunt in low light conditions. Given the high tannin content and low transparency of many Chilean waterways, predation by rainbow trout may be less of a threat than initially thought (Arismendi et al., 2012). But, these references also highlight a challenge in interpreting the scientific literature with regard to the impacts of any one species of salmonid among the several introduced and still farmed in Chile (e.g., De Leaniz et al., 2010; Soto et al., 2001; Buschmann et al., 2009).

In Chile and elsewhere in the Southern Hemisphere, the primary concern is the impact of nonnative 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." Escaped rainbow trout has been found to significantly decrease the abundance of several species of Galaxiidae (Sepulveda et al. 2013)(Correa and Hendry 2012)(Vanhaecke et al. 2012)(Habit et al. 2010), as well as a variety of native fish species in Argentinian Patagonia (Cussac et al. 2014). For instance, Maldonado-Márquez et al. (2020) provide an update about the diversity and distribution of fish populations in the Robalo River basin in one of the last wild areas of the planet, the Cape Horn Biosphere Reserve. The study confirms that rainbow trout actively predates on *G. maculatus*, feeds on the same prey, and is found within the same habitats, reiterating that rainbow trout's predation on and competition with native fish may lead to locally imperiled populations of native species. In addition, Chile's Ministry of the Environment has classified three endemic species (*A. taeniatus*, *A. zebra*, and *A. marinus*) of this southern Patagonia region as endangered since 2011. Though the classification is based on limited data, the species face a high risk of extinction (Ministerio del Medio Ambiente, 2011). In contrast, Young et al. (2010) have demonstrated that native Galaxiid species can and do coexist with rainbow trout. But, the authors speculate about whether it is possible that local extirpations can occur with time. Although major declines in abundance have been observed, Galaxiid genetic diversity has not been shown to be affected by aquaculture escapees, though more research is required to truly explain the impact of escaped rainbow trout on native fish populations (Vanhaecke et al. 2012).

Although rainbow trout was fully ecologically established in Chile before aquaculture began (Carcamo et al. 2015), it is believed that escapes from farms have aided the high establishment success and rapid expansion of the species through increased propagule pressure and the maintenance/enhancement of genetic diversity in feral populations. There is contradicting evidence on the potential impacts of escaped rainbow trout on native ecosystems and their biodiversity. Nonetheless, there is confirmation that this species competes for food, predates upon wild species, interferes with native ecosystems, and can even act as vectors for disease and parasites (see Criterion 7). Therefore, competition, predation, and impacts to wild species, habitats, or ecosystems may occur, but are not considered likely to affect the population status of wild species in Regions X and XI, resulting in a score for Factor 6.2—Competitive and Genetic Interactions of 4 out of 10.

These impacts are now an increasing concern for Region XII, where the most recent industry expansion is taking place (see Figure 4) and where a single escape event of 51,000 rainbow trout has already been recorded (Sernapesca, 2021). Here, additional concern exists, given the pristine nature of the region, the presence of endangered endemic species, and the documented competitive and predatory impacts of rainbow trout. This location in Chile is considered a pristine ecoregion, including one of the last wild areas of the planet, the Cape Horn Biosphere Reserve, and it provides habitat to three endemic and endangered species (*A. taeniatus*, *A. zebra*, and *A. marinus*). So far, the data (Figures 32 and 33) show a strong correlation between salmonids' production level and the number of escapees, with no indicators suggesting that a different outcome could be achieved in Region XII.

Though rainbow trout were established in this region well before aquaculture (justifying a score of 8 out of 10), the species has a high potential for impact, and given the increasing production volumes and, in turn, increasing escape numbers, an increase in range and impact is possible (justifying a score of 0 out of 10) (Soto et al., 2022). Therefore, an intermediate score is applied on a precautionary basis, and Factor 6.2—Competitive and Genetic Interactions is scored 1 out of 10 for Region XII.

Conclusions and Final Score

Large escape events of farmed salmonids continue to occur in Chile. Escape events totaling 410,000 escaped fish were reported in 2020, including a single escape event of 51,000 rainbow trout in the ecoregion of Magallanes. 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, 3.8 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 escaped salmonids on average in Regions X and XI (noting that some, e.g., by local fishers, may not be reported), but because of the lack of artisanal fishers and lower predation pressure by native predators such as sea lions, recaptures in Region XII are considered insignificant. Large numbers of salmonids still enter the environment every year, and the production system remains vulnerable in all regions.

Escaped rainbow trout poses a significant threat to native Chilean ecosystems because of the species' unique potential to establish naturalized populations. Decades of intentional stocking for recreational fishing have established populations throughout southern Chile, and although rainbow trout is known to predate upon the Galaxiid spp., it appears to have reached a balance that allows them to cohabit. The contradictions in the literature make it challenging to score this criterion with a high level of confidence, which is why it is pertinent to use the precautionary approach in this case. Regions X and XI are not considered pristine habitats, and significant aquaculture production of rainbow trout has been occurring in these regions for decades. This is not the case for Region XII, where industry expansion is ongoing and which is considered a pristine ecoregion, providing habitat to three endemic and endangered species. Rainbow trout (nonnative) was established in this region for sport fishing well before aquaculture began, and it only accounted for 2.4% of the samples captured during a study carried by IFOP; nonetheless, the potential increase in escapees of trout bred for farming (as opposed to stocking), as a result of the ongoing industry expansion, increases the risk of escapees affecting the population status of wild species.

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). With a production system vulnerable to large escape events and trickle losses, and a small adjustment for recaptures (in Regions X and XI), the net pen systems' vulnerability to escape results in a Factor 6.1 score of 3 out of 10 for Regions X and XI and 2 out of 10 for Region XII. Regarding Factor 6.2, competition, predation, and impacts to wild species, habitats, or ecosystems may occur, but are not considered likely to affect the population status of wild species in Regions X and XI, therefore scoring 4 out of 10 and resulting in a Criterion 6—Escapes final score of 3 out of 10. But, Factor 6.2 in Region XII was scored 2 out of 10, because of rainbow trout's high potential to affect the population status of wild species and its possible further expansion within this range. As a result, the Criterion 6—Escapes final score is 2 out of 10.

Criterion 7. Disease; Pathogen and Parasite Interactions

Impact, unit of sustainability and principle

- Impact: Amplification of local pathogens and parasites on fish farms and their 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

Rainbow trout in all regions

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

Criterion 7—Disease

Brief Summary

Disease-related losses and increased production costs have been a defining characteristic of the development of salmonid farming in Chile, but with control improving, the mortality due to disease is relatively low (15.9% for rainbow trout in 2020). Of 54 active rainbow trout production sites in 2020, 7 were classified as centers of high pathogen dissemination (CAD, its Spanish acronym) for SRS in 2020 (all sites under surveillance) and 12 for sea lice in 2021. The IFOP monitoring of wild-caught fish for the presence of pathogens of concern to salmonid 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 infectious pathogens and parasites that may be transmitted to wild fish (including species endemic to Chile). Parasitic sea lice in Region XII appears 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). Still, 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 do or do not affect wild fish, the Risk-Based Assessment method is used. Ultimately, despite the widespread employment of biosecurity protocols, Chilean salmonid farms are challenged with diseases, and the openness of the net pen production system directly connects farmed rainbow trout to wild populations. Although diseases are more commonly detected in Regions X and XI, mainly because of higher production levels, the new detections of the parasitic sea lice in Region XII make the overall risks applicable to all regions. The final score for Criterion 7—Disease is 4 out of 10.

Justification of Rating

Without a robust understanding of how on-farm disease affects wild organisms (i.e., Criterion 1 scored 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 emergence 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[66]). 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 2007–09, 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, piscirickettsiosis (SRS), and parasitic sea lice (*Caligus rogercressyi*).

The Chilean industry and the government have invested heavily in research, particularly on key diseases such as SRS. A large volume of literature is linked to projects such as the Program for Sanitary Management in Aquaculture (Programa para la Gestión Sanitaria en Acuicultura, PGSA).[67] Although this research is important to reduce the impact of diseases on farms and secondary aspects such as 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. Mortality rates vary from month to month, with higher values occurring from January to July, corresponding somewhat with higher water temperatures in the austral summer (January to April) (Sernapesca, 2021). The highest mortality month in 2020 for rainbow trout was July, with a rate of ≈2.4%, increasing to ≈2.8% in

[66] www.sernapesca.cl
[67] http://pgsa.sernapesca.cl/

April 2021 (Sernapesca, 2021). Rainbow trout experienced the lowest mortality rate during November in 2020 (0.5%) and in October in 2021 (0.4%) (Sernapesca, 2021). Overall, the monthly average mortality rate for rainbow trout in 2021 was 1.29%, which is similar to that of coho salmon (1.3%) and higher than that of Atlantic salmon (1.08%) (Sernapesca, 2021). Average monthly mortality rates are generally substantially lower in Region XII (0.46%) than in Regions X (1.34%) and XII (1.2%) (Sernapesca data, 2021).

There are a variety of mortality causes on salmonid farms, and infectious diseases of interest in this report were responsible for 15.9% of mortalities in rainbow trout (Sernapesca, 2020). For rainbow trout, SRS is the dominant disease (67.3%), followed by tenacibaculosis (10%; caused by the bacterium *Tenacibaculum maritimum*), idiopathic trout syndrome (≈5%; SIT), bacterial kidney disease (≈5%; BKD), and infectious pancreatic necrosis (≈5%; IPN) (Figure 35). SRS is caused by *Piscirickettsia salmonis*, an intracellular bacterium, and results in mortality during the grow-out stage (at sea) of the productive cycle (Flores-Kossack et al., 2020). *Tenacibaculum maritimum* is a member of the family Flavobacteriaceae, which usually affects fish by eroding their mouth, causing skin ulcers, fin necrosis, and tail rot; such injuries are susceptible to other opportunistic pathogens, such as *Vibrio* spp. (Perez-Pascual et. al., 2017). SIT first appeared in the industry in 2012, and the causative pathogen is still not known (Aqua, 2015b); recent work has failed to link SIT to an infectious agent, suggesting that etiology may not be infectious (pers. comm., D. Jimenez, Intesal-SalmonChile, July 2017).

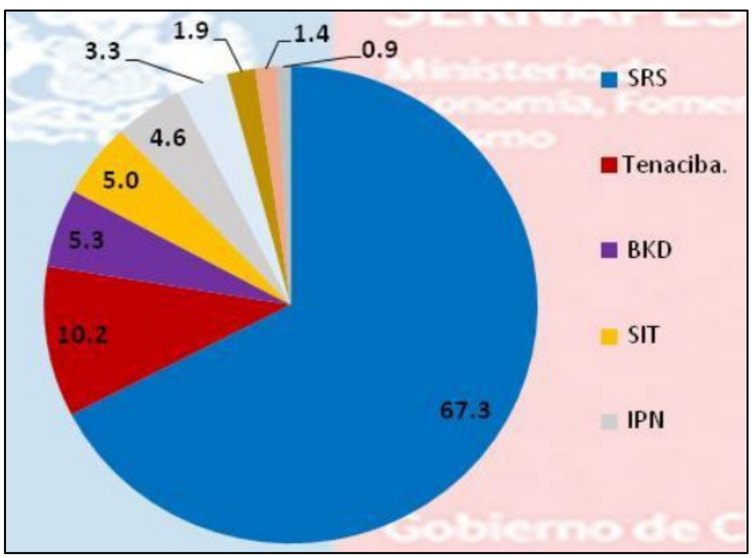

Figure 35. Distribution of infectious disease mortality for rainbow trout in Chile in 2020. SRS = salmon rickettsial septicemia, Tenaciba. = tenacibaculosis; BKD = bacterial kidney disease, SIT = idiopathic trout syndrome, and IPN = infectious pancreatic necrosis. Image copied from Sernapesca, 2020.

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

The amplification of pathogens on fish farms and their potential retransmission to wild fish is of primary concern for ecological impact. Though farmed fish are commonly infected by environmental pathogens, they can also be vectors of pathogen discharge into the marine environment before any disease-related mortality (e.g., Shea et al., 2020).

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. Sernapesca breaks down the number and percentage of piscirickettsiosis CADs by productive-cycle stage per species. For all salmonids, the highest number of CADs for *Piscirickettsia salmonis* was detected in stage T3 in 2019 and 2020. In 2020, 85.7% (six out of seven sites) of CADs producing rainbow trout at T3 detected dissemination of this agent (Table 14) (Sernapesca 2020). But, in 2021 there were no CADs reported for rainbow trout at any stage of its production cycle (Sernapesca, 2021).

Table 14. Rainbow trout piscirickettsiosis CADs per production-cycle stage, by weight. Sernapesca, 2020

Production-Cycle Stage	Weight Range (kg)	Piscirickettsiosis—CAD%
T1	0 to 1	0%
T2	>1 to 2	14.3%
T3	>2	85.7%

Sernapesca's annual health report also includes maps showing the spatial distribution of CADs by region and species concerning the parasitic sea louse, *Caligus rogercresseyi*, in 2021. A visual examination revealed that 9 CADs for rainbow trout were identified in Region X, where 33 active trout sites operated in 2021. In Region XI, where 16 active trout sites operated, only 3 CADs were identified. And in Region XII, where there were only five active trout sites, there were no CADs identified. The number of CADs detected per region aligns with the level of production in each region, which has been identified as a driving factor for the decimation of *C. rogercresseyi* by numerous authors (Lepe-López et al., 2021; Dresdner et al. and Mancilla-Schulz et al., 2019; Arriagada and Marin, 2018; Bravo et al., 2011; Kristoffersen et al., 2013). Therefore, rainbow trout farms in Chile are potential sources of pathogens and parasites that could potentially infect and affect 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 a high concern in salmonid 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 through the annual program for the high-risk pathogens of IPN, PRV, *P. salmonis*, *F. psychrophilum*, and *R. salmoninarum*, 71 (1.69%) were positive. When considering only the salmonid farming Regions X, XI and XII, the percentage 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 and the one with the highest number of samples that tested positive (22 out of 38 or 58% of total positive samples) during research fishing was robalo (*Eleginops maclovinus*), with a 1.8% positivity rate (IFOP, 2019). Although rainbow trout only accounted for 2.6% (1 out of 38 positive samples) of the number of samples that tested positive for all species, its positivity rate of 2.4% (1 positive sample out of 41 total trout samples) was higher than that for robalo (IFOP, 2019). The highest regional detection of *P. salmonis*, for all species, was in Region XI (n = 18), but an IFOP analysis of farm-level salmonid 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). For PRV, rainbow trout showed a positivity rate of 0.8% (all positive samples from Region X), lower than that for Atlantic salmon (11.1%) and coho salmon (2.8%). Similarly, 0.92% of the 646 rainbow trout samples tested positive for *F. psychrophilum*, mainly from Region X. None of the 665 rainbow trout samples tested positive for IPN and *R. salmoninarum* (IFOP, 2019).

Lozano-Muñoz et al. (2021) noted that *Piscirickettsia* 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 that rickettsia-like organisms (RLOs) are a part of the normal microbiota of aquatic animals (and proposed a hypothesis that an alteration in the balance of the bacterial population in fish leads to the development of the pathology piscirickettsiosis in farmed fish). Quintanilla et al. (2021), noted that robalo transferred *P. salmonis* to rainbow trout in cohabiting challenge tests and, although the trout developed characteristic pathological lesions with 46% mortality, the robalo did not and did not suffer any mortality. Similarly, robalo that was inoculated with two strains of *P. salmonis* showed no mortality (Soto-Dávila et al., 2020).

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 external parasites such as sea lice. It is worth noting that internal parasites are highly unlikely to be present on farmed trout and thus highly unlikely to be transferred to wild species; farmed trout exclusively consume manufactured pellet feeds, and the primary vector for internal parasites is through the consumption of intermediate hosts (e.g., snails and worms). From the 467 samples that tested positive, 149 (31.9%, including all parasitic species) were rainbow trout—the second-highest percentage of parasitism per species (IFOP, 2019). Nevertheless, of concern is the recent establishment of sea lice on 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[68]) (Arriagada 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 before the noted epidemic behavior. Although Arriagada et al. (2019) note that the parasite may have been introduced to Region XII via the frequent movements of fish farm vessels from Regions X and XI (Arriagada et al., 2019), Bravo et al. (2006) note the presence of *C. rogercreseyi* in Argentina. Arriagada et al. (2019) also noted a 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 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 that 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., 2021) conclude that wild salmon are exposed to a low infection pressure from fish farming. This also agrees with Wallace et al. (2017), who conclude that 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 that 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. Though this approach has not been taken in Chile, these findings suggest that it is possible that the pathogen profile of farmed salmonids in Chile includes uncharacterized pathogens that may affect wild species in Chile. Therefore, it is important to carry out similar efforts in Chile to ensure that disease monitoring is comprehensive and inclusive of all potential threats.

The detection of pathogens in wild fish does not indicate disease presence, but the epidemiology of disease in wild fish is poorly understood, and information with which to make judgments about pathogen spillback is sparse (Jones et al., 2015). Because of the challenges of

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

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., 2020).

Conclusions and Final Score

Disease-related losses and increased production costs have been a defining characteristic of the development of salmonid farming in Chile, but with control improving, the mortality due to disease is relatively low (15.9% for rainbow trout in 2020). Of 54 active rainbow trout production sites in 2020, 7 were classified as centers of high pathogen dissemination (CAD, its Spanish acronym) for SRS in 2020 (all sites under surveillance) and 12 for sea lice in 2021. The IFOP monitoring of wild-caught fish for the presence of pathogens of concern to salmonid 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). Although 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 infectious pathogens and parasites that 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). Still, 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 do or do not affect wild fish, the Risk-Based Assessment method is used. Ultimately, despite the widespread employment of biosecurity protocols, Chilean salmonid farms are challenged with diseases, and the openness of the net pen production system directly connects farmed rainbow trout to wild populations. Though diseases are more commonly detected in Regions X and XI, mainly because of higher production levels, the new detections of the parasitic sea lice in Region XII make the overall risks applicable to all regions. The final score for Criterion 7—Disease is 4 out of 10.

Criterion 8X. Source of Stock—Independence from Wild Fisheries

Impact, unit of sustainability and principle

- Impact: The removal of fish from wild populations
- 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

Rainbow trout in all regions

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

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

Justification of Ranking

Salmonid aquaculture has seen a multidecade establishment of breeding programs aimed at the selection of traits advantageous to farming (e.g., fast growth, disease resistance), which has been integral to the rapid growth of the industry (Asche et al., 2013)(Heino et al., 2015)(Gutierrez et al., 2016). Rainbow trout is no different and it has been selectively bred for beneficial traits, such as growth rate and disease resistance, for decades throughout the world (Carcamo et al., 2015)(Janssen et al., 2015)(Reis Neto et al., 2019). Chile is no exception; all stock is sourced from domestic hatcheries (see Criterion 10X).

Conclusions and Final Score

Because of the ubiquitous use of hatchery-raised fingerlings in the marine net-pen culture of Chilean rainbow trout, the industry is considered to be completely independent of wild rainbow trout fisheries for the supply of either broodstock or fingerlings. Because the Chilean rainbow trout industry is completely independent of wild populations, the score for Criterion 8—Source of Stock is 0 out of –10.

Criterion 9X: Wildlife and Predator Mortalities

Impact, unit of sustainability and principle

- Impact: Mortality of predators or other wildlife caused or contributed to by farming operations
- 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

Rainbow trout in all regions

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 salmonids 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 salmonid farms in Chile is limited and has been shown to be of questionable validity, particularly considering the remote areas in which the industry operates. Thus, without a robust understanding of the impact on 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 the southern sea lion and birds are considered to interact with farms regularly. There are records of accidental cases of mortalities of sea lions, dolphins, humpback whale, and recently a single sei whale. Though 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 salmonid and shellfish industries) is large and has a significant potential for interactions with blue whale. The potential disturbance is addressed in Criterion 3—Habitat, and the risk of mortality to cetaceans from collisions with aquaculture vessels appears low. Overall, regulations and management practices for nonharmful exclusion and control are in place. Still, accidental mortalities (such as those resulting from entanglement) cannot be prevented, and mortality numbers are unknown. There is no evidence with which to differentiate impacts by salmonid species, and the final score for Criterion 9X—Wildlife Mortalities is –4 out of –10 for rainbow trout.

Justification of Ranking
In Chile, trout are farmed in production systems where the same technology is used independently of the species under cultivation. Consequently, this section was reproduced almost in its entirety from the Atlantic and Coho salmon report. 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 salmonids 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 typically feed on native fish stocks (Sepulveda et al., 2015)(Espinosa-Miranda et al., 2020). Although some may threaten production, they can also become entangled in nets and other farm infrastructure, resulting in 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) was established primarily by the World Wildlife Fund–Chile (WWF) concerning 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 salmonid 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. 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[69] from intentional killing,[70] 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 require all such events to be reported to Sernapesca, including the causes and the measures adopted by the farm to prevent repeat events.

Intesal[71] reports the number of sightings, the number of wildlife within the vicinity of the operation, and the number of entanglements during May to August for 2020 and 2021; however, it does not explicitly report on the number of mortalities. Other than the information reported by Intesal, there are no additional public data available on marine mammal mortalities in Chile. Data on intentional and accidental marine mammal mortalities from GSI for eight

[69] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/http://www.sernapesca.cl/sites/default/files/res.ex_.2811-2021_0.pdf
[70] Except for exceptional situations where human life is at risk.
[71] https://www.intesal.cl/informe-cuatrimestral/may-ago/

Chilean salmon farming companies show that only 2 companies reported any mortalities in 2019 (species not defined), with an average of 1 accidental mortality per 200 sites and no intentional mortalities. The average marine mammal mortality for the last 3 years is 1 per 223 sites according to the GSI data, all of which were accidental.

Without industry-wide public data (and even perhaps with it), there are concerns that the required reporting to Sernapesca is not fully effective and whether or not 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 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 dolphin (*Cephalorhynchus eutropia*), and two involving humpback whale (*Megaptera novaeangliae*) (one of which, a calf, was fatal, and the other was released alive). But, only two of the dolphin mortalities and one of the humpback entanglements (the nonlethal one) were present in the official Sernapesca records (Espinosa-Miranda et al., 2020), and the authors 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 lion (*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 that the lack of reporting suggests noncompliance with national legislation. This limitation is considered 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 that these are difficult to evaluate without the context of local population sizes. For humpback whale, the same authors also note that it is not clear if these occasional entanglements would inhibit this species' strong recovery (from overexploitation in commercial whaling). Most recently, industry media[72] 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

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

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 to 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 salmonids) because there is plasticity to their feeding strategies and individuals can learn to exploit situations where salmonids are concentrated and vulnerable. In Chile, a strong operational interaction between the South American sea lion and the salmonid farming industry has been previously described, but there are no reports of the fur seal (*Arctocephalus australis*) 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 proximity of salmonid 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 salmonids that are not currently penned within salmonid farms).

It is considered here that the uncertainty in reporting of marine mammal mortalities to Sernapesca identified by Espinosa-Miranda et al. (2020) also applies 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 whale (*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 salmonid farming industry, and Bedriñana-Romano et al. (2021) noted the relatively large size of the aquaculture fleet (which includes vessels servicing shellfish farms). Research from COPAS-Sur Austral and WWF–Chile also suggests that noise pollution causes communication problems in cetaceans, limiting their feeding ability (WWF Chile, 2022). Although 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[73]). Their research identified only three documented large whale mortality events linked

[73] 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,

to vessel collisions in northern Chilean Patagonia (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, and it appears likely that the risk of lethal interactions between aquaculture vessels and whales (of relevance to this criterion) is low. But, more robust data, including complete agreement between government data and independent research, would provide greater confidence in the understanding of the salmonid 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 areas with salmonid 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 3 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 this author's own experience of visiting salmonid 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 salmonid farms are not considered likely to affect population sizes negatively.

Conclusions and Final Score

The presence of cultivated salmonids 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 salmonid farms in Chile is limited and has been shown to be of questionable validity, particularly considering the remote areas in which the industry operates. Thus, without a robust understanding of the impact on 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 the southern sea lion and birds are considered to interact with farms regularly. There are records of accidental cases of mortalities of sea lions, dolphins, humpback whale, and recently a single sei whale. Although 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.

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tanker, cruise, and military vessels is an important reflection of the relative potential for aquaculture vessels to affect whales due to direct collision.

The aquaculture vessel fleet in Chile (which includes vessels servicing both the salmonid and shellfish industries) is large and has a significant potential for interactions with blue whale. The potential disturbance is addressed in Criterion 3—Habitat, and the risk of mortality to cetaceans from collisions with aquaculture vessels appears low. Overall, regulations and management practices for nonharmful exclusion and control are in place. Still, accidental mortalities (such as those resulting from entanglement) cannot be prevented, and mortality numbers are unknown. There is no evidence with which to differentiate impacts by salmonid species, and the final score for Criterion 9X—Wildlife Mortalities is –4 out of –10 for rainbow trout.

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

Rainbow trout in all regions

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

Brief Summary

The biosecurity of animal movements within Chile is understood to be high, with strict controls in place to prevent the spread of nontarget organisms, including pathogens. Concerning broodstock and fingerling biosecurity, broodstock is generally housed in tank-based recirculation systems with high biosecurity, while fingerlings are grown in lakes, introducing some possibility, albeit remote, of biosecurity breaches. Nonetheless, the utilization of health management zones and the fact that trans-water-body movements are between fresh and saltwater dramatically reduce this risk. In addition, rainbow trout farming has not relied on imported eggs since 2016. Concluding that there is minimal risk for the escape of secondary species, this results in a final score for Criterion 10x—Escape of Secondary Species of 0 out of –10.

Justification of Rating

According to the UN FAO (2012), the expanded and occasionally erratic global movements of live aquatic animals have been accompanied by the transboundary spread of a 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. The import of infected salmon eggs from Norway was believed to be the reason for the ISA outbreak in Chile in 2007, which led to a significant tightening of regulations concerning the movement of fish and fish products into Chile (Anderson, 2012).

Factor 10Xa: International or trans-water body live animal shipments

The ISA crisis in the salmon industry led to a significant tightening of regulations concerning the movement of fish and fish products into Chile. As a result, a quite small portion of eggs is now imported into Chile, considerably reducing the risk of importing unwanted or dangerous organisms. As Chile has become self-sufficient in salmonid egg production, the importation of eggs has declined to approximately 400,000 of exclusively Atlantic salmon eggs 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).

Data from Sernapesca (Estadística de Importación de Ovas por origen[74]) indicate that no imports of rainbow trout eggs (ova) into Chile have been registered since 2016. From 2011 to 2016, the importation of trout eggs declined from 70 million to less than a million (Figure 36). Sernapesca also reports that Chile's domestic production was almost 93 million rainbow trout eggs in 2020 (DAS 2020).

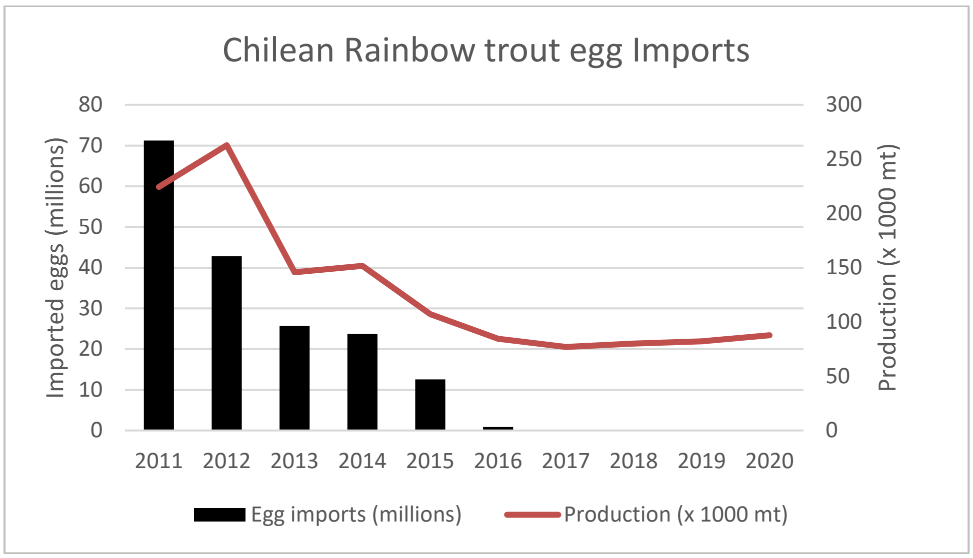

Figure 36. Black bars show live salmon egg imports, 2011–2020. Data from Sernapesca's website, Estadística de Importación de Ovas por origen. Red line shows annual production ×1,000 mt (Sernapesca 2021).

Movements of smolts from hatcheries to seawater grow-out sites are an integral part of the salmonid production system in Chile. For instance, broodstock is generally housed in tank-based recirculation systems with high biosecurity. Their offspring grow in freshwater until a portion is transferred to open-net pens in the sea. 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

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

(Solicitud de Autorización de Movimiento). The ISA crisis resulted in the implementation of regulations to ban the 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 salmonid 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 water-body. Therefore, the score for Factor 10Xa: International or trans-water-body live animal shipments is 10 out of 10 for rainbow trout.

Factor 10Xb: Biosecurity of source/destination
Because the score for Factor 10Xa is 10 out of 10, Factor 10Xb does not need to be assessed.

Conclusions and Final Score
The biosecurity of animal movements within Chile is understood to be high, with strict controls in place to prevent the spread of nontarget organisms, including pathogens. Concerning broodstock and fingerling biosecurity, broodstock is generally housed in tank-based recirculation systems with high biosecurity, while fingerlings are grown in lakes, introducing some possibility, albeit remote, of biosecurity breaches. Nonetheless, the utilization of health management zones and the fact that trans-water-body movements are between fresh and saltwater dramatically reduce this risk. In addition, rainbow trout farming has not relied on imported eggs since 2016. Concluding that there is minimal risk for the escape of secondary species, this results in a final score for Criterion 10x—Escape of secondary species of 0 out of –10.

Overall Recommendation

The overall recommendation is as follows:

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

– **Best Choice** = Final score ≥6.6 AND no individual criteria are Red (i.e., <3.3)
– **Good Alternative** = Final score ≥3.3 AND <6.6, OR Final score ≥ 6.6 and there is one individual "Red" criterion.
– **Red** = Final score <3.3, OR there is more than one individual Red criterion, OR there is one or more Critical score.

Criterion	**Scores**			**Critical?**
	Region X	**Region XI**	**Region XII**	
C1 Data	6.59	6.59	6.59	
C2 Effluent	4.00	4.00	2.00	NO
C3 Habitat	6.40	6.40	6.40	NO
C4 Chemicals	2.00	2.00	6.00	NO
C5 Feed	4.59	4.59	4.59	NO
C6 Escapes	3.00	3.00	2.00	NO
C7 Disease	4.00	4.00	4.00	NO
C8X Source	0.00	0.00	0.00	NO
C9X Wildlife mortalities	–4.00	–4.00	–4.00	NO
C10X Secondary species escape	0.00	0.00	0.00	
Total	**26.58**	**26.58**	**27.58**	
Final score (0–10)	**3.80**	**3.80**	**3.94**	

OVERALL RANKING	**Rainbow Trout**		
	Region X	**Region XI**	**Region XII**
Final Score	**3.80**	**3.80**	**3.94**
Initial rank	YELLOW	YELLOW	YELLOW
Red criteria	2	2	2
Interim rank	RED	RED	RED
Critical Criteria?	0	0	0
Final Rating	RED	RED	RED

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About Seafood Watch®

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

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

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

Disclaimer

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

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Guiding Principles

Seafood Watch® defines sustainable seafood as originating from sources, whether fished[75] or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

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

Seafood Watch will:

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

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

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

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

Best Choices/Green: Buy first, they're well managed and caught or farmed in ways that cause little harm to habitats or other wildlife.

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

Avoid/Red: Don't buy, they're overfished or caught or farmed in ways that harm other marine life or the environment.

Appendix 1 - Data Points and All Scoring Calculations

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

Regions X, XI, and XII

Criterion 1: Data	
Data Category	**Data Quality**
Production	10.0
Management	7.5
Effluent	7.5
Habitat	5.0
Chemical Use	7.5
Feed	2.5
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

Criterion 2: Effluent	**Region X and XI**	**Region XII**
Effluent Evidence-Based Assessment	**Data and Scores**	**Data and Scores**
C2 Effluent Final Score (0–10)	**4**	**2**
Critical?	NO	NO

Regions X, XI, and XII

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	2
3.2b Enforcement of habitat management measures	4
3.2 Habitat management effectiveness	3.200
C3 Habitat Final Score (0–10)	**6.400**
Critical?	No

Criterion 4: Chemical Use	Regions X and XI	Region XII
All-species assessment	**Data and Scores**	**Data and Scores**
Chemical use initial score (0–10)	2	6
Trend adjustment	0	0
C4 Chemical Use Final Score (0–10)	**2**	**6**
Critical?	No	No

Regions X, XI, and XII

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 %	6.370
Fishmeal from by-products, weighted inclusion %	3.430
By-product fishmeal inclusion (@ 5%)	0.172
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	5.700
Fish oil from by-products, weighted inclusion %	2.900
Byproduct fish oil inclusion (@ 5%)	0.145
Fish oil yield value, weighted %	5.000
eFCR	1.300
FFER Fishmeal value	**0.378**
FFER Fish oil value	**1.520**
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	**4**

5.2 Net Protein Gain or Loss (%)	Data and Scores
Weighted total feed protein content	40.000
Protein INPUT kg/100kg harvest	52.000
Whole body harvested fish protein content	17.800
Net protein gain or loss	–65.769
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
GWP (kg CO_2-eq kg^{-1} farmed seafood protein)	**12.629**
Contribution (%) from fishmeal from whole fish	4.053
Contribution (%) from fish oil from whole fish	2.434
Contribution (%) from fishmeal from by-products	2.183
Contribution (%) from fish oil from by-products	1.255
Contribution (%) from crop ingredients	71.430
Contribution (%) from land animal ingredients	10.021
Contribution (%) from other ingredients	8.624
Factor 5.3 score	**7**
C5 Final Feed Criterion Score	**4.59**
Critical?	**No**

Criterion 6: Escapes	Regions X and XI	Region XII
	Data and Scores	**Data and Scores**
F6.1 System escape risk	2	2
Percent of escapees recaptured (%)	14.000	0
F6.1 Recapture adjustment	1.120	0
F6.1 Final escape risk score	3.120	2
F6.2 Invasiveness score	4	2
C6 Escape Final Score (0–10)	**3.0**	**2.0**
Critical?	No	No

Regions X, XI, and XII

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

Regions X, XI, and XII

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

Regions X, XI, and XII

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

Regions X, XI, and XII

Criterion 10X: Introduction of Secondary Species	Data and Scores
Production reliant on trans-water-body movements (%)	0
Factor 10Xa score	10
Biosecurity of the source of movements (0–10)	10
Biosecurity of the farm destination of movements (0–10)	10
Species-specific score 10X score	0.000
Multispecies assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**0.000**
Critical?	n/a