Atlantic Salmon

Salmo salar

Image © Monterey Bay Aquarium

Norway

Marine Net Pens

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Seafood Watch Consulting Researcher

Contents

About Seafood Watch®

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

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

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

Guiding Principles

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

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

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

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

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

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

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

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

Final Seafood Recommendation

Atlantic salmon

Salmo salar

Norway - Production Areas 1 to 13

Marine net pens

Criterion	**Production Areas and scores**												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
C1 Data	7.05	7.05	7.05	7.05	7.05	7.05	7.05	7.05	7.05	7.05	7.05	7.05	7.05
C2 Effluent	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
C3 Habitat	6.93	6.93	6.93	6.93	6.93	6.93	6.93	6.93	6.93	6.93	6.93	6.93	6.93
C4 Chemicals	4.00	6.00	2.00	2.00	4.00	6.00	4.00	4.00	4.00	4.00	4.00	4.00	6.00
C5 Feed	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80
C6 Escapes	4.00	6.00	0.00	1.00	3.00	4.00	3.00	1.00	0.00	0.00	0.00	5.00	4.00
C7 Disease	4.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.00	2.00	4.00	4.00	4.00
C8X Source of stock	-5.00	-5.00	-1.00	-1.00	-3.00	-1.00	-1.00	-1.00	0.00	0.00	0.00	0.00	0.00
C9X Wildlife mortalities	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00
C10X Introductions	-2.00	-3.00	-1.20	-1.20	-3.00	-1.20	-1.20	-1.20	-1.20	-1.20	-1.20	-1.20	-1.20
Total	24.78	23.78	19.58	20.58	20.78	27.58	24.58	24.58	24.58	24.58	26.58	31.58	32.58
Final score (0-10)	**3.54**	**3.40**	**2.80**	**2.94**	**2.97**	**3.94**	**3.51**	**3.51**	**3.51**	**3.51**	**3.80**	**4.51**	**4.65**

OVERALL RATING

	1	**2**	**3**	**4**	**5**	6	7	8	9	10	11	12	13
Final Score	3.54	3.40	2.80	2.94	2.97	3.94	3.51	3.51	3.51	3.51	3.80	4.51	4.65
Initial rating	Y	Y	R	R	R	Y	Y	Y	Y	Y	Y	Y	Y
Red criteria	0	1	3	3	2	1	2	2	2	2	1	0	0
Interim rating	Y	Y	R	R	R	Y	R	R	R	R	Y	Y	Y
Critical Criteria?	0	1	2	2	1	1	1	1	1	1	1	0	0
Final Rating	**Y**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**Y**	**Y**

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

Summary

- The final numerical scores for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Norway's Production Areas 1, 12 and 13 range from 3.54 to 4.65, and with no red criteria, the final rating is yellow and a recommendation of Good Alternative.
- The final numerical scores for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Norway's Production Areas 2, 6 and 11 range from 3.40 to 3.94, which is in the yellow range, but with one Critical criterion (either Escapes or Disease), the final rating is red and a recommendation of Avoid.

- The final numerical scores for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Norway's Production Areas 3-5 and 7-10 range from 2.80 to 3.51, which are in the red and yellow ranges, but with multiple red criteria and at least one Critical criterion, the final rating is red and a recommendation of Avoid.

Executive Summary

Norway is the world's largest farmed salmon producer, harvesting 1,377,185 mt in 2020 from approximately 700 active net pen production sites along the coast. The long coastline is divided into thirteen Production Areas (Area 1 begins at the Swedish border in the south, and Area 13 ends at the Russian border in the north). Approximately 350 million salmon smolts are stocked per year and the standing stock (of 400 million fish) is about 800 times the number of wild salmon returning to the rivers in Norway annually. Norway is home to more than 400 wild Atlantic salmon populations (plus other native salmonids such as brown trout and Arctic char) whose conservation, particularly salmon, is highly prioritized. While the historic declines in wild Atlantic salmonid populations observed across the Atlantic are not associated with aquaculture production, given their current status of the populations, any potential contributions to their more recent declines or inhibitions of their recovery (if any) are considered here.

The assessment involves criteria covering impacts associated with effluent, habitats, wildlife mortalities, chemical use, feed production, escapes, introduction of secondary species (other than the farmed species), disease, the source stock, and general data availability[1]. As noted below, the data availability in Norway is good and many types of data are available at the site level. Resources such as the Institute of Marine Research's annual Risk Assessment for Norwegian Aquaculture (and the accompanying comprehensive "knowledge status" review) analyze the industry in each of the Production Areas along the coast. Each Area has complex environmental and industry variables, but the good availability of data allows this Seafood Watch assessment to consider each of the thirteen Production Areas separately for many criteria.

For more detail on data availability, Norwegian agencies such as Directorate of Fisheries, the Institute of Marine Research, the Veterinary Institute, the Environment Agency, the Norwegian Food Safety Authority, and others have numerous annual reports and/or regularly updated statistics on many aspects of production and monitoring of impacts in the environment, particularly to wild salmonids. Production information is often available on a site-by-site basis in various mapped databases, and several key impacts are analyzed at the scope of each of the country's 13 Production Areas, particularly in the Institute of Marine Research (IMR) annual Risk Assessment of Norwegian Fish Farming. Company annual reports and other industry

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

publications provide further information, but feed data were limited. A large and rapidly growing body of academic research supports the government and industry data, but some impacts continue to be challenging to understand conclusively. Many reports are published only in Norwegian and while online translation is effective, some loss of detail is inevitable. Overall, the score for Criterion 1 – Data is 7.05 out of 10 for all Production Areas.

It is notable that for the large majority of the coast of Norway, aquaculture is the major source of soluble nutrients to coastal waters. However, the IMR's 2020 risk assessment provides a comprehensive review of the industry's impact to the water column, and by combining modelling results and physical monitoring data, it determined with high confidence that there is a low risk of environmental impacts as a result of increased soluble nutrient supply from aquaculture in all Production Areas.

Emissions of particulate wastes from fish farming are high, and the impact on the seabed can become substantial during production; however, the emissions consist primarily of easily degradable compounds and the impact is reversible. Monitoring in the immediate farm areas shows greater than 90% of sites are consistently in "Very good" or "Good" condition in all regions, with similar results when the sampling a larger area surrounding farms. There are limitations in monitoring of hard- or mixed-bottom sites and there are as-yet uncertain contributions to potential fjord-level impacts associated with cumulative inputs from other sources. In this context, the IMR risk assessment considers the risk of environmental impact due to particulate emissions to be low on soft seabed sites, and moderate on hard seabed sites in all Production Areas. Across the industry, the data show that effluent discharges result in occasional yet temporary impacts within the immediate vicinity of the farm, but there remains potential for cumulative impacts at the waterbody or regional scale. The final score for Criterion 2 – Effluent is 6 out of 10 for all Production Areas (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

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

The regulatory system for siting and impact assessment in Norway is comprehensive and inclusive of aquaculture's co-existence with other industrial, recreational, and conservation interests, but 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. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management effectiveness is robust. The final score for Criterion 3 – Habitat is of 6.93 out of 10 for all Production Areas.

Antimicrobial use in Norway is low, with a total of 17 prescriptions were written in 2020 for salmon in marine net pens (with approximately 675 active sites). The total use of 230 kg in 2020 represents 0.17 grams per mt of salmon production and a frequency of much less than one treatment per site. As 30% of the total used is categorized as critically important for human medicine by the World Health Organization, and the remainder as highly important for human medicine, the necessity for judicious use remains. Chemical pesticide use, mostly to treat parasitic sea lice, has declined by more than 90% over the last five or six years, mainly due to the resistance developed by the target sea lice. The increasingly ineffective chemical treatments have largely been replaced with non-chemical alternatives (often at the expense of animal welfare and increased mortality). The resistance is still widespread in sea lice throughout Norway and may not decline as rapidly as the use of chemicals due to the establishment of resistance genes within lice populations. A 2020 audit of pesticide regulations showed a small percentage of pesticide bath treatments continue to be discharged close to shrimp habitats and cod spawning habitats. The use of pesticides is highly variable by Production Area (both in the total number of prescriptions and the number of treatments per site), with three regions (2,5,6) having the lowest with less than one treatment per site per year in 2020. The IMR's comprehensive risk assessment concluded the risk of environmental effects on non-target species was moderate for the use of five of the main chemical treatments (emamectin benzoate, deltamethrin, diflubenzuron, teflubenzuron, and hydrogen peroxide) and low for azamethiphos (with moderate knowledge certainty in these findings).

The use of copper antifoulants has steadily increased in recent years, with 1,698 mt used by Norwegian aquaculture in 2019. The use is variable by Production Area. The IMR risk assessment considers the risk of impact from copper use to be low in five Production Areas (9-13), moderate in six areas (1,2,5,6,7,8), and high in areas 3 and 4. Overall, these characteristics of chemical use define the final score in each of the Production Areas: for Production Areas 2 and 6, the <1 pesticide treatments per site in 2020 predominantly of treatments of a moderate concern, combined with the moderate copper concern results in a final score for Criterion 4 – Chemical Use of 6 out of 10. For Production Area 13, the >1 pesticide treatments per site in 2020 of predominantly low concern pesticides at a low number of active sites combined with a low copper concern also results in a final score of 6 out of 10. For Production Areas 1, 5 and 7-12, the >1 pesticide treatments per site in 2020 of predominantly moderate concern pesticides combined with a moderate or low copper concern result in a final score of 4 out of 10. And for Production Areas 3 and 4, the >1 pesticide treatments per site in 2020 of predominantly moderate concern pesticides combined with a high copper concern result in a final score of 2 out of 10.

In the absence of specific feed composition information from Norwegian feed mills, data from the reference feeds in the academic literature and company reports were used. Using total fishmeal and fish oil inclusions of 14.5% and 11.1% respectively and an eFCR of 1.3, from first principles, 2.18 mt of wild fish must be caught to supply the fish oil needed to produce 1.0 mt of farmed salmon. This value is higher than that reported for three Norwegian salmon farming companies by GSI and is likely due to minor variations in the values used for the feed conversion ratio and for the yield and inclusion level of fish oil. This can only be verified with better data availability. Information on the sustainability of source fisheries for three major feed companies published by the Ocean Disclosure Project showed a moderate overall sustainability and resulted in a Wild Fish Use score of 1.65 out of 10. There is a substantial net loss of 63.8% of feed protein (score of 3 out of 10) but a small feed ingredient footprint (7.32 kg CO_2-eq. per kg of harvested protein (score of 8 out of 10) due to the high use of crop ingredients. Overall, the three factors combine to result in a final score for Criterion 5 – Feed of 3.80 out of 10.

Salmon continue to escape from Norwegian farms in both large-scale events and in small-scale trickle losses. As a result of escapees interbreeding with wild Atlantic salmon, only 33% of wild populations in Norway have good or very good genetic status; 27% have poor or very poor status and 30% have moderate status. The most recent annual risk assessment on salmon farming (2021 publication) conducted by the Institute of Marine Research (IMR) concluded that this has led to a reduced production of wild salmon, as well as changes in important biological properties in wild stocks such as age at sexual maturity and migration time for smolts. The IMR notes regional variations in the risk of these impacts and uses two primary factors in separate risk assessments for each of the 13 Production Areas: 1) the occurrence of escaped farmed salmon in the spawning grounds, and 2) the robustness of the wild stocks against new genetic introgression). These two IMR factors (and their sub-factors which include recaptures) closely mirror the two Seafood Watch Escape Criterion Factors 6.1 (escape risk, including recaptures) and 6.2 (competitive and genetic interactions), and the IMR risk assessment has largely been used to inform the Seafood Watch scores.

The final Seafood Watch scores for Criterion 6 – Escapes show escaping farmed salmon are a critical conservation concern in Production Areas 3, 4, 8, 9, 10 and 11 (scores of 0 and 1 out of 10), and a high concern in Areas 5 and 7 (score 3 out of 10). These Seafood Watch results largely reflect the “Poor” outcomes of the IMR risk assessment in these Areas. Production Areas 1, 2, 6, 12 and 13 have moderate scores of 4 out of 10 (PA 1 and 6,), 5 out of 10 (PA 12) and 6 out of 10 (PA2) and largely reflect the presence of a “Moderate” outcome in either one of the IMR risk assessment factors. Overall, the IMR risk assessment had a moderate “knowledge status” in all Production Areas (except Area 3, where it was good) and the application of the Seafood Watch Aquaculture Standard produced slightly more conservative results compared to those of the IMR (e.g., in PA2). It is also of interest to note that genetic changes have also been observed in wild wrasse populations due to the escape of imported cleaner fish, but these have not currently affected the scores in this assessment.

The detection of bacterial and viral pathogens in wild salmonids in Norway is low, and while farms can still act as chronic reservoirs of pathogens, the focus of this Disease Criterion is on parasitic sea lice. While the industry typically keeps lice below regulatory levels at individual farms, the cumulative dispersal of sea lice from the industry creates a substantial infection pressure in coastal waters that can infect and affect wild salmon migrating past farms and/or those species spending longer periods of time in coastal waters such as sea trout. The "traffic light" system in Norway is the most important regulatory tool with regard to annual sea lice impacts on juvenile wild salmon in each of the Production Areas. As such, the findings of the traffic light expert working group are important, but with a consideration of a longer-term dataset and cumulative impacts (from 2012 to 2020), and particularly the full inclusion of impacts to sea trout (and Arctic char), the results of the IMR risk assessment are the focus here. The IMR assesses two primary factors in each of the Production Areas which are combined to determine the risk of lice-induced mortality for juvenile salmon and sea trout. The first factor is the risk that wild fish will be infected by sea lice from farms, which is informed by the environmental conditions for lice, the emissions of lice from farms, and the overlap between wild fish and lice in time and space. The second factor is the wild fish's tolerance to sea lice infection, which mainly considers the fish size at the potential time of infection. The IMR risk assessment is also supported by a separate comprehensive knowledge status review, and the evidence-based assessment option has been used in the Seafood Watch standard.

The IMR's "low" risk of sea lice induced mortality in juvenile wild salmon or sea trout typically results from either low emission of lice from farms or from little overlap in the timing of lice emissions and the presence of wild salmon or sea trout (such that there is a low probability that they will be infected with lice). Nevertheless, mortality may be moderate in some rivers in some years, and the "low" IMR category allows annual mortality of up to 10%. With consideration of this potential level of lice-induced mortality, the score for Criterion 7 – Disease in Production Areas with a "low" IMR outcome is therefore 4 out of 10 as sea lice can cause mortality but are not considered to have a population-level impact. Conversely, a "high" risk of mortality (high lice emissions and high overlap) is associated with population-level impacts to wild salmon or sea trout, and the score for Criterion 7 – Disease is 0 and a "Critical" conservation concern due to the vulnerable nature of wild salmon and sea trout populations in Norway. For the intermediate "moderate" risks of mortality to wild salmon and sea trout (with a 10% to 30% annual mortality range), the final score for Criterion 7 – Disease is 2 out of 10 as sea lice are considered to negatively impacts the affected species' population size or its ability to recover. The Seafood Watch Aquaculture Standard scoring therefore takes a more precautionary approach to the mortality categories used by both the traffic light system and the IMR risk assessment, and in summary, Production Areas 1 and 11-13 have a final score for Criterion 7 – Disease of 4 out of 10. Production Areas 8-10 have a low score of 2 out of 10, and Areas 2-7 have a "Critical" final score for Criterion 7 – Disease.

As is common throughout the global salmon aquaculture industry, Norwegian salmon farming production is based on hatchery-raised broodstocks selectively bred over many generations. As such, the industry is considered to be independent of wild salmon fisheries for broodstock, eggs, or juveniles. With increasing use of non-chemical alternatives to sea lice treatment, the use of cleaner fish (which can eat the sea lice parasites) is now substantial. In 2020, 51.5 million cleaner fish were used in Norway, of which 17.4 million (33%) were wild caught, consisting primarily of four species of wrasse. The wrasse fishery established a quota of 18 million fish in 2018 alongside other management measures, but there is still a high potential for local stocks to be overfished. Approximately 65% to 70% of Norwegian salmon farms use cleaner fish (i.e., both wild and farmed), but the use (particularly of wild-caught sources) varies across the 13 Production Areas. Only Areas 1 to 8 are considered to use wild caught wrasse with relatively higher use in the southern Areas (which are also the focus of the wild capture fisheries in Norway and geographically closer to the fishing areas in Sweden). The final scores for Criterion 8X – Source of Stock is based on the proportion of farmed salmon production that is dependent on the use of wild caught fish, in this case wrasse. As such, it is estimated here that 53% of salmon farming production in Areas 1 and 2 (using the number of sites as a proxy for production) is dependent on wild caught wrasse, 18% in Areas 3 and 4, 37% in Area 5, and 11% in Areas 6 and 7. Given that Grefsrud et al (2021a) note the use of wild caught wrasse extends in to Area 8, the same 11% of production is also considered to be dependent on them. These values relate to final scores for Criterion 8X – Source of Stock of a deduction of -5 out of -10 for Production Areas 1 and 2, -1 out of -10 for Production Areas 3, 4, 6, 7, and 8, and -3 out of -10 for Production Area 5.

Harbor seals are the most likely marine mammals to interact with salmon pens in Norway, and Norwegian regulations for the control of seals allow them to be killed if they damage fishing gear or farm infrastructure at sea when “reasonable efforts and other measures to avert damage” have failed. Other than three companies reporting (zero mortalities) through GSI, there are no robust mortality (lethal control or entanglement) data. GSI also report a low number of bird entanglements (average of 2.1) per site each year, but again, further data are not available. The Norwegian Marine Mammal Scientific Advisory Board describes the regulations and management measures in place for marine mammals, and many species continue to be hunted to some extent in Norway. Information on the status of the harbor seal population indicates any mortalities on salmon farms are unlikely to affect the population status. With mortality numbers unknown, the Risk-Based Assessment method was used and the final score for Criterion 9X – Wildlife Mortalities is -4 out of -10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Movements of live fish are a characteristic of the Norwegian salmon farming industry, with shipments of smolts from freshwater hatcheries to open net pen farms, fish for slaughter from net pens to slaughter facilities, and shipments of cleaner fish from wild fisheries to net pen salmon farms. Assessing the risk of introducing a non-target species during those movements is complex given the characteristics of the different source and destination. The industry’s reliance on movements of live salmon across different waterbodies was estimated to be 50% of production (Factor 10Xa score of 4 out of 10), but the freshwater hatcheries that are the primary source of movements have good biosecurity and a low risk of introducing secondary species at the source (Factor 10Xb score 8 out of 10). This was considered to be consistent across all Production Areas and resulted in a final score for Criterion 10X of -1.2 out of -10 (i.e., a small deduction) for the movements of salmon in all Production Areas.

Data from the Directorate of Fisheries show the use of wild caught cleaner fish (mostly four species of wrasse) is highly variable across Production Areas, and the IMR risk assessment on the risk of spreading infection during movements of these fish describes the typical movements into and out of the fishing zones and salmon farming Production Areas. Based on the proportions of farmed salmon production in each Area that are dependent on the use of wild wrasse (calculated in Criterion 8X – Source of Stock), between 8% and 26% of farmed salmon production in different Areas are considered to be dependent on wild wrasse that have been moved across waterbodies (and that therefore represent a risk of unintentionally transporting secondary species). Factor 10Xa scores therefore range from 7 out of 10, to 10 out of 10. The movements of wild caught wrasse are considered to have minimal biosecurity at both the source and destination (Factor 10Xb score of 0 out of 10).

Factor 10Xa (the reliance on movements of live fish) and 10Xb (the biosecurity of those movements) combine as follows to give a final score for Criterion 10X – Escape of Secondary Species. For Production Areas 3, 4, and 6 to 13 the final score is a deduction of -1.2 out of -10 based on salmon movements. Production Areas 2 and 5 have a final score of -3 out of -10 based on movements of wild caught cleaner fish, and Area 1 has a final score -2 out of -10, also based on movements of wild cleaner fish. For reference, these results do not match the outcomes of the IMR assessment on the risk of infection spread due to the use of wild wrasse (which was considered to be low in Area 1, moderate in Areas 2-4, and high in Areas 5-8). This is due the use here of data on the numbers of farmed and wild caught cleaner fish in each Production Area for this Seafood Watch assessment, combined with the number of farming sites in each Area. This is considered to more closely reflects the proportion of farmed salmon in each Area that is dependent on wild cleaner fish use.

Overall, there continue to be environmental performance problems in many Production Areas that fail to meet the country’s sustainability goals. In particular, documented impacts to wild salmon and sea trout from escapes and sea lice continue to be high concerns in some Production Areas (in addition to the use of chemicals and/or capture and movement of wild caught cleaner fish to control sea lice). With good data availability, the final scores and final Seafood Watch recommendations were calculated for each of the thirteen Production Areas.

- The final numerical scores for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Norway’s Production Areas 1, 12 and 13 range from 3.54 to 4.65, and with no red criteria, the final rating is yellow and a recommendation of Good Alternative.
- The final numerical scores for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Norway’s Production Areas 2, 6 and 11 range from 3.40 to 3.94, which is in the yellow range, but with one Critical criterion (either Escapes or Disease), the final rating is red and a recommendation of Avoid.

- The final numerical scores for Atlantic salmon (*Salmo salar*) farmed in marine net pens in Norway's Production Areas 3-5 and 7-10 range from 2.80 to 3.51, which are in the red and yellow ranges, but with multiple red criteria and at least one Critical criterion, the final rating is red and a recommendation of Avoid.

All data points are available in Appendix 2, and all scoring tables and calculations are available in the Seafood Watch Aquaculture Standard.

Introduction

Scope of the analysis and ensuing recommendation

Species: Atlantic salmon (*Salmo salar*)
Geographic coverage: Norway: Production Areas 1 to 13
Production method: Marine net pens

Species Overview

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

Norway is home to approximately 440 wild Atlantic salmon populations (plus other native salmonids such as brown trout and Arctic char) whose conservation, particularly salmon, is highly prioritized.

Production System and Production Areas

All farmed salmon in Norway are produced in floating net pens in coastal inshore environments, typical to the industry worldwide. The hatchery phase is conducted primarily in tanks in indoor recirculation systems on land. The industry is divided into 13 Production Areas along the coast (Figure 1). Area 1 starts at the Swedish border in the south, and Area 13 ends at the Russian border in the north.

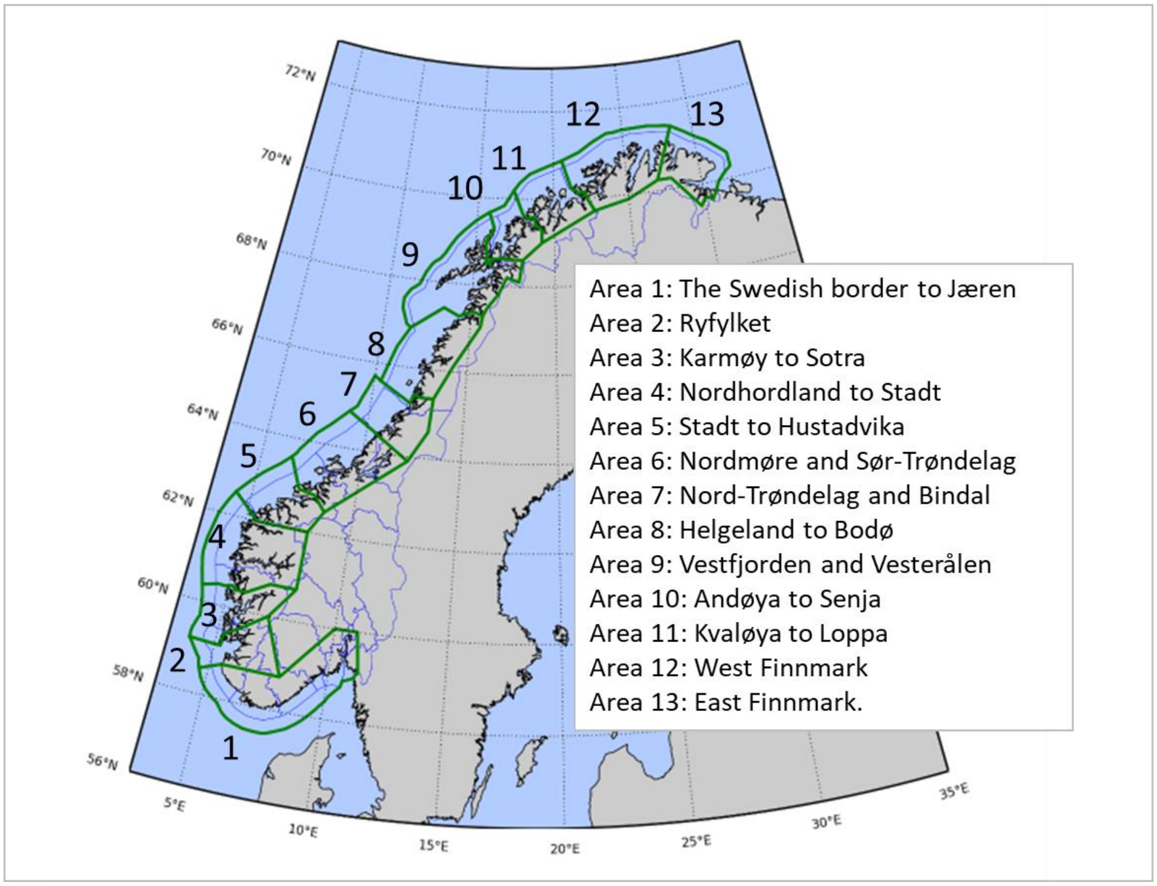

Figure 1: Map of the 13 Production Areas along the Norwegian coast. Image edited from Lovdata.no.

Each Production Area is named and geographically defined in the 2017 "Regulations on production areas for aquaculture of food fish in the sea of salmon, trout and rainbow trout (production area regulations)"[2] (Anon, 2017a), and can be found in the government's regulatory database (Lovdata.no[3]). A map and description of each Production Area from this regulation is provided in Appendix 1.

According to the Directorate of Fisheries[4], Norway had 986 marine growout sites for salmonids (including a small number for trout) in 2020. While each registered aquaculture site in Norway site is mapped in various databases (e.g., the Directorate of Fisheries[5] or Barents Watch[6]), the numbers of active (i.e., stocked) sites per Production Area are not readily available (for example, the Directorate of Fisheries publishes the number of active sites by county and not by Production Area), and they must be manually aggregated in the Barents Watch database. A separate analysis of active sites was found in Vollset et al. (2020) for 2019, and the data in Barents Watch was analyzed here to produce a second set of figures; both are shown in Table

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[2] In Norwegian: Forskrift om produksjonsområder for akvakultur av matfisk i sjø av laks, ørret og regnbueørret (produksjonsområdeforskriften)

[3] search for "produksjonsområder for akvakultur" which can be translated directly online

[4] Statistics for Aquaculture: https://www.fiskeridir.no/English/Aquaculture/Statistics

[5] https://open-data-fiskeridirektoratet-fiskeridir.hub.arcgis.com/

[6] https://www.Barents Watch.no/

1. Note the totals of 707 and 675 sites are substantially lower than the 986 active sites listed (by county) by the Directorate of Fisheries (Figure 3 below). The reason for the discrepancy is not known.

Table 1: Number of actives sites per Production Area in 2019. Data "A" from Vollset et al. (2020), data "B" aggregated from Barents Watch.

Production Area	1	2	3	4	5	6	7	8	9	10	11	12	13
# Sites (A)	6	35	112	105	29	106	45	70	68	49	29	49	4
# Sites (B)	6	32	109	108	22	88	51	69	72	48	24	43	3

Production Statistics

Data from the Norwegian Directorate of Fisheries (Fiskeridirektoratet) show Norway is the world's largest farmed salmon producer, harvesting 1,377,185 metric tons (mt) in 2020. Approximately 350 million smolts are stocked per year, with a standing stock of approximately 400 million fish in net pens along the coast (Grefsrud et al., 2020 – who note this is about 800 times the number of wild salmon returning to the rivers in Norway annually). Figure 2 shows annual production from the years 2000 to 2020 with a regional breakdown in Figure 3 (note that the Directorate of Fisheries reports production data by eight groups of Norwegian counties which do not directly align with the 13 Production Areas described above).

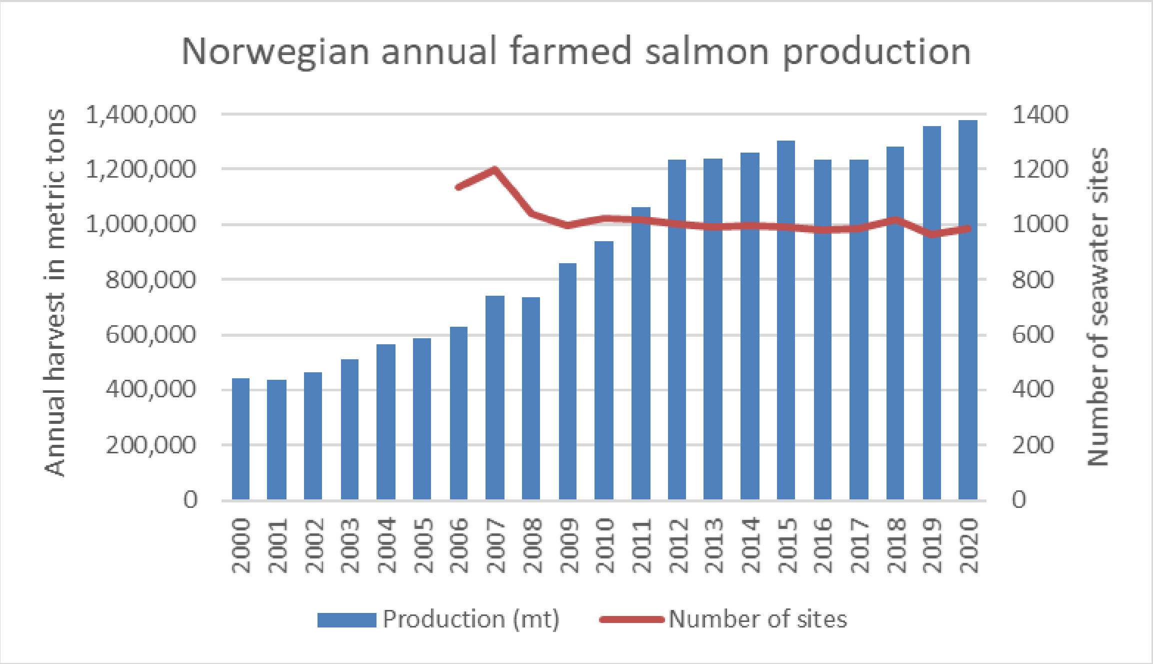

Figure 2: Atlantic farmed salmon production and the number of seawater sites in Norway. Data from the Directorate of Fisheries (Fiskeridirektoratet).

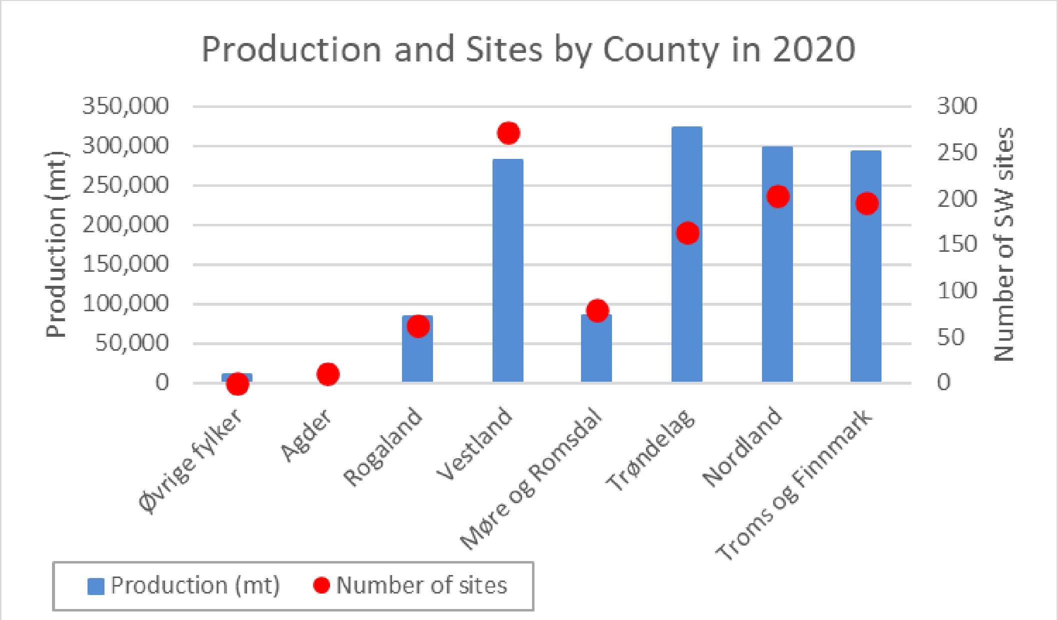

Figure 3: Annual production of farmed salmon in Norway and number of active seawater (SW) sites by county in 2020. Note these counties progress from south to north (left to right along the x-axis) but are not the same as the Production Areas in Figure 1. Data from the Directorate of Fisheries.

Import and Export Sources and Statistics

In 2019, the Directorate of Fisheries data show Norway exported around 1.28 million mt of farmed salmon, of which 67,988 mt (approximately 5%) was exported to the US. According to the US National Marine Fisheries Service, the US imported 52,249 mt from Norway (15% of total Atlantic salmon imports in 2019). The reason for the discrepancy with the Directorate of Fisheries data is not known.

Common and Market Names

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

Product Forms

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

Criterion 1: Data quality and availability

Impact, unit of sustainability and principle

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

All Production Areas

C1 Data Category	Data Quality
Production	10.0
Management	10.0
Effluent	7.5
Habitat	5.0
Chemical Use	7.5
Feed	5.0
Escapes	7.5
Disease	7.5
Source of stock	7.5
Wildlife mortalities	5.0
Introduction of secondary species	5.0
C1 Data Final Score (0-10)	**7.05**
	Green

Brief Summary

A large amount of information is available on the salmon farming industry in Norway. Norwegian agencies such as Directorate of Fisheries, the Institute of Marine Research, the Veterinary Institute, the Environment Agency, the Norwegian Food Safety Authority, and others have numerous annual reports and/or regularly updated statistics on many aspects of production and monitoring of impacts in the environment, particularly to wild salmonids. Production information is often available on a site-by-site basis in various mapped databases, and several key impacts are analyzed at the scope of each of the country's 13 Production Areas, particularly in the Institute of Marine Research (IMR) annual Risk Assessment of Norwegian Fish Farming. Company annual reports and other industry publications provide further information, but feed data were limited. A large and rapidly growing body of academic research supports the government and industry data, but some impacts continue to be challenging to understand conclusively. Many reports are published only in Norwegian and while online translation is effective, some loss of detail is inevitable. Overall, the score for Criterion 1 – Data is 7.05 out of 10 for all Production Areas.

Justification of Rating

Industry and Production Statistics

The Norwegian Directorate of Fisheries (Fiskeridirektoratet[7]) publishes a considerable body of information on aquaculture production in Norway. Some of it is only available on the Norwegian version of their website, but most data can be comprehended by simple online translations. Their annual report "Key figures from aquaculture Industry"[8] includes country- and county-level data including numbers of licenses, sites, companies, employees, fish inputs, harvests and sales, production losses, and exports. The Directorate of Fisheries website also has an interactive and publicly accessible map-format database[9] (in Norwegian) with large amounts of data on various production parameters shown for each farming site throughout the country. Most data are species-specific, but some categories are aggregated with trout and other marine species. While every site is listed in the database, there is some discrepancy in the aggregated total numbers of "active sites" reported per county by the Directorate of Fisheries and those for each Production Area (e.g., in Vollset et al., 2020, or Barents Watch[10]). Further information on production is available in company annual reports or other industry publications such as Marine Harvest's Salmon Industry Handbook[11]. Unfortunately, the annual production for each Production Area is not readily available. Data on salmon imports into the United States are available from the United States National Marine Fisheries Service (noting there is some discrepancy between these import data and the Norwegian Directorate of Fisheries export figures). Overall, the data availability is excellent and the data score for the Industry and Production Statistics is 10 out of 10.

Management and Regulations

In a collaboration between the Ministry of Justice and the Faculty of Law at the University of Oslo, the Lovdata database[12] was built with a purpose to create, maintain, and operate systems for legal information in Norway, and all the country's regulations are available on the site. An English version is available. At the company level, aggregated information is available from various annual reports and online documents, but management standards or requirements for production at the farm level are typically less transparent. Various technical standards are available from Fiskeridirektoratet for aspects such as fish containment and escape management. Information and data on key management strategies such as the Traffic Light System (see Criterion 7 – Disease) are sometimes challenging to obtain and translate fully but are considered fully available. Overall, information on the industry's management and regulation is readily available and the data score for Management and Regulations is 10 out of 10.

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[7] https://www.fiskeridir.no/

[8] https://www.fiskeridir.no/Akvakultur/Tall-og-analyse/Statistiske-publikasjoner/Noekkeltall-for-norsk-havbruksnaering

[9] https://open-data-fiskeridirektoratet-fiskeridir.hub.arcgis.com/

[10] https://www.Barents Watch.no/

[11] http://marineharvest.com/globalassets/investors/handbook/2016-salmon-industry-handbook-final.pdf

[12] https://lovdata.no/info/information_in_english

Effluent

Data on soluble effluents at salmon farm sites are not typically collected (it is not legally required) in Norway, but water quality is monitored along the coast (reviewed in Grefsrud et al., 2021a,b). The Directorate of Fisheries maps the salmon production density in mt of salmon per km^2 in fjords and bays along the coast, and academic studies on nutrient dynamics in salmon farming areas, particularly in densely farmed areas, generally provide clear conclusions and have also been reviewed (for each Production Area) in the 2020 risk assessment by the Institute of Marine Research[13] (IMR; Grefsrud et al., 2021a,b). For particulate wastes on the seabed, benthic survey results (MOM-B and -C) are available for every site and in aggregated presentations from Fiskeridirektoratet. These results are also reviewed (by each Production Area) by Grefsrud et al. (2021a,b) and the latest results for individual sites are also available on the interactive map-database hosted on the website of Fiskeridirektoratet[14]. There remains some uncertainty regarding the impact to hard- and mixed-bottom sites and the cumulative impact in some bays and fjords. Overall, the data score for Effluent is 7.5 out of 10.

Habitat

The location and layout of each site's mooring system is available in the Directorate of Fisheries mapped database, and with readily available satellite images (e.g., Google Earth), these allow a simple overview of salmon farm locations and habitats. These also demonstrate a broad lack of functional conversion of habitats for farm construction and installation. The review of McKindsey (2011) provides a useful compilation of potential impacts associated with the infrastructure, and other academic studies provide additional information on the attraction or repulsion of wildlife, hydrodynamics, and other operational activities such as the use of submerged lights. In general, there are few specific data available on the impacts of the infrastructure or their operation (other than the discharge of nutrient wastes addressed in Criterion 2 – Effluent) and these potential impacts have been poorly studied and are difficult to quantify. Regulations on siting and environmental impact assessments for new sites in Norway are also available from the directorate (although the impact assessment reports themselves do not appear to be readily available to the public). With some uncertainties in poorly understood impacts of industrial activities in the coastal zone, the data score for Habitat is 5 out of 10.

Chemical Use

Site-specific information on chemical treatments is available from the Barents Watch website[15]. The Norwegian Food Safety Authority established the Veterinary Prescription Register (VetReg) in 2011, and data on chemical use are published in associated reports, for example the Norwegian Veterinary Institute produces an annual report on antimicrobial use and the occurrence of antimicrobial resistance in Norway (e.g., NORMVET, 2019) and an annual Fish Health Report (e.g., Sommerset et al., 2021) which is a comprehensive review of the disease situation in Norway and includes information on antimicrobial use, sea lice pesticide

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[13] https://www.hi.no/hi

[14] http://www.fiskeridir.no/Akvakultur

[15] https://www.Barents Watch.no/

treatments, numbers of prescriptions and the development of resistance (of both antimicrobials and pesticides). Data on the quantities of pesticides used (by weight) no longer appear to be readily available from these sources after 2019 and only prescription data, including full or partial site treatments are currently available, but the Global Salmon Initiative (GSI) database publishes relative data on antimicrobial and pesticide use (grams active ingredient per mt of production) for three companies in Norway. The Norwegian Veterinary Institute published a report on the Surveillance Programme for Resistance in Salmon Lice (*Lepeophtheirus salmonis*) in Norway 2020 (Helgesen et al., 2021), and the Directorate of Fisheries has also published an excerpt from the 2020 audit of the environmental impact of sea lice medicines (Torvik, 2021). The IMR's annual risk assessment (Grefsrud et al., 2021a,b) assesses the risk of use of the main chemical treatments also includes a review of copper antifoulant use. The use of chemicals in Norwegian salmon farming is generally well understood, although the impacts are still not yet fully understood, 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. Categorical information was obtained from company annual reports and the Mowi industry handbook[16], and these data were supplemented by specific ingredients in each category from the Norwegian reference diets of Mørkøre et al. (2020) and Aas et al. (2019). As such, a best-fit feed composition was created that is considered to adequately represent Norwegian feeds for the purposes of this assessment. Performance results (e.g., FFER) could be checked against data from three Norwegian companies reporting through the GSI, and the significant difference in the calculated value highlights the need for better feed data in Norway. The Global Feed LCA Institute database was used for the feed footprint calculations. The data score for Feed is 5 out of 10.

Escapes

The Norwegian Directorate of Fisheries[17] (Fiskeridirektoratet) provides information on every reported escape event, including the number of fish, location (county), company, species, fish size, date, and number of escapees recaptured. The data cover each of the last ten years, although recapture data are only available from 2014 onwards. The information also includes a breakdown of the main causes of escapes. The interactive mapping tool from Fiskeridirektoratet also shows each escape event location and magnitude throughout the country for any year; an example is shown in Figure 16 in the Escapes Criterion.

The fate and potential impact of farmed salmon escapees is the subject of a large and continually evolving body of scientific research. Direct monitoring results are available, such as the annual report "Escaped farmed salmon in Norwegian rivers in 2019" (Aronsen et al., 2020) and the recent review by Glover et al. (2017) ("Half a century of genetic interaction between farmed and wild Atlantic salmon: Status of knowledge and unanswered questions") along with

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

[17] http://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Roemmingsstatistikk

other reviews, such as Forseth et al. (2019) and Thorstad et al. (2020) providing a comprehensive review of recent monitoring in Norway. The annual IMR risk assessment and accompanying Status of Knowledge report review the available data and literature, and provide assessments for each of the 13 Production Areas. Many questions remain about the fate and impact of escapes in Norway, but the data availability is good, and the data score for Escapes is 7.5 out of 10.

Disease

Regional reporting of disease outbreaks in addition to a wide variety of fish health aspects are available in the Norwegian Veterinary Institute's Fish Health Report (Sommerset et al. 2020). Site-specific data on fish health and sea lice monitoring data is available in detail from Barents Watch. There is a substantial amount of data available on wild fish monitoring associated with the national monitoring program (NALO); e.g., Nilsen et al. (2020) and substantial subsequent analysis and review, e.g., Madhun et al. (2021), Karlsen et al. (2020a). The annual IMR risk assessment (Grefsrud et al., 2021a) assesses the risk or mortality to wild salmon and sea trout from viral pathogens and sea lice, and is accompanied by a comprehensive status of knowledge report (Grefsrud et al., 2021b). The traffic light system also provides important risk information for the annual impacts to wild salmonids in each Production Area (Vollset et al., 2020). Most of these reports are in Norwegian but can be adequately translated using online services. Given acknowledged uncertainties in the data and impacts, the data score for Disease is 7.5 out of 10.

Source of Stock

With the ubiquitous use of domesticated broodstock in the global salmon industry, the source of Norwegian farmed salmon stock is well established. Data on the use of cleaner fish are available from the Directorate of Fisheries, including the proportions of wild-caught and hatchery-raised fish. Grefsrud et al. (2021a,b) and others give a review of the fisheries for wild cleaner fish and recent regulatory changes, and Overton et al. (2020) and Barrett et al. (2020) provide data on the number of farms in Norway using them. With some uncertainties in the medium- and long-term sustainability of cleaner fish fisheries and the proportion of farms using wild caught versus hatchery-raised sources, the data score for the Source of Stock is 7.5 out of 10.

Wildlife and Predator Mortalities

The annual report from the Norwegian Marine Mammal Scientific Advisory Board (Bjørge et al., 2020) and other reports from these scientists describe the management measures and stock status for the many species of marine mammals in Norway, but while personal communication with this board confirms seals can be shot at farms in some circumstances, the only mortality data (for marine mammals and birds) are from three companies reporting through GSI.
The data score for Wildlife Mortalities is 5 out of 10.

Introduction of Secondary Species

The Norwegian Veterinary Institute's annual Fish Health Report (Sommerset et al., 2020), and the annual risk assessment (Grefsrud et al., 2021a,b) provides information on the movements and disease transfer risks of smolts and cleaner fish in Norway. The Directorate of Fisheries and

Sommerset et al. (2020) provide data on smolt production by county and smolt stocking which can be used to infer cross-county movements. Lillehaug (2015) provides a review of biosecurity in Atlantic salmon production which provides details particularly for the hatcheries and smolt units that are a common source of live fish movements. There is a lack of evidence of fish health diagnostic or screening procedures or regulations for the transport and transfer of wrasse or other cleaner fish; therefore, the data score for Introduction of Secondary Species is 5 out of 10.

Conclusions and Final Score

A large amount of information is available on the salmon farming industry in Norway. Norwegian agencies such as Directorate of Fisheries, the Institute of Marine Research, the Veterinary Institute, the Environment Agency, the Norwegian Food Safety Authority, and others have numerous annual reports and/or regularly updated statistics on many aspects of production and monitoring of impacts in the environment, particularly to wild salmonids. Production information is often available on a site-by-site basis in various mapped databases and various analyses, particularly the IMR's annual risk assessment, provide useful information for each Production Area. Company annual reports and other industry publications provide further information, but feed data were limited. A large and rapidly growing body of academic research supports the government and industry data, but some impacts continue to be challenging to understand conclusively. Overall, the score for Criterion 1 – Data is 7.0 out of 10 for all Production Areas.

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

Evidence-Based Assessment

All Production Areas

C2 Effluent Final Score (0-10)	**6**	Yellow

Brief Summary

With good data availability on nutrient-related impacts of the salmon industry, the Evidence-Based Assessment method is used. It is notable that for the large majority of the coast of Norway, aquaculture is the major source of soluble nutrients to coastal waters. However, the IMR's 2020 risk assessment provides a comprehensive review of the industry's impact to the water column, and by combining modelling results and physical monitoring data, it determined with high confidence that there is a low risk of environmental impacts as a result of increased soluble nutrient supply from aquaculture in all Production Areas.

Emissions of particulate wastes from fish farming are high, and the impact on the seabed can become substantial during production; however, the emissions consist primarily of easily degradable compounds and the impact is reversible. Monitoring in the immediate farm areas shows greater than 90% of sites are consistently in "Very good" or "Good" condition in all regions, with similar results when the sampling a larger area surrounding farms. There are limitations in monitoring of hard- or mixed-bottom sites and there are as-yet uncertain contributions to potential fjord-level impacts associated with cumulative inputs from other sources. In this context, the IMR risk assessment considers the risk of environmental impact due to particulate emissions to be low on soft seabed sites, and moderate on hard seabed sites in all Production Areas. Across the industry, the data show that effluent discharges result in occasional yet temporary impacts within the immediate vicinity of the farm, but there remains potential for cumulative impacts at the waterbody or regional scale. The final score for Criterion 2 – Effluent is 6 out of 10 for all Production Areas (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Justification of Rating

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

Salmon excrete both soluble and particulate wastes, primarily as a result of incomplete digestion and absorption of their feeds, and salmon net pen aquaculture represents a substantial release of nutrients and particulate matter into the environment in which farms are sited. These discharges are in addition to nutrients released into coastal waters by population (sewage), industry, and agriculture (Grefsrud et al., 2021a,b). In the far south of Norway (from the Swedish border to Jæren in Rogaland) it is mainly sources other than aquaculture that contribute the largest emissions to coastal waters, while from Rogaland to Finnmark at the northern border (i.e., the large majority of the coast of Norway), aquaculture is the major source of nutrients discharged into coastal waters (Grefsrud et al., 20121a,b). Primary production on the coast and in the fjords in Norway is relatively low, and the biological production in deep areas is often limited by nutrient deficiencies; therefore, the high discharge of nutrients from salmon farms has the potential to change ecosystems adapted to low nutrient levels (Grefsrud et al., 2021a,b).

The analysis of the salmon industry's nutrient-related impacts is separated into soluble effluents and their impacts in the water column, and, secondly, particulate wastes and their impacts on the seabed. However, it is important to note that these impacts are connected; that is, increased production of phytoplankton and zooplankton in the water column (resulting from increased nutrient availability) also leads to increased settlement of organic material to the seabed (with consequences for benthic and suprabenthic oxygen concentrations and animal communities). Also, the breakdown and resuspension of concentrated wastes on the seabed below net pens returns nutrients to the water column and/or results in resettlement in distant locations (Grefsrud et al., 2021a,b; Keeley et al., 2013).

Soluble effluent

Grefsrud et al. (2021a,b) estimate annual emissions from salmon farms in 2018 and 2019 were 52,111 mt of dissolved nitrogen and 6,885 mt of dissolved phosphorus (approximately 38.4 kg dissolved nitrogen and 5.1 kg dissolved phosphorous per mt of salmon production). For context, the same authors compare this to 48,000 mt of dissolved nitrogen and 2,600 mt of dissolved phosphorus were released from agriculture, sewage, and land-based industries.

The potential impacts of soluble nutrient releases from fish excretion (e.g., increased phytoplankton production) varies primarily by location (e.g., enclosed fjords verses open coast) and the intensity of production (Grefsrud et al., 2021a,b; Hoddevik, 2019). The Directorate of Fisheries maps the salmon production density in mt of salmon per km^2 in small areas along the coast[18] (note these are smaller than the Production Areas, typically at the scale of a single fjord or bay). Hoddevik (2019) summarizes these data, reporting there are many areas in the lower range of 50-200 mt fish/km^2, a small number exceeding 200 mt fish/km^2, and an even smaller number approaching 600 mt fish/km^2.

Studies have detected enhanced nutrient concentrations up to 100m downstream of the farm when fish biomass was high (i.e., the period of peak feeding in the production cycle), and a potential zone of influence could occasionally reach >1 km (Jansen et al., 2018). However, the same authors conclude the rapid decrease in nutrient concentrations with increasing distance from the net pens suggests that individual farms are not causing significant degradation of surface water quality. Grefsrud et al. (2021a,b) note most Norwegian salmon farms are currently located in areas with good surface flow which provides for the replacement of the surface water and helps spread and dilute the dissolved nutrients. This in turn reduces the likelihood of eutrophication. Grefsrud et al. (2021a,b) subsequently note that while increased nutrient concentrations can be measured near the farms, they are usually dispersed and diluted rapidly.

There is no legal requirement for routine monitoring of soluble effluent from fish farms in Norway, but the concentration of nutrients is measured at stations along the coast through various monitoring programs (Grefsrud et al., 2021a,b). These authors estimated the increase in phytoplankton production due to emissions from fish farming to vary from 1.0% to 17.7% across the country's 13 Production Areas. The most densely farmed area (Production Area 3) receives emissions of 1,250 kg of dissolved nitrogen and 170 kg of dissolved phosphorus per km^2 per year, resulting in an estimated 17.7% increase in phytoplankton production, but this is well below the 50% increase classified as eutrophication by Svasand et al. (2017; referencing OSPAR, 2010).

Grefsrud et al. (2021a,b) note that this densest farming area (Production Area 3) has had regular monitoring of environmental quality since 2013, and the in-situ measurements of phytoplankton show "Very good" to "Good" environmental condition (i.e., using phytoplankton density as an indicator of eutrophication) at all monitoring stations, and they state with high confidence (due to the combination of their modelling results and physical monitoring data) that there is a low risk of environmental effects (i.e., eutrophication) as a result of increased nutrient supply from aquaculture. Svåsand et al. (2017) note there is a large variation in phytoplankton biomass and species composition during any one year and between years, and significant differences in small geographical areas are also recorded; they also note a high level of uncertainty surrounding the amount of dissolved nutrients discharged from farms and therefore a potential for impacts in some local areas remains. The 2020 risk assessment (Grefsrud et al., 2021a) recognizes these uncertainties in the knowledge base in some areas but concludes there is a low risk of environmental effects as a result of increased nutrient supply from fish farming in all of the 13 Production Areas.

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

Particulate effluent

Approximately 540,000 to 670,000 mt of organic material in the form of settling fecal particles and uneaten feed are discharged annually from Norwegian fish farms (Grefsrud et al., 2021a,b) which settle on the seabed in an area controlled largely by the settling speed of the particles, the water depth, and the current speed; as a result, they generate a localized gradient of organic enrichment in the underlying and adjacent sediments (Black et al., 2008; Keeley et al., 2013, 2015). Grefsrud et al. (2021a,b) note the variability in the types of seabed along the coast in Norway, including at small spatial scales, and confirm that a localized impact under net pen farms is inevitable.

Keeley et al. (2013) describe the major pathways of bio-deposition from a typical net pen salmon farming system, showing that of the total particulates leaving the net pen, some will dissolve or release nutrients before reaching the seabed; of the portion settling on the seabed in the primary area of deposition, some will be consumed directly by benthic organisms, some will accumulate and consolidate, and some will be re-suspended and transported to far-field locations. During that transport, further nutrients will be dissolved, diluted, and assimilated, and the remainder will finally settle in far-field locations.

Monitoring of areas in close proximity to fish farms in Norway occurs with mandatory "Environmental monitoring of marine fish farm" (MOM) surveys under the Norwegian Standard NS 9410: 2016. The MOM-B investigations are performed under and in the closest vicinity of the net pen arrays, whereas the MOM-C system is a broader scale investigation of several locations within the extended area of influence (transition zone) around farms. They are based on qualitatively determined indicators of the organic enrichment and the impact on biodiversity in infaunal communities (primarily in soft-bottomed sites), such as chemical parameters (pH and redox potential) and presence/absence of macro-infauna (Grefsrud et al. 2021b). Whereas all sites must have MOM-B surveys, only approximately 10% of the total sites in Norway have MOM-C surveys according to Taranger et al. (2015). The impact is divided into state classes from "Very good" to "Very poor" based on the level of organic enrichment. Note the MOM-B and -C surveys are primarily used for soft-bottom seabeds; for mixed or hard-bottom sites, the assessment is carried out visually using remotely operated cameras[19] but Grefsrud et al. (2021a,b) note the limitations in this method (i.e., its ability to detect impacts and the limited numbers of surveys done).

Site-specific MOM-B data available from the Directorate of Fisheries[20] show that in 2020, greater than 90% of sites were in "Very good" or "Good" condition in all regions (Figure 4), and a longer time series of data from the Directorate of Fisheries (presented in Grefsrud et al., 2021a,b) shows these results have been largely consistent from 2009 to 2020, with minimal annual variation.

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[19] Alternative monitoring of hard and mixed bottom: https://www.fiskeridir.no/Akvakultur/Drift-og-tilsyn/Overvaaker-miljoepaavirkningen/Alternativ-overvaaking-av-hard-og-blandingsbunn

[20] Downloaded for all sites from the mapped database: https://kart.fiskeridir.no/akva

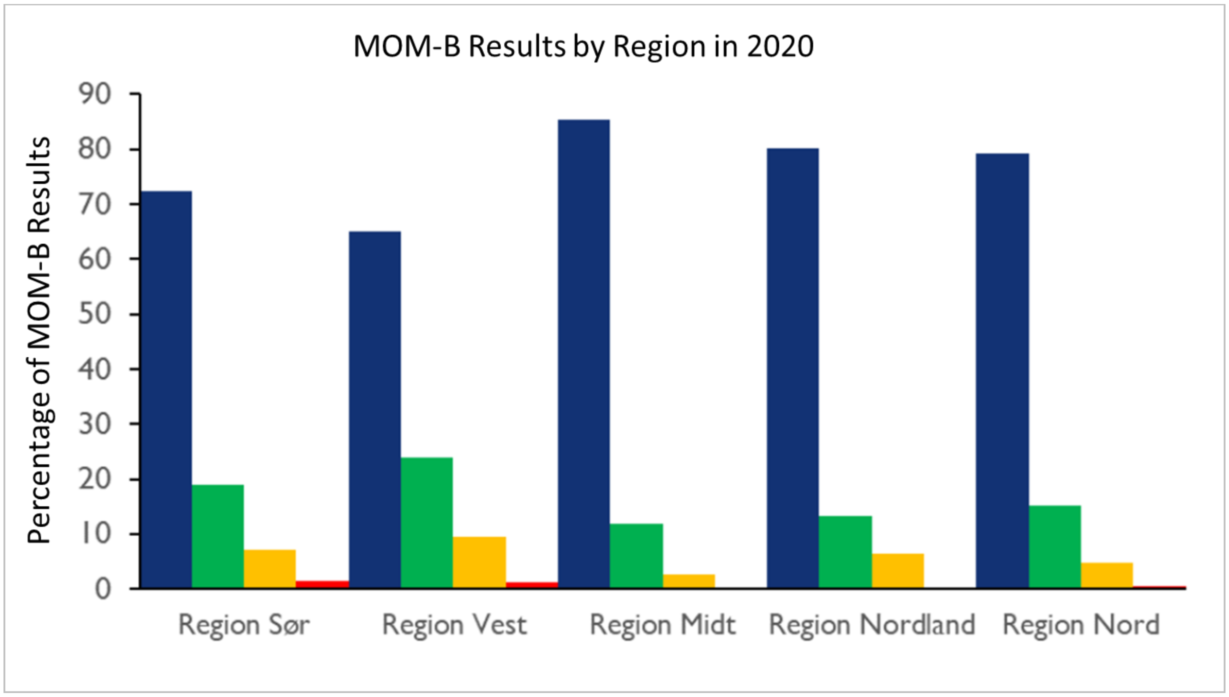

Figure 4: MOM-B survey results average by region for 2020. Blue = Very good; Green = Good; Yellow = Poor; Red = Very Poor. Regions: Sør = south (Production Areas 1-2), Vest = west (Production Areas 3-5), Midt = mid (Production Areas 6-7), Nordland = Nordland (Production Area 8-10), Nord = North (Production Areas 11-13). Image edited from Grefsrud et al. (2021b).

The results of MOM-C studies are more complex (published in a report format) and while individual site-specific reports are available from the Directorate of Fisheries, they are not in a format that allows aggregation and analysis of the results across regions or for the country as a whole. However, Grefsrud et al. (2021b) show on average, approximately 95% of MOM-C surveys show the sites are in “Good” or “Very Good” condition (Figure 5).

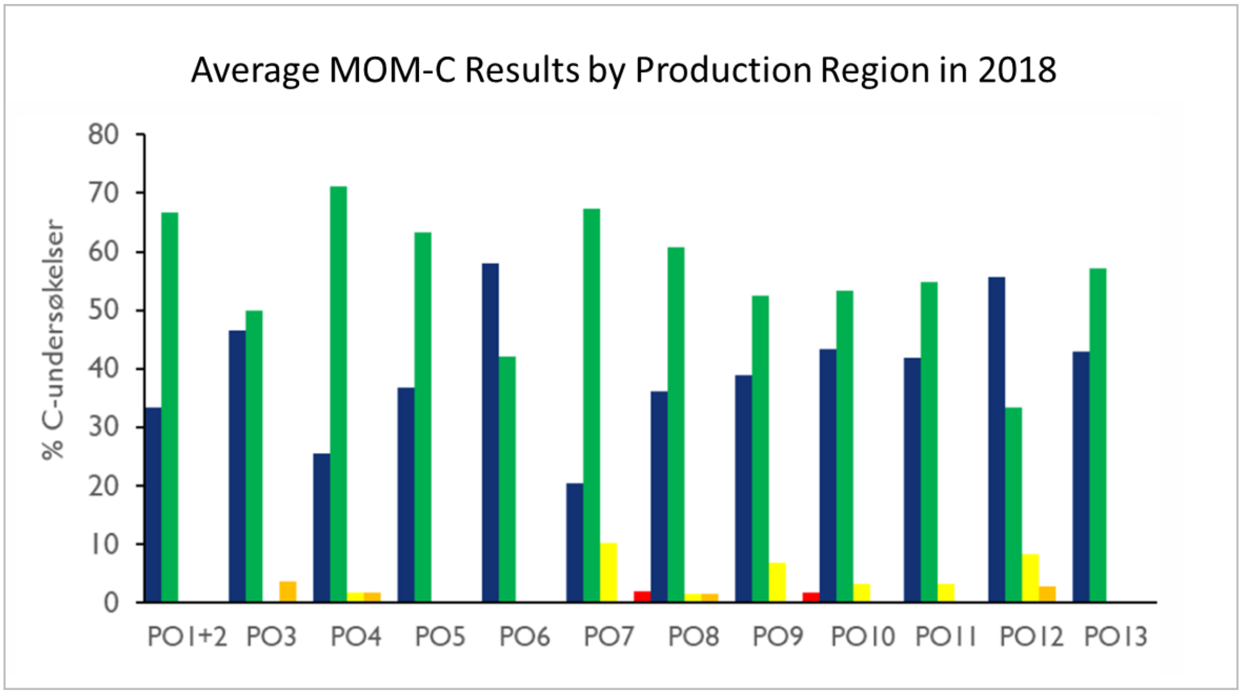

Figure 5: Average MOM-C survey results by region in 2018. Category 1 = Very good (dark blue), 2 = Good (green), 3 = Moderate (yellow), 4 = Poor (orange), 5 = Very poor (red). The x-axis shows the 13 Production Areas, and the y-axis shows the percentage of MOM-C sample results. Image copied from Grefsrud et al. (2021b).

These results agree broadly with the scientific literature from multiple global salmon farming regions which show that any effects on the benthic environment rapidly decrease with increasing distance from the edge of net pen farm sites (Keeley et al., 2013; Chang et al., 2011; Mayor and Solan, 2011; Mayor et al., 2010; Brooks and Mahnken, 2003). In addition, Grefsrud et al.'s (2021a,b) review (also supported by research in other regions) notes the emissions consist of easily degradable compounds and the impact is reversible by fallowing or other cessation of production, with seabed regeneration requiring a few months to a few years.

A 60-day fallow period is a regulatory requirement in Norway, and this can be considered to be a form of habitat restoration, but the occurrence of fallowing between production cycles only temporarily improves the benthic conditions before production begins again. Impacts are thus cyclical in nature (Keeley et al., 2015), but the MOM-B and -C results demonstrate medium-term stability (e.g., the Directorate of Fisheries shows MOM-B results have been similar in all years since at least 2009). Nevertheless, research in Norway also shows some uncertainty regarding how aquaculture wastes affect special habitat such as deep fjords, eelgrass beds, calcareous algal communities, and kelp forests, and highlights an acute shortage of knowledge in this regard (Husa et al., 2016). In addition (noting the limitations of the MOM-C to rocky seabeds mentioned above), there continues to be some uncertainty in the eventual destination of particulate wastes at dispersive sites; for example, Law and Hill (2019) showed that (in contrast to non-dispersive sites, where particulate wastes are concentrated immediately below the net pens) the percentage of organic matter in bottom sediment at a dispersive site increased significantly further away from the net pens and out to 200 m (the limit of their monitoring).

With regard to potential cumulative impacts at the waterbody scale, the resuspension and dispersal of particulate wastes and long-term changes in benthic community structures at the fjord level associated with increased anthropogenic inputs (including salmon farms) is associated with a reduced resilience in some sheltered fjords (Johansen et al., 2018).

Overall, while MOM-B and -C results indicate particulate wastes have a low impact at the large majority of sites, the limitations of monitoring of hard- or mixed-seabed sites is noted again here. Grefsrud et al. (2021a,b) conclude that for soft seabeds, good monitoring tools have been developed, and the risk associated with the environmental effects of organic particulate emissions from fish farming is considered to be low throughout the country. The limitations in the monitoring techniques for hard seabed sites combined with limited overview of how many farms are located over hard seabed and the knowledge that some habitats and organisms associated with hard bottom can be vulnerable to increased sedimentation of particles, Grefsrud et al. (2021a,b) assess the risk of environmental effects of organic particulate matter from fish farming on hard bottom to be moderate throughout the country.

Conclusions and Final Score

With good data availability on nutrient-related impacts of the salmon industry, the Evidence-Based Assessment method is used. It is notable that for the large majority of the coast of Norway, aquaculture is the major source of soluble nutrients to coastal waters. However, the IMR's 2020 risk assessment provides a comprehensive review of the industry's impact to the water column, and by combining modelling results and physical monitoring data, it determined with high confidence that there is a low risk of environmental impacts as a result of increased soluble nutrient supply from aquaculture in all Production Areas.

Emissions of particulate wastes from fish farming are high, and the impact on the seabed can become substantial during production; however, the emissions consist primarily of easily degradable compounds and the impact is reversible. Monitoring in the immediate farm areas shows greater than 90% of sites are consistently in "Very good" or "Good" condition in all regions, with similar results when the sampling a larger area surrounding farms. There are limitations in monitoring of hard- or mixed-bottom sites and there are as-yet uncertain contributions to potential fjord-level impacts associated with cumulative inputs from other sources. In this context, the IMR risk assessment considers the risk of environmental impact due to particulate emissions to be low on soft seabed sites, and moderate on hard seabed sites in all Production Areas.

Across the industry, the data show that effluent discharges result in occasional yet temporary impacts within the immediate vicinity of the farm, but there remains potential for cumulative impacts at the waterbody or regional scale. The final score for Criterion 2 – Effluent is 6 out of 10 for all Production Areas (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

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

All Production Areas

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

Brief Summary

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

The regulatory system for siting and impact assessment in Norway is comprehensive and inclusive of aquaculture's co-existence with other industrial, recreational, and conservation interests, but 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. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management effectiveness is robust. The final score for Criterion 3 – Habitat is of 6.93 out of 10 for all Production Areas.

Justification of Rating

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

Factor 3.1. Habitat conversion and function

Data on site locational coordinates for every site in Norway in addition to an overview of the lease area and map of the anchoring locations are available from the Directorate of Fisheries mapped database. From readily available satellite images (e.g., Google Earth) it is apparent that the floating net pen containment system does not result in any gross functional conversion of surface habitats compared to (for example) the construction of ponds, but that is not to say there are no habitat impacts.

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

Figure 6 shows a typical mooring pattern of anchor lines at a site randomly selected from the Directorate of Fisheries database, and the positioning of the anchors (notably at approximately 1 km from southeast end of the net pen array in this example) shows the extent of the physical structures.

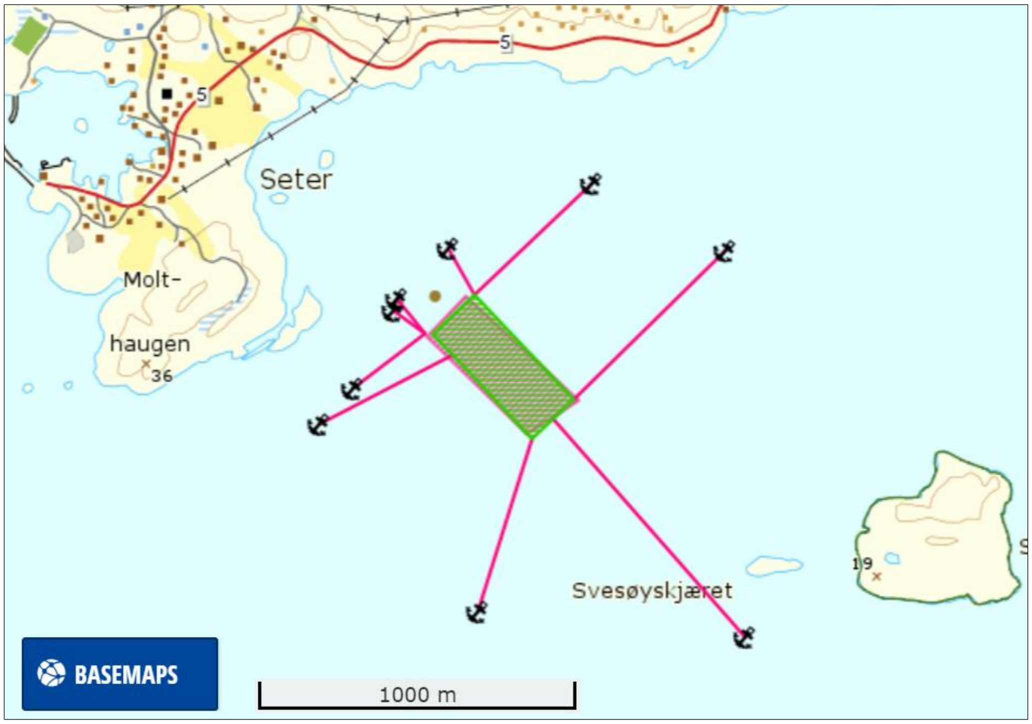

Figure 6: Illustration of the anchoring array of a Norwegian salmon farm (selected at random). Image copied from the Directorate of Fisheries' mapped database (https://kart.fiskeridir.no/)

McKindsey (2011) provided a detailed review of "Aquaculture-related physical alterations of habitat structure as ecosystem stressors[21]", and for net pen finfish aquaculture, the report is summarized as follows:

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

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

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

noted that major recent reviews on aquaculture-environment interactions (at that time) did not discuss the implications of these structures or did so only in a very limited way.

A brief search for relevant literature since 2011 adds additional potential impacts; for example, the Canadian Department of Fisheries and Ocean (DFO - in a 2017 information webpage on the Alteration of Habitats[22]) also notes the use of underwater lights may influence the behavior of wild fish by attracting them to—or causing them to avoid—farm sites, but also notes the lights do not penetrate more than a few meters beyond marine nets, suggesting that their use has minimal effect on the surrounding environment. Floerl et al. (2016) note a large number of fish (and mussel) farms in North America, Europe and New Zealand support extensive populations of biofouling invasive species, and the in-situ cleaning of fouled net pens may inadvertently support the persistence and distribution of such species within aquaculture regions by the localized dispersal of non-indigenous propagules and fragments, or by the use of farm structures as stepping-stones for range expansion (Bloecher and Floerl, 2020). In New Zealand, MPI (2013) also note the potential for impacts to benthic habitats due to shading, but in keeping with McKindsey (2011), they note that no studies exist that separate the effects of shading from that of benthic enrichment; presumably because they occur concurrently, and the latter is thought to be the dominant stressor.

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

DFO (2014) note that the abundance of predators (i.e., seals) near Atlantic salmon farms in the Bay of Fundy has been suggested as a source of post-smolt mortality of wild salmon and as a potential limit to recovery for the endangered Inner Bay of Fundy salmon populations. However, DFO also note that Atlantic salmon in the Bay of Fundy have many potential predators and there are insufficient data on the form and extent of predation to assess the current impact on persistence and recovery. This is considered here to likely be similar to the situation in Norway, and as such, the impacts of seals, birds, and other predators, both near salmon farms and in other areas, remains an unresolved issue that has the potential to affect recovery of wild salmonid populations.

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

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

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

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

Factor 3.2. Farm siting regulation and management

Factor 3.2a: Content of habitat management measures

Full details on Norwegian aquaculture regulations can be found (in Norwegian) on the aquaculture section of the Directorate of Fisheries website. The Directorate of Fisheries is responsible for the control measures at each farm site, and these measures are regionally managed by each county in Norway. The Aquaculture Act (2006)[23], administered by The Ministry of Fisheries and Coastal Affairs, and the Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry guide aquaculture industry planning and management.

The Aquaculture Act has a strong emphasis on industry profitability and growth[24], but restricts the issuance of new licenses. A license is required for aquaculture, but the number of new licenses is now limited and allocated only in defined production areas (13 Production Areas defined by the Norwegian Ministry of Trade, Industry and Fisheries cover the entire coastline). All farms must comply with the Planning and Building Act and require an initial environmental assessment (Matfiskanlegg Overvåking Modellering, also known as Forundersøkelse) with the most recent regulations updated in July 2017[25]. It is considered here that this process will regulate the location of salmon farm infrastructure (i.e., the site itself and hardware such as anchors, etc.).

The Norwegian Aquaculture Act states that the relationship to other user interests is central to the Act and proposes that the establishment of aquaculture activities shall take place based on an assessment of how the coastal area can best be utilized for various forms of aquaculture and other land use and user interests. However, the dominant aspects of the site-level regulatory system are benthic impacts from nutrient wastes, and while Norway's 13 Production Areas cumulatively regulate the siting of farms, the production capacity of each area is based on the impact of sea lice (*Lepeoptheirus salmonis*; see Criterion 7 - Disease) on wild fish rather than direct habitat impacts of the site installations. Given the uncertainty attributed to the impacts described in Factor 3.1, and the apparent dominance of benthic impacts, this is perhaps not surprising, and overall, the management system is considered to require farms to be sited according to ecological principles or environmental considerations at the site level. There appears to be limited consideration of potential cumulative habitat impacts associated with the combined infrastructures of the industry, but the industry does have a cumulative management system in place and considers multiple industries and marine users in site planning. With consideration of the uncertainties in the scale of the impacts described in Factor 3.1 and the comprehensive nature of the site licensing process, the score for Factor 3.2a is 3 out of 10.

Factor 3.2b: Enforcement of habitat management measures

The large volume of monitoring data available from the Fiskeridirektoratet and other sources provides ample evidence that regulatory monitoring takes place throughout Norway. The Directorate of Fisheries register of aquaculture permits[26] provides information on each site and permit. The Fiskeridirektoratet website also has a section (in Norwegian) outlining sanctions,

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[23] Available from the Ministry of Fisheries and Coastal Affairs, or http://www.regjeringen.no/en/dep/fkd/Documents/Acts-and-regulations/Acts-and-regulations/the-norwegian-aquaculture-act.html?id=430160

[24] The document states "*the purpose of the new act is to promote the profitability and competitiveness of the aquaculture industry within the framework of a sustainable development and contribute to the creation of value on the coast*" – see page 4 of the act for the full statement.

[25] https://www.fiskeridir.no/Akvakultur/Tildeling-og-tillatelser/Konsekvensutredninger

[26] https://register.fiskeridir.no/akvareg/

coercive fines, penalties, and other measures, but no data on the frequency or severity of regulatory infringements. Overall, the enforcement organizations are identifiable and active, but with regard to the potential impacts outlined in Factor 3.1, the activities are perhaps limited in their effectiveness and/or have some gaps in transparency particularly with regard to any potential cumulative impacts. Nevertheless, the enforcement of the site licensing process is robust and the score for Factor 3.2b - Enforcement of habitat management measures is therefore 4 out of 10.

Factor 3.2 Final Score
The final score for Factor 3.2 combines the scores for the regulatory content (Factor 3.2a, 4 out of 5) with the effectiveness of the enforcement (Factor 3.2b, 4 out of 5) resulting in a Factor 3.2 score of 6.4 out of 10.

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

The regulatory system for siting and impact assessment in Norway is comprehensive and inclusive of aquaculture’s co-existence with other industrial, recreational, and conservation interests, but 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. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management effectiveness is robust. The final score for Criterion 3 – Habitat is of 6.93 out of 10 for all Production Areas.

Criterion 4: Chemical Use

Impact, unit of sustainability and principle

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

Criterion 4 Summary

C4 Chemical Use	Final Score (0-10)	Rating	Critical?
Production Areas 2, 6, 13	**6.0**	Yellow	No
Production Areas 1, 5, 7-12	**4.0**	Yellow	No
Production Areas 3, 4	**2.0**	Red	No

Brief Summary

Antimicrobial use in Norway is low, with a total of 17 prescriptions were written in 2020 for salmon in marine net pens (with approximately 675 active sites). The total use of 230 kg in 2020 represents 0.17 grams per mt of salmon production and a frequency of much less than one treatment per site. As 30% of the total used is categorized as critically important for human medicine by the World Health Organization, and the remainder as highly important for human medicine, the necessity for judicious use remains. Chemical pesticide use, mostly to treat parasitic sea lice, has declined by more than 90% over the last five or six years, mainly due to the resistance developed by the target sea lice. The increasingly ineffective chemical treatments have largely been replaced with non-chemical alternatives (often at the expense of animal welfare and increased mortality). The resistance is still widespread in sea lice throughout Norway and may not decline as rapidly as the use of chemicals due to the establishment of resistance genes within lice populations. A 2020 audit of pesticide regulations showed a small percentage of pesticide bath treatments continue to be discharged close to shrimp habitats and cod spawning habitats. The use of pesticides is highly variable by Production Area (both in the total number of prescriptions and the number of treatments per site), with three regions (2,5,6) having the lowest with less than one treatment per site per year in 2020. The IMR's comprehensive risk assessment concluded the risk of environmental effects on non-target species was moderate for the use of five of the main chemical treatments (emamectin benzoate, deltamethrin, diflubenzuron, teflubenzuron, and hydrogen peroxide) and low for azamethiphos (with moderate knowledge certainty in these findings).

The use of copper antifoulants has steadily increased in recent years, with 1,698 mt used by Norwegian aquaculture in 2019. The use is variable by Production Area. The IMR risk assessment considers the risk of impact from copper use to be low in five Production Areas (9-

13), moderate in six areas (1,2,5,6,7,8), and high in areas 3 and 4. Overall, these characteristics of chemical use define the final score in each of the Production Areas: for Production Areas 2 and 6, the <1 pesticide treatments per site in 2020 predominantly of treatments of a moderate concern, combined with the moderate copper concern results in a final score for Criterion 4 – Chemical Use of 6 out of 10. For Production Area 13, the >1 pesticide treatments per site in 2020 of predominantly low concern pesticides at a low number of active sites combined with a low copper concern also results in a final score of 6 out of 10. For Production Areas 1, 5 and 7-12, the >1 pesticide treatments per site in 2020 of predominantly moderate concern pesticides combined with a moderate or low copper concern result in a final score of 4 out of 10. And for Production Areas 3 and 4, the >1 pesticide treatments per site in 2020 of predominantly moderate concern pesticides combined with a high copper concern result in a final score of 2 out of 10.

Justification of Rating

This assessment focuses on antimicrobials and sea lice pesticides as the dominant veterinary chemicals applied to salmon farming. While other types of chemicals may be used in salmon aquaculture (e.g., antifoulants, anesthetics), the risk of impact to the ecosystems which receive them is widely acknowledged to be less than that for antimicrobials and pesticides. Hannisdal et al. (2019) report that of 13,920 fish sampled in 2018 from all stages of the farming cycle, no residues of illegal compounds were detected, and the use of illegal chemicals is not considered to be a concern in Norway.

Antimicrobial use

Norway's antimicrobial use in salmon farming has dropped by 99% since its peak in 1987 (NORMVET, 2019), and the World Health Organization (WHO) has previously referred to Norwegian salmon farming as an example of declining antimicrobial use and a model for all food-animal production systems (WHO, 2011). Antimicrobial use remains low (despite large increases in farmed salmon production) primarily due to the availability of vaccines for bacterial pathogens (NORMVET, 2019). Data from the Institute of Public Health published by the Norwegian Veterinary Institute (in Sommerset et al., 2021) show the total use of antimicrobials (in kg of active ingredient) in 2020 was 230 kg (or 0.17 grams per mt of production). Annual variability (see Figure 7) is caused by specific disease outbreaks; for example, in 2017 and 2018, antimicrobial use increased due to a small number of treatments of large salmon in the sea against yersiniosis.

The dominant antimicrobials in 2020 were florfenicol (50.9% by weight; 117 kg in 2020) and oxolinic acid (48.7% by weight; 112 kg in 2020) with the remainder being minor amounts of oxytetracycline (0.72 kg in 2020), enrofloxacin (0.04 kg in 2020) and amoxicillin (0.09 kg in 2020) (Sommerset et al., 2021). The WHO categorizes florfenicol as highly important for human medicine and oxolinic acid, enrofloxacin and amoxicillin as critically important (WHO, 2019). It is important to note that due to the difference in toxicity and therapeutic doses, any comparison of antimicrobial weights must be made with caution.

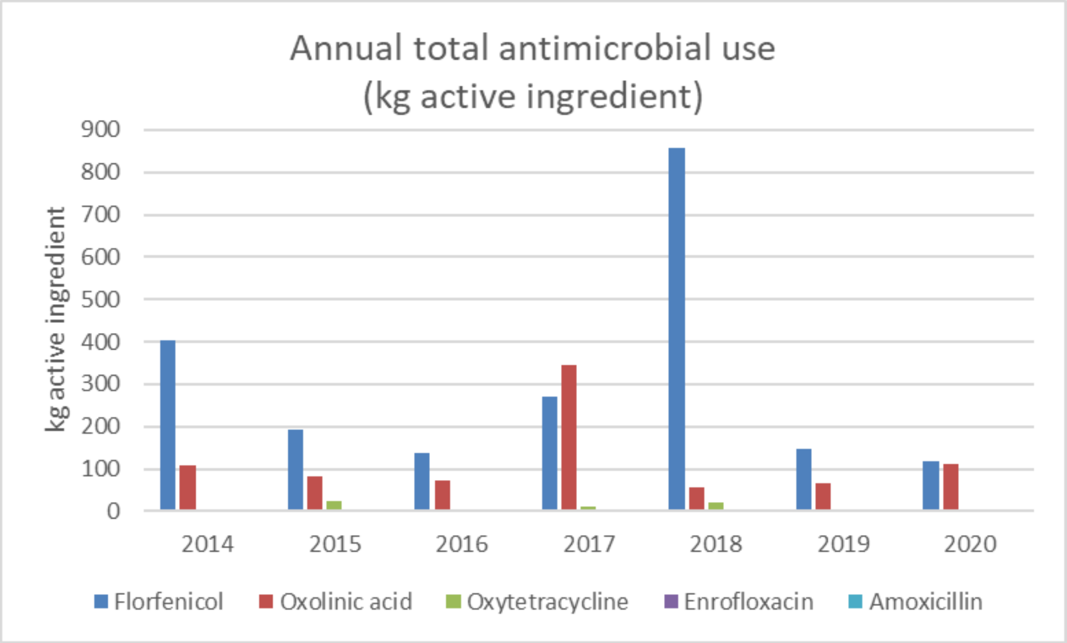

Figure 7: Annual total antimicrobial use from 2014 to 2020 in kg active ingredient. Data from the Institute of Public Health, published in Sommerset et al. (2021).

The annual number of antimicrobial treatments remains low; a total of 17 prescriptions were written in 2020 for salmon in marine net pens, of which seven were for ongrowing fish and ten were for broodstock, with a further five treatments reported in hatchery production (Sommerset et al., 2021). In 2019, only 1.6% of the salmon ongrowing sites were administered an antimicrobial treatment (NORMVET, 2019). The use of antimicrobials for cleaner fish (i.e., lumpsuckers used to control sea lice) has decreased from a peak of 189 treatments in 2016 to 25 in 2020 (Sommerset et al., 2021). Despite the higher number of prescribed treatments for cleaner fish, the total quantity used is low compared to farmed salmon for human consumption; for example, the NORMVET (2019[27]) report separates the two and shows that of the total 931 kg of total antimicrobial use reported in 2018, only 60 kg were used for cleaner fish.

Antimicrobial resistance

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

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[27] The latest report available as of September 2021

toxicity, microbial community selection for antimicrobial resistance and the emergence of multi-antibacterial resistant strains (Lulijwa et al., 2019).

The Norwegian Veterinary Institute continually monitors antimicrobial sensitivity in production animals (also in humans, food, pets and pet food) including a large number of bacterial isolates from farmed fish and a smaller number of isolates from wild salmonids each year (Sommerset et al., 2021). As noted above, the institute publishes an annual report (Usage of Antimicrobial Agents and Occurrence of Antimicrobial Resistance in Norway; NORMVET, 2019) and also recently published a 2020 report on the status of antimicrobial resistance in animals and in food in Norway[28] (Urdahl et al. 2020); however, neither of these reports include the results from farmed fish.

Sommerset et al. (2021) do discuss these sensitivity monitoring results in the Veterinary Institute's annual Fish Health Report, and conclude they show a favorable situation with very low incidence of antimicrobial resistance in disease-causing bacteria in Norwegian fish farms. While the results do show occasional decreased sensitivity to oxolinic acid, there is little sign of any increase over time, and no evidence of decreased sensitivity in isolates from cleaner fish which are treated more frequently than farmed salmon; as such, Sommerset et al., (2021) conclude there is little concern regarding the resistance situation in Norwegian farmed fish.

Sea lice chemical treatments

Parasitic sea lice dominate the disease situation in Norway (see Criterion 7 – Disease) and control has been heavily dependent on chemical treatment (Hjeltnes et al., 2019); however, Overton et al. (2019) note a rapid and recent paradigm shift in the industry's approach to lice control from chemotherapeutants (i.e., pesticides) to non-chemical operations (i.e., physical methods such as water pressure, temperature shocks and freshwater baths, and biological methods such as the use of cleaner fish).

Figure 8 shows the quantities of pesticides (by weight) used per year up to 2020 and show the use of pesticides has decreased markedly for all chemical groups, reflecting the shift to non-chemical methods. According to Helgesen et al. (2021) this shift has been due to the development of resistance and the loss of efficacy of chemical pesticides.

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[28] Report in Norwegian: Antimikrobiell resistens hos dyr og i mat – status i Norge i 2020.

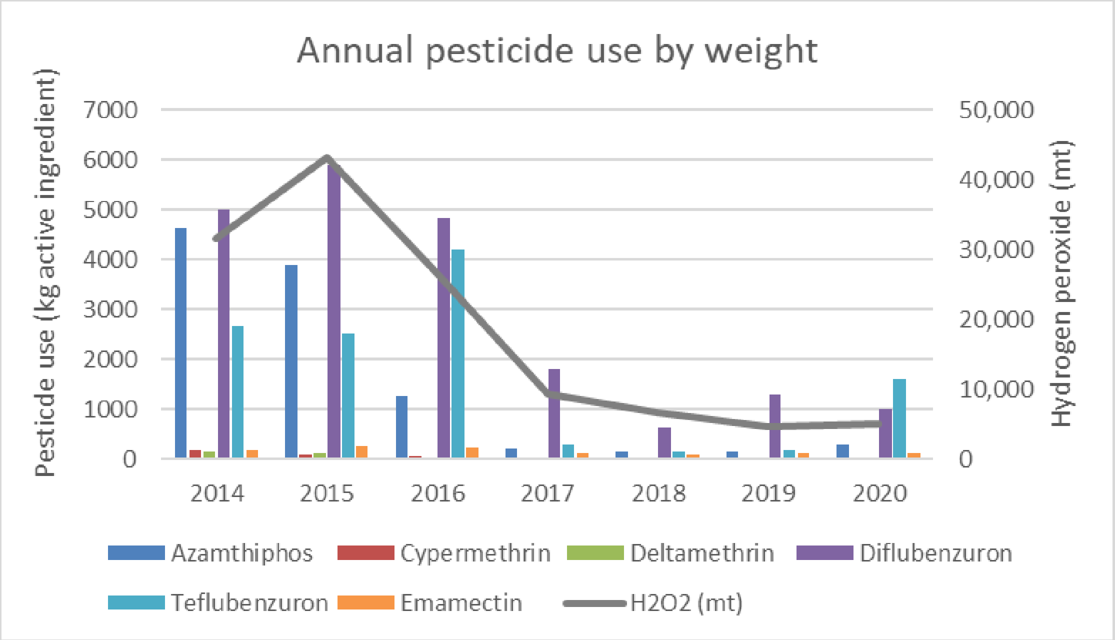

Figure 8: Annual pesticide use by treatment weight of active ingredient. Hydrogen peroxide (H2O2 - grey line) is on the secondary y-axis in units of metric tons, others are in units of kg active ingredient. Data from the Institute of Public Health, published in Sommerset et al. (2020a, 2021a).

Note that due to the varying potency or toxicity of these chemicals, any comparisons of the weights of different pesticides must be made with caution. Also note that for the same reason, the total weights do not reflect a comparable frequency of use across the different treatments.

Data on the numbers of pesticide prescriptions (and thereby the frequency of use) are collected in the Norwegian Food Safety Authority's VetReg database. Aggregated data are published in the Norwegian Veterinary Institute's annual Fish Health Report (Sommerset et al., 2021) and in their annual "Surveillance programme for resistance in salmon lice (*Lepeophtheirus salmonis*) in Norway 2020" (Helgesen et al., 2021). It is important to note that these data include prescriptions written for partial and complete site treatments, i.e., one prescription in this dataset may represent a small treatment to one net pen, or a large treatment of all the pens on a site (see Figure 10 below). Figure 9 shows these prescription data from 2011 to 2020 across five chemical groups, and similarly reflects the reduction in chemical use associated with the shift to non-chemical methods.

It must be noted that there are substantial differences in the reported numbers of prescriptions or treatments in different datasets; for example, in 2020 the number of prescriptions from Helgesen et al. (2021) was 683 compared to 924 discreet treatments reported in the site-level Barents Watch[29] data. The reason for the differences in these values is not clear, but it is possible that some prescriptions reported in Helgesen et al. (2021) result in multiple "treatments" in the Barents Watch data. Similarly, the number of active sites varies by data source (986 from the Directorate of Fisheries and 675 from Barents Watch). Given that the

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[29] https://www.Barents Watch.no/fiskehelse/

Barents Watch data represents discreet uses and therefore discharges of pesticides at specific sites, their detailed data has been used in further calculations of treatment frequency below.

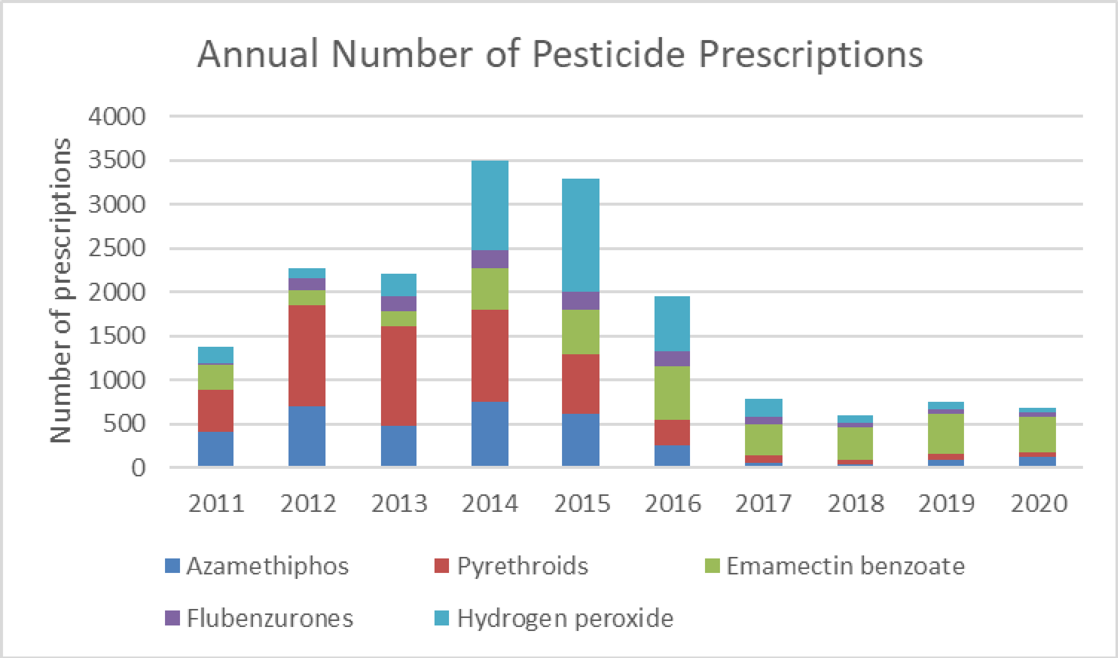

Figure 9: Number of prescriptions for the given substances/class of substances applied to control salmon lice in 2011 to 2020. Note these prescriptions can be for a single net pen or a full site. Pyrethroids include cypermethrin and deltamethrin. Flubenzurons include diflubenzuron and teflubenzuron. Data from Helgesen et al. (2021).

Pesticide use (in terms of the number of prescriptions) is highly variable by Production Area, likely reflecting the scale of production in addition to complex variables associated with sea lice infection pressures. In addition, Barents Watch[30] categorizes site-level data by partial treatments where some but not all of the net pens on the site, and full-site where all net pens are treated. Figure 10 shows the number of full-site treatments per Production Area in 2020 (blue bars), and partial treatments (green bars), and by calculating the number of sites per Production Area (from Barents Watch) the number of treatments per site in each Production Area can also be calculated (red dots). For all treatments in 2020, the Barents Watch data show 58.2% were for full sites and 41.8% were for partial sites, with a range from 0.53 treatments per site in Production Area 6, to 2.42 in Production Area 10.

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[30] https://www.Barents Watch.no/

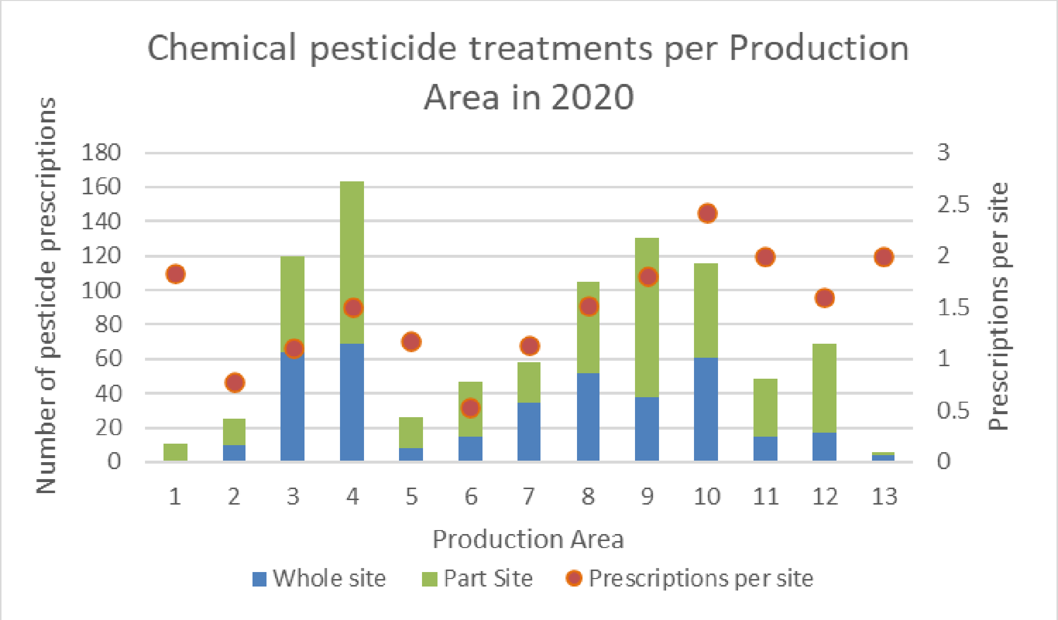

Figure 10: Number of prescriptions for each Production Area in 2020. The blue and green bars (and primary y-axis) show the number of whole site treatments (blue) and partial site treatments (green) per Production Area, and the red dots (secondary y-axis) show the number of treatments per site in each Production Area. All figures calculated from Barents Watch data.

For reference, it is also noted here that the pesticide praziquantel is also used by the Norwegian salmon farming industry (to treat intestinal worms), but like the pesticides described above, the total annual use has declined dramatically from 942 kg in 2014 to 123 kg in 2020 (Sommerset et al., 2021a). Due to the low total use, this pesticide is not considered further here.

Overall, Figure 10 shows most Production Areas had greater than one treatment per site per year in 2020 (two Areas, 2 and 6, had infrequent use with less than one treatment per site), with three areas (10, 11 and 13) having two or more treatments, but the large drops in pesticide use over the last 4-6 years (Figure 9) shows that salmon lice control in Norway is increasingly based on non-chemical treatments and other non-medicinal measures. While this decline is welcomed, it is of note that the alternative non-chemical sea louse control methods are now among the leading causes of mortality and poor welfare in farmed fish (Sommerset et al. 2021).

Resistance to sea lice treatments

Increased tolerance (i.e., resistance) has been noted in sea lice for the pesticides dichlorvos, azamethiphos, emamectin benzoate, deltamethrin, and cypermethrin in Norway for many years (Borno and Sviland, 2010; Jones et al., 2013). To assess the status and development of sea lice sensitivity to different pesticides used in Norwegian salmon farming, a national surveillance program was implemented in 2013 (Helgesen et al., 2021). For a review of drug resistance in sea lice (i.e., mechanisms of resistance and global examples), see Aaen et al. (2015).

Helgesen et al. (2021) report that the results obtained in the resistance surveillance program show the level of resistance in salmon lice remained high in 2020 and resistance towards deltamethrin, azamethiphos and emamectin benzoate was generally widespread along the Norwegian coast. In addition, Helgesen et al. (2015) reported initial cases of resistance to hydrogen peroxide amongst sea lice populations in Norway, and Hjeltnes et al. (2016, 2019) reported that reduced sensitivity to hydrogen peroxide was increasingly widespread. Helgesen et al. (2021) reported less resistance to hydrogen peroxide than the other medicines but continued to note reduced hydrogen peroxide sensitivity in several areas.

For a specific example on pyrethroids (cypermethrin and deltamethrin), Fjørtoft et al. (2020) noted that the genotype associated with resistance was not detected in lice collected from throughout the North Atlantic in the years 2000 or 2002, but from 2009 onwards it was found in lice from fish farms throughout much of the North Atlantic. By 2014, the samples displayed very high frequencies of the genotype associated with resistance, particularly in intensive aquaculture regions of Norway (>90% of sampled lice) (and Scotland, >70%) driven by extensive pyrethroid use on salmon farms. The data in Figure 9 above now show minimal use of these treatments due to their reduced efficacy.

Somewhat remarkably, Helgesen et al. (2021) note the use of fresh water for delousing is of particular concern in Norway, partly due to the indications that sea lice are also increasing their tolerance to this “non-chemical” alternative to pesticides. As wild sea trout (*Salmo trutta*) infected with sea lice return to fresh and brackish water to rid themselves of lice (Haltunen et al., 2018), they are increasingly vulnerable to lice with increased freshwater tolerance. With the widespread development of resistance to a variety of chemicals, aquaculture has thus been described as a major driver of salmon lice population structure (Fjørtoft et al., 2019).

The large decrease in the use of pesticides over the last six years is a positive indicator for resistance. Yet, resistance remains present and widespread despite the reduction in medicinal treatments, probably because resistance genes are now well established within the louse populations most closely associated with both wild and farmed salmon and because all use of medicine selects for resistance (Sommerset et al., 2021; Helgesen et al., 2021).

Quantifying impacts

The decreased use of pesticide treatments in Norway noted above greatly reduces the overall concern regarding environmental impacts, but where treatments continue to be used, they are released into the surrounding environment, exposing non-target species in the water column and on the seabed. Understanding the impacts to the ecosystems which receive them upon discharge is challenging. Grefsrud et al. (2021b) have a useful review of the different sea lice treatments and the aspects of concern regarding their use and potential subsequent impacts.

It is important to note that the use of well boats to conduct pesticide bath treatments has increased (as opposed to treating the fish within the net pens at the site), and this method typically discharges the treatment water at a location beyond the immediate site area (Torvik, 2021); therefore, potential pesticide impacts are not limited to the immediate farm area.

The fate and environmental impact of sea lice treatments and their metabolites varies according to the chemical type and the treatment method. The dominant treatments used in Norway by weight are diflubenzuron, azamethiphos, and teflubenzuron (according to 2019 data – Figure 8), while the most frequently used is emamectin benzoate. Azamethiphos is a bath treatment, while diflubenzuron, teflubenzuron and emamectin benzoate are administered orally in feed. These pesticides are non-specific (i.e., their toxicity is not specific to the targeted sea lice) and, therefore, may affect non-target organisms – in particular crustaceans – in the vicinity of treated net pens (Grefsrud et al., 2021a).

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

Sea lice chemicals administered as bath treatments are released to the environment as a water column plume. Though some authors contest that such treatments may retain toxicity for a substantial period after release (Burridge et al., 2010), Macken et al. (2015) conclude that, as bath treatments such as azamethiphos, cypermethrin, and deltamethrin have a rapid release, dispersion, and dilution post treatment, they primarily impact non-target organisms in an acute manner with limited potential for chronic impacts. In their study on the epibenthic copepod *Tisbe battagliai* (Macken et al., 2015), azamethiphos was acutely toxic at high concentrations, but was found to cause no developmental effects at lower concentrations. More recently, Parsons et al. (2020) report that while azamethiphos is acutely toxic to European lobster larvae (*Homarus gammarus*) at levels below the recommended treatment concentrations, due to the hydrodynamic models of dispersion, the impact zones around farms were relatively small (mean area of 0.04–0.2 km^2).

The dynamics of acute and chronic toxicity are complex, particularly with regard to laboratory and in-situ testing of teflubenzuron and diflubenzuron. Lillicrap et al. (2016) provide a review and risk analysis, and indicate that there is a significant risk to non-target organisms from the use of these treatments at some sites around the coast of Norway. Lillicrap et al. (2016) note that at therapeutic doses, there is a possibility (not yet demonstrated) of pronounced effects on non-target organisms within a site's typical allowable zone of effect, but they note that with increasing resistance, more aggressive treatment regimens may increase the risk of impacts. Samuelsen et al. (2020) measured the concentrations of teflubenzuron in wild crustacean species, including shrimp species, in the vicinity of Norwegian fish farms, both during and after teflubenzuron medication; their results suggest that exposure to low doses of this compound can pose a significant risk to wild shrimp populations.

The Norwegian regulations are intended to ensure the environmentally sound use of sea lice pesticides, but in 2021 the Directorate of Fisheries published an excerpt from a 2020 audit of the environmental impact of sea lice medicines intended to test the internal control systems of these regulations (Torvik, 2021). The audit identified many deviations from the regulations and seven cases with clear violations of the ban against releasing medicines within 500 m of important shrimp habitats or cod spawning grounds. In most cases the aquaculture companies did not have sufficient knowledge of the environments into which sea lice pesticides were discharged. The audit tracked pesticide use both at the farm site and discharges from well boats, and compared them to defined areas of importance to shrimp and to cod spawning. Figure 11 shows that in 2015, there were 758 incidents[31] where pesticides bath treatments occurred in prohibited areas within 500 m of areas important to shrimp and cod. Since then, there has been a rapid decrease in these events (likely following the general reduction in pesticide use noted above and also improved understandings of the regulations) and there were 75 such incidences in 2020 (Torvik, 2021). With 986 active sites in 2020, there was a potential maximum of 51,272 site-treatment weeks in that year (986 sites x 52 weeks) of which 75 incidents is a small proportion (0.14% of site-weeks). Alternatively, the 75 incidences in 2020 represent 11.0% of the 683 total pesticide prescriptions written that year, or 34.6% of the relevant bath treatments (azamethiphos, pyrethroids and hydrogen peroxide). Given that the reasons for the deviations from the regulations were for varied reasons including insufficient information provided by the Directorate of Fisheries, a focus on what Torvik et al. (2021) describe as seven clear violations is associated with approximately 1% of prescribed treatments. Torvik et al. (2021) noted that the audit was useful, the available guidance has been more effectively communicated by the Directorate of Fisheries to the industry, and improvements have been made to ensure the regulations are now complied with.

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[31] Each “incident” refers to a week in which bath treatments took place at a location within a prohibited zone.

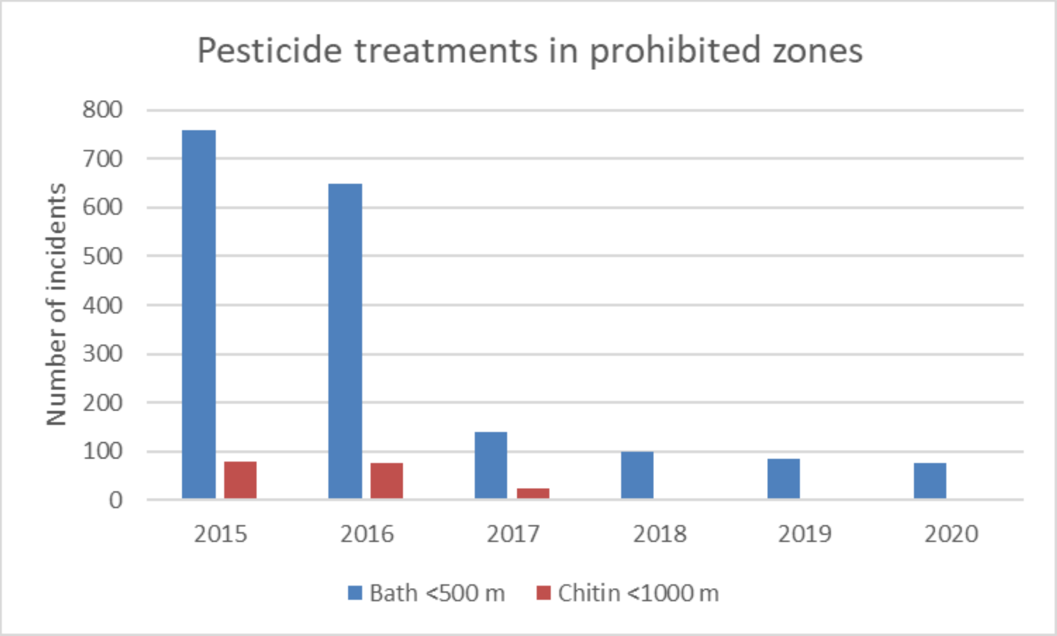

Figure 11: Use of pesticide bath treatments within 500 m of shrimp and cod spawning habitats (blue bars), and the use of chitin inhibitors (teflubenzuron and diflubenzuron) within 1000 m of shrimp habitats (red bars). Each incident refers to a week where medicine has been used at a locality that lies within prohibition zone around these areas. New regulations regarding the use of chitin inhibitors came into effect during 2017 after which there have been no more incidences. Data from Torvik (2021).

While the impacts of pesticide use in general continue to be studied and reviewed, Urbina et al. (2019) consider the real effects of these pharmaceuticals on the marine environment to remain largely uncertain. Bjørkan & Rybråten (2019) highlight this uncertainty in impacts (in this case to wild shrimp) where shrimp fishermen in Norway are certain of a direct link between chemical use and declining shrimp stocks, whereas the Norwegian Seafood Association argue there is a lack of evidence and no proven link. Even the exposure to hydrogen peroxide at relatively low concentrations, which has broadly been considered environmentally benign (Lillicrap et al., 2015), has recently been associated with irreversible negative effects on polychaete species (Fang et al., 2018). Therefore, while it continues to be challenging to quantify the level of concern with regard to pesticides, it is clear that it is not insignificant.

The risk assessment (Grefsrud et al., 2021a) considered many aspects of pesticide use including the quantity used, dilution and spreading, product degradation, seasonal variations, overlaps in consumption and occurrence of non-target species, and the sensitivity of likely non-target species. As such, they conclude that when a farm is treated with the pesticides discussed here, it will probably have a local effect on non-target species, but they note that the effect will vary with the chosen treatment type, time of year and local conditions at the time of treatment/discharge. Overall, with consideration of all the available information, Grefsrud's comprehensive risk assessment concluded that the risk of environmental effects on non-target species through the use of five of the main treatments was moderate (emamectin benzoate, deltamethrin, diflubenzuron, teflubenzuron, and hydrogen peroxide) and low for azamethiphos. It is important to note that the knowledge certainty for these assessments was moderate, and that even with increased knowledge, it will be a great challenge to identify effects at the ecosystem level as there are many factors and the interactions between them are very complex (Grefsrud et al., 2021).

Antifoulants

Copper is used as a minor element in feed (the majority of which will be deposited in feed and fecal wastes on the seabed) but the much greater use is for antifoulant coatings on fish farm nets (Grefsrud et al., 2021a,b). Copper is an important factor for some enzyme reactions in organisms but is toxic if the concentration of copper compounds becomes too high and can affect different organisms at different stages of development. It can lead to reduced species diversity if the concentration in a given habitat is higher than the species' tolerance limits (Grefsrud et al., 2021a,b). In 2019, 1,698 mt of copper were sold for use aquaculture (all species), and Figure 12 shows this total has been steadily increasing.

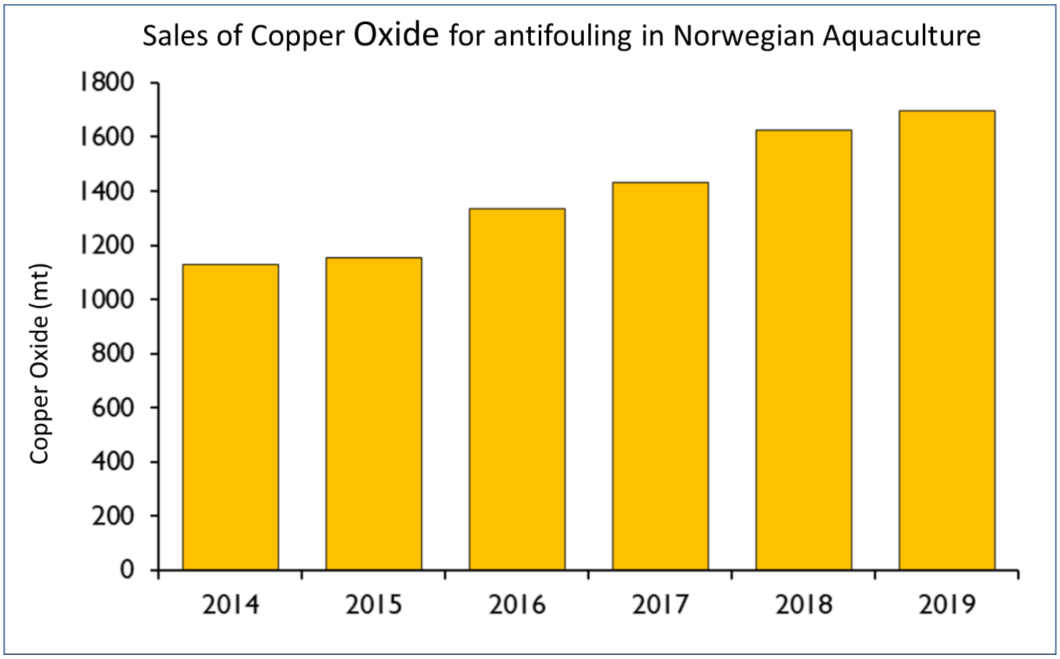

Figure 12: Sales of copper oxide for use in aquaculture (all species) in 2019. Image copied from Grefsrud et al. (2021b) with data from the Norwegian Product Register.

Grefsrud et al. (2021a) assessed the risk of environmental effects as a result of emissions of copper from aquaculture by production area, and concluded the risk is low in the northern regions 9-13. It was moderate for regions 1, 2, 5, 6, 7, 8, but high for regions 3 and 4. While some species changes would be detected in MOM-C benthic surveys (see Criterion 2 – Effluent), Grefsrud et al. (2021a,b) note these data have not been systematized and analyzed with regard to copper. As such, there is considered to be a good knowledge of concentrations of copper below and in the near zone of the fish farms, but there is a lack of knowledge about how available different copper forms are in the sediment and there is also a lack of toxicity data for several of the species living in sediment under the fish farms (Grefsrud et al., 2021a,b).

Conclusions and Final Score

Antimicrobial use in Norway is low, with a total of 17 prescriptions were written in 2020 for salmon in marine net pens (with approximately 675 active sites). The total use of 230 kg in 2020 represents 0.17 grams per mt of salmon production and a frequency of much less than one treatment per site. As 30% of the total used is categorized as critically important for human medicine by the World Health Organization, and the remainder as highly important for human medicine, the necessity for judicious use remains. Chemical pesticide use, mostly to treat parasitic sea lice, has declined by more than 90% over the last five or six years, mainly due to the resistance developed by the target sea lice. The increasingly ineffective chemical treatments have largely been replaced with non-chemical alternatives (often at the expense of animal welfare and increased mortality). The resistance is still widespread in sea lice throughout Norway and may not decline as rapidly as the use of chemicals due to the establishment of resistance genes within lice populations. A 2020 audit of pesticide regulations showed a small percentage of pesticide bath treatments continue to be discharged close to shrimp habitats and cod spawning habitats. The use of pesticides is highly variable by Production Area (both in the total number of prescriptions and the number of treatments per site), with three regions (2,5,6) having the lowest with less than one treatment per site per year in 2020. The IMR's comprehensive risk assessment concluded the risk of environmental effects on non-target species was moderate for the use of five of the main chemical treatments (emamectin benzoate, deltamethrin, diflubenzuron, teflubenzuron, and hydrogen peroxide) and low for azamethiphos (with moderate knowledge certainty in these findings). The use of copper antifoulants has steadily increased in recent years, with 1,698 mt used by Norwegian aquaculture in 2019. The use is variable by Production Area. The IMR risk assessment considers the risk of impact from copper use to be low in five Production Areas (9-13), moderate in six areas (1,2,5,6,7,8), and high in areas 3 and 4.

Overall, the final score for Criterion 4 – Chemical Use for each Production Area is based on the number of treatments per production area and on findings of the comprehensive IMR risk assessment. The following Table 2 and text summarize these results for pesticides and copper (noting antimicrobial use is considered very low and not included).

Table 2:Summary of pesticide use in 2020 with the number of prescriptions (Rx) per Production Area and per site, and the percentage of the treatments that were considered of moderate risk (MOD) and low risk (LOW) by Grefsrud et al. (2021a). The risk of environmental impact from coper use in each Production Area is also from Grefsrud et al. (2021a).

Production Area	Active Sites	Total Pest Treatments	Pest Treatment per site	% of treatments of MOD risk	% of treatments of LOW risk	Copper Risk	Score
1	6	11	1.8	81.8	18.2	Mod	4
2	32	25	0.8	95.8	4.2	Mod	6
3	109	120	1.1	63.0	37.0	High	2
4	108	163	1.5	77.2	22.8	High	2
5	22	26	1.2	92.0	8.0	Mod	4
6	88	47	0.5	91.5	8.5	Mod	6

7	51	58	1.1	93.1	6.9	Mod	4
8	69	105	1.5	87.4	12.6	Mod	4
9	72	130	1.8	89.6	10.4	Low	4
10	48	116	2.4	83.5	16.5	Low	4
11	24	48	2.0	93.8	6.3	Low	4
12	43	69	1.6	68.2	31.8	Low	4
13	3	6	2.0	33.3	66.7	Low	6

- Production Areas 2, 6: The <1 pesticide treatments per site in 2020 predominantly of treatments of a moderate concern, combined with the moderate copper concern results in a final score of 6 out of 10.
- Production Area 13: The >1 pesticide treatments per site in 2020 of predominantly low concern pesticides at a low number of active sites (6) combined with a low copper concern also results in a final score of 6 out of 10.
- Production Areas 1, 5 and 7-12: The >1 pesticide treatments per site in 2020 of predominantly moderate concern pesticides combined with a moderate or low copper concern result in a final score of 4 out of 10.
- Production Areas 3 and 4: The >1 pesticide treatments per site in 2020 of predominantly moderate concern pesticides combined with a high copper concern result in a final score of 2 out of 10.

Criterion 5: Feed

Impact, unit of sustainability and principle

- Impact: feed consumption, feed type, ingredients used and the net nutritional gains or losses vary dramatically between farmed species and production systems. Producing feeds and their ingredients has complex global ecological impacts, and their efficiency of conversion can result in net food gains, or dramatic net losses of nutrients. Feed use is considered to be one of the defining factors of aquaculture sustainability.
- 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

All Production Areas

C5 Feed parameters	**Value**	**Score**
F5.1a Forage Fish Efficiency Ratio	2.18	
F5.1b Source fishery sustainability score (0-10)		5
F5.1: Wild fish use score (0-10)		2.10
F5.2a Protein INPUT (kg/100kg fish harvested)	46.67	
F5.2b Protein OUT (kg/100kg fish harvested)	16.90	
F5.2: Net Protein Gain or Loss (%)	-63.79	3.00
F5.3: Species-specific kg CO2-eq kg-1 farmed seafood protein	7.32	8.00
C5 Feed Final Score (0-10)		3.80
Critical?	No	Yellow

Brief Summary

In the absence of specific feed composition information from Norwegian feed mills, data from the reference feeds in the academic literature and company reports were used. Using total fishmeal and fish oil inclusions of 14.5% and 11.1% respectively and an eFCR of 1.3, from first principles, 2.18 mt of wild fish must be caught to supply the fish oil needed to produce 1.0 mt of farmed salmon. This value is higher than that reported for three Norwegian salmon farming companies by GSI and is likely due to minor variations in the values used for the feed conversion ratio and for the yield and inclusion level of fish oil. This can only be verified with better data availability. Information on the sustainability of source fisheries for three major feed companies published by the Ocean Disclosure Project showed a moderate overall sustainability and resulted in a Wild Fish Use score of 1.65 out of 10. There is a substantial net loss of 63.8% of feed protein (score of 3 out of 10) but a small feed ingredient footprint (7.32 kg CO_2-eq. per kg of harvested protein (score of 8 out of 10) due to the high use of crop ingredients. Overall, the three factors combine to result in a final score for Criterion 5 – Feed of 3.80 out of 10.

Justification of Rating

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

Feed composition

The feed composition data for this assessment were compiled from global and regional data in Mowi's Salmon Industry Handbook (Mowi, 2020) and specific ingredients in two salmon reference diets in Mørkøre et al. (2020) and Aas et al. (2019), both based on Norwegian feeds. The available data sources, particularly those focused on Norway, have been used to create a best-fit feed composition as shown in Table 3, along with each ingredient's Global Feed Lifecycle Institute (GFLI) Climate Change (CC)/ton value (see Factor 5.3). While the feed composition used here might not reflect the exact ingredients and their inclusions in practice, it is considered to be sufficiently representative of a typical Norwegian salmon feed for this assessment.

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

Feed Ingredient	Inclusion (% of total feed)	GFLI value
Fishmeal whole fish	11.7	1.1843
Fishmeal byproducts	2.8	1.1843
Fish oil whole fish	8.3	0.8176
Fish oil byproducts	2.8	0.8176
Wheat	8.8	0.7813
Wheat gluten	9.0	3.9989
Soy protein concentrate	17.0	6.417
Fava (broad) beans	3.4	0.7080
Sunflower meal	1.6	0.8766
Corn gluten	3.6	1.5647
Pea protein concentrate	1.3	1.3535
Pea starch	1.8	0.4732
Rapeseed (canola) oil	20.0	2.9154
Vitamin/minerals etc.	7.9	No data
Total	100	

Economic feed conversion ratio (eFCR)

General eFCR values in the academic literature for Atlantic salmon (i.e., not specific to any region) are 1.3 (Tacon et al., 2021; Naylor et al., 2021; Tacon, 2020) and agree with the Norway specific value in Aas et al. (2019) and in Mowi's Industry Handbook (2021). The value of 1.3 is therefore used here.

Factor 5.1. Wild Fish Use

Factor 5.1a – Feed Fish Efficiency Ratio (FFER)

Using the data in Table 3 along with the eFCR value of 1.3 and the standard yield values for fishmeal and fish oil (22.5% and 5% respectively), the Forage Fish Efficiency Ratio (FFER) is 0.68 for fishmeal and 2.18 for fish oil.

These FFER values are higher than the three-year average (2018-2020) of three Norwegian salmon companies that report values for fishmeal (0.44) and fish oil (1.69) through GSI (GSI report as "FFDR", though the metric is the same). The discrepancy is likely due to minor variations in the values used for eFCR and/or the fishmeal and fish oil inclusion levels and yields, but without specific data from Norwegian feed companies, the value of 2.18 is used here based on the available published data. This means that from first principles, 2.18 mt of wild fish must be caught to supply the fish oil needed to produce 1.00 mt of farmed salmon. It is of interest to note that the FFDR for fish oil for the three companies reporting to GSI has increased substantially over the last four years, while the values for fishmeal have continued to decline (Figure 13).

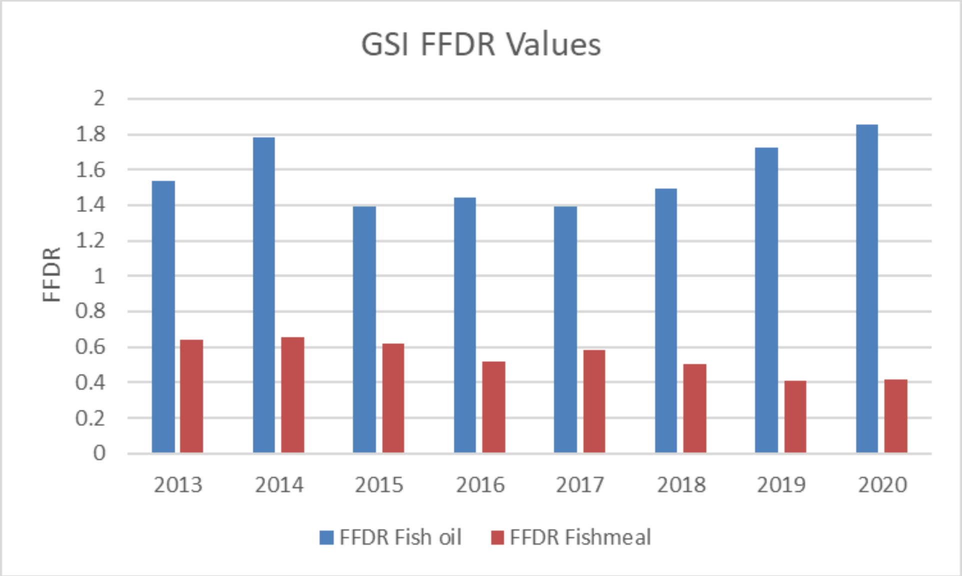

Figure 13: FFDR value for fishmeal and fish oil averaged across the three companies currently reporting to GSI. Data from GSI.

Factor 5.1b –Sustainability of the Source of Wild Fish

Without specific data for source fisheries supplying fishmeal and fish oil to Norwegian salmon feeds, the global data for three major feed companies (Biomar, Ewos-Cargill, and Skretting) reporting through the Ocean Disclosure Project were used[32]. While each company has a sustainable sourcing policy, the fisheries used are the more practical manifestation of their sourcing policies.

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[32] https://oceandisclosureproject.org/

The Ocean Disclosure Project data covered approximately 38 different fisheries used by the three companies, and provide the management status of the fishery, i.e., certified, well-managed, managed, needs improvement, and not rated[33]. 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 Norwegian feeds and how much). Therefore, an aggregated sustainability score for fishmeal and fish oil has been generated across all three feed companies and used here for Norway. Again, this may not reflect the exact fisheries sources used in Norwegian salmon feeds but is considered to be acceptably representative.

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

Fishery status	Percent of fisheries	SFW Sustainability score	Weighted score
Certified	38.4	7	2.7
Well Managed	7.2	6	0.4
Managed	25.8	4	1.1
In need of improvement	19.2	3	0.4
Not rated	9.4	2	0.2
		Weighted sustainability score (0-10)	**4.7**

The weight-calculated sustainability score is 4.7 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 2.18, results in a final score for Factor 5.1 - Wild Fish Use of 2.1 out of 10.

Factor 5.2. Net Protein Gain or Loss

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

Therefore, one ton of feed contains 359 kg of protein, and 1.3 tons of feed are used to produce 1.0 tons of farmed salmon (eFCR). The net protein input per ton of farmed salmon production is 466.7 kg. With only 169 kg of protein in one ton of harvested whole salmon, there is a net loss of 63.8% of protein. This results in a score of 3 out of 10 for Factor 5.2.

Factor 5.3. Feed Footprint

This factor is an approximation of the embedded climate change impact (kg CO_2-eq) of the feed ingredients required to grow one kilogram of farmed seafood protein. The calculation is performed by mapping the ingredient composition of a feed used against the Global Feed LCA Institute (GFLI) database[34] to estimate the climate change impact (CCI) of one metric ton of feed, followed by multiplying this value by the eFCR and the protein content of whole

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

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

harvested salmon. If an ingredient of unknown or unlisted origin is found in the GFLI database, an average value between the listed global “GLO” value and worst listed value for that ingredient is applied; this approach is intended to incentivize data transparency and provision. Detailed calculation methodology can be found in Appendix 3 of the Seafood Watch Aquaculture Standard.

Calculations based on the GFLI values presented in Table 3 above and following the methodology in the Seafood Watch Aquaculture Standard, the CCI is 7.32 kg CO_2-eq per kg of farmed salmon protein. This equates to a score of 8 out of 10 for Factor 5.3.

Conclusions and Final Score

The final score is a combination of the three factors with a double weighting for the Wild Fish Use factor. Factors 5.1 (2.1 out of 10), 5.2 (3 out of 10), and 5.3 (8 out of 10) combine to result in a final score of 3.80 out of 10 for Criterion 5 – Feed.

Criterion 6: Escapes

Impact, unit of sustainability and principle

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

Criterion 6 Summary

C6 Escape parameters						
Production Area	**F6.1** System escape risk (0-10)	**F6.1** Recapture adjustment (0-10)	**F6.1** Final escape risk (0-10)	**F6.2** Competitive and genetic interactions (0-10)	**C6 Escapes Final score (0-10)**	Critical?
1	6	0	6	4	4	No
2	6	0	6	8	6	No
3	2	0	2	0	0	Yes
4	4	0	4	0	1	Yes
5	4	0	4	4	3	No
6	4	0	4	4	4	No
7	2	0	2	4	3	No
8	4	0	4	0	1	Yes
9	2	0	2	0	0	Yes
10	2	0	2	0	0	Yes
11	2	0	2	0	0	Yes
12	4	0	4	8	5	No
13	6	0	6	4	4	No

Brief Summary

Salmon continue to escape from Norwegian farms in both large-scale events and in small-scale trickle losses. As a result of escapees interbreeding with wild Atlantic salmon, only 33% of wild populations in Norway have good or very good genetic status; 27% have poor or very poor status and 30% have moderate status. The most recent annual risk assessment on salmon farming (2021 publication) conducted by the Institute of Marine Research (IMR) concluded that this has led to a reduced production of wild salmon, as well as changes in important biological properties in wild stocks such as age at sexual maturity and migration time for smolts. The IMR notes regional variations in the risk of these impacts and uses two primary factors in separate risk assessments for each of the 13 Production Areas: 1) the occurrence of escaped farmed salmon in the spawning grounds, and 2) the robustness of the wild stocks against new genetic introgression). These two IMR factors (and their sub-factors which include recaptures) closely mirror the two Seafood Watch Escape Criterion Factors 6.1 (escape risk, including recaptures) and 6.2 (competitive and genetic interactions), and the IMR risk assessment has largely been used to inform the Seafood Watch scores.

The final Seafood Watch scores for Criterion 6 – Escapes show escaping farmed salmon are a critical conservation concern in Production Areas 3, 4, 8, 9, 10 and 11 (scores of 0 and 1 out of 10), and a high concern in Areas 5 and 7 (score 3 out of 10). These Seafood Watch results largely reflect the "Poor" outcomes of the IMR risk assessment in these Areas. Production Areas 1, 2, 6, 12 and 13 have moderate scores of 4 out of 10 (PA 1 and 6), 5 out of 10 (PA 12) and 6 out of 10 (PA 2) and largely reflect the presence of a "Moderate" outcome in either one of the IMR risk assessment factors. Overall, the IMR risk assessment had a moderate "knowledge status" in all Production Areas (except Area 3, where it was good) and the application of the Seafood Watch Aquaculture Standard produced slightly more conservative results compared to those of the IMR (e.g., in PA 2). It is also of interest to note that genetic changes have also been observed in wild wrasse populations due to the escape of imported cleaner fish, but these have not currently affected the scores in this assessment.

Justification of Rating

According to the Norwegian Scientific Advisory Committee for Atlantic Salmon, escaped farmed salmon (and sea lice) have the greatest negative impact on wild salmon in Norway and are regarded as an expanding population threat, which means they are affecting populations to the extent that populations may be critically endangered or lost in nature and have a high likelihood of causing even further reductions (Thorstad et al., 2020). Figure 14 ranks 17 impact factors considered by the Scientific Advisory Committee for Atlantic Salmon in 2019 according to their effects on wild Atlantic salmon populations and the likelihood of a further negative development. Escapes are prominent, having a high effect (impact) and high risk of further development.

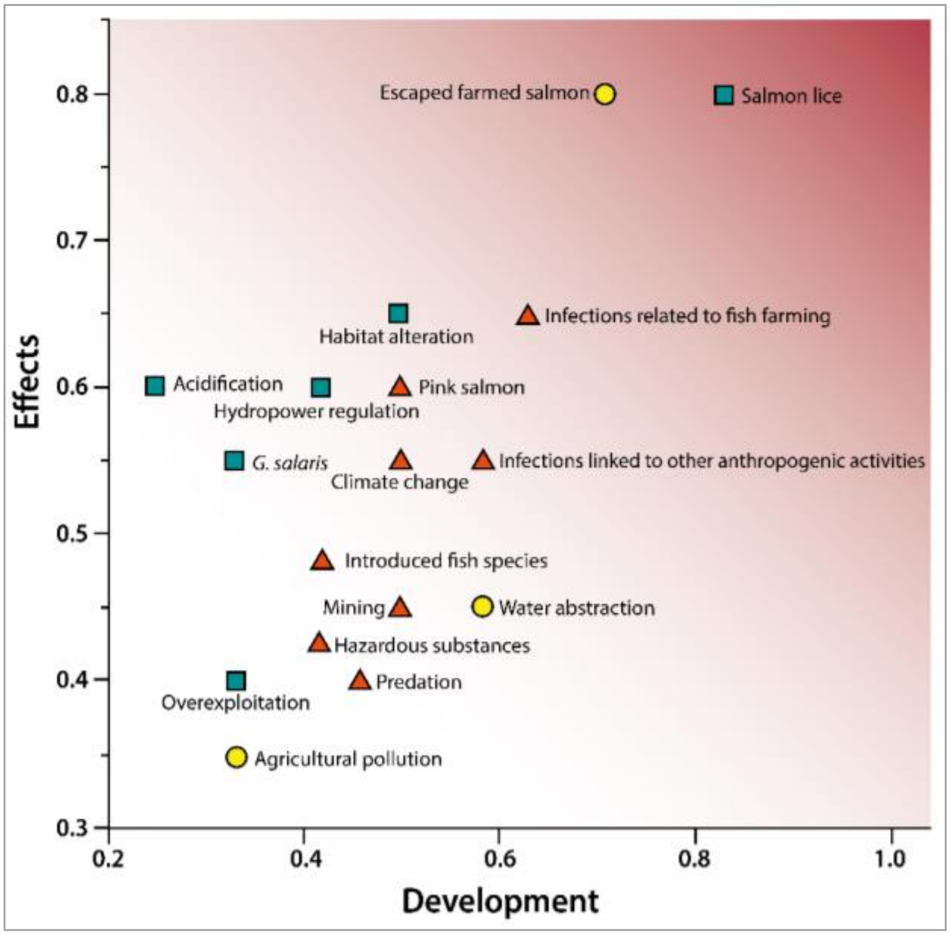

Figure 14: Rating of 17 impact factors considered in 2019, according to their effects on wild Atlantic salmon populations and the likelihood of a further negative development. The knowledge of each impact factor and the uncertainty of future development is indicated by the color of the markers. Green squares indicate extensive knowledge and small uncertainty; yellow circles indicate moderate knowledge and moderate uncertainty; red triangles indicate poor knowledge and high uncertainty. Image from Thorstad et al. (2020).

However, the Institute of Marine Research's (IMR) risk assessment shows that these impacts vary across production regions, and the granularity of the available information and data, particularly through the IMR risk assessment and associated knowledge status report (Grefsrud et al., 2021a,b), enables an assessment here for each Production Area.

Table 5 shows the two primary factors and five sub-factors used by Grefsrud et al. (2021a) in determining the risk of further genetic change in wild salmon as a result of escaped farmed salmon in each of the 13 Production Areas. The two primary factors are combined to assess the risk of further genetic change in wild salmon as a result of escaped farmed salmon.

Table 5: Factors and subfactors used in the IMR risk assessment to determine the risk of further genetic change in wild salmon as a result of escaped farmed salmon in each of the 13 Production Areas. The two primary factors are combined to give the risk of further genetic change in wild salmon as a result of escaped farmed salmon.

The risk of further genetic change in wild salmon as a result of escaped farmed salmon		
Primary Factors	**1: Escaped farmed salmon in the spawning grounds**	**2: Resilience of wild stocks to new genetic introgression**
Secondary Factors	1a: Numbers of escapes	2a: Wild salmon population status
	1b: Proportion of escaped farmed salmon in rivers	2b: Wild salmon genetic status
	1c: Fishing and removal of escaped farmed salmon from the river (recaptures)	

Note that while the outcome of the IMR risk assessment in this case is a risk of <u>further</u> genetic change, the assessment is based on the comprehensive monitoring data that is conducted annually in Norway. To elaborate, the IMR's risk of "further genetic change in wild salmon as a result of escaped farmed salmon" in each Norwegian Production Area is determined by the risk of farmed salmon being present in the spawning grounds (Factor 1) and the robustness of the relevant wild stocks to further genetic change (Factor 2). Factor 1 is determined by the numbers of escapes, the proportion of farmed fish among the wild population in rivers in each Production Area, and the numbers of those farmed fish that are recaptured. Factor 2 is determined by the population status and genetic status of wild salmon stocks in each Production Area. The IMR risk assessment is supported by comprehensive monitoring data as described in the knowledge status report (Grefsrud et al., 2021b) and each of the factors in Table 5 is given a knowledge status rank of "Good", "Moderate" or "Poor".

In the Seafood Watch Aquaculture Standard, Criterion 6 – Escapes also assesses two primary factors; firstly, the risk of escape and/or the detection of escaped fish in the wild (Factor 6.1) and secondly, the evidence or potential for genetic and/or competitive 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. These two factors (6.1 and 6.2) and the information used to assess them closely mirror the IMR risk assessment used to determine the risk of further genetic change in wild salmon as a result of escaped farmed salmon (Grefsrud et al., 2021a,b).

Background information is provided below for context but given the comprehensive risk assessment and knowledge status report for each of Norway's 13 Production Areas (noting the fundamental similarity with the Seafood Watch methodology), the IMR's risk assessment is heavily relied upon here in this Seafood Watch assessment.

Factor 6.1. Escape Risk

An average Norwegian salmon farm is stocked with almost one million smolts (Sistiaga et al., 2020) and as long as aquaculture facilities are not fully contained, the escape of farmed fish into the wild is inevitable (Glover et al., 2017). With the open nature of net pen systems, there is an inherent high risk of fish escapes caused by several internal and external factors, which result in the occasional release of a large number of individuals (massive escape events) and/or the recurrent release of a small number of fish (chronic or leakage escapes) (Atalah & Sanchez-Jerez, 2020).

Norway's Aquaculture Regulation 38 obliges companies to notify the Directorate of Fisheries[35] as soon as they know or suspect that any fish have escaped. The Directorate provides information on every reported escape event, including the number of fish, location (county), company, species, fish size, date, and number of fish recaptured (recapture data are available from 2014). Figure 15 shows the total number of reported escapes each year from 2001 to 2020, the number of reported recaptures from 2014 to 2020, and the number of escape events from 2006 to 2020. It is important to note that during this period (2001-2020), production volumes increased enormously, from approximately 400,000 mt to more than 1,300,000 mt, but the data in Figure 15 are important in absolute terms. While the most recent data show 43,364 salmon escapes in 2020, a much higher total of 289,663 salmon were reported escaped in 2019 (noting 115,035 were reportedly recaptured - see further discussion on recaptures below).

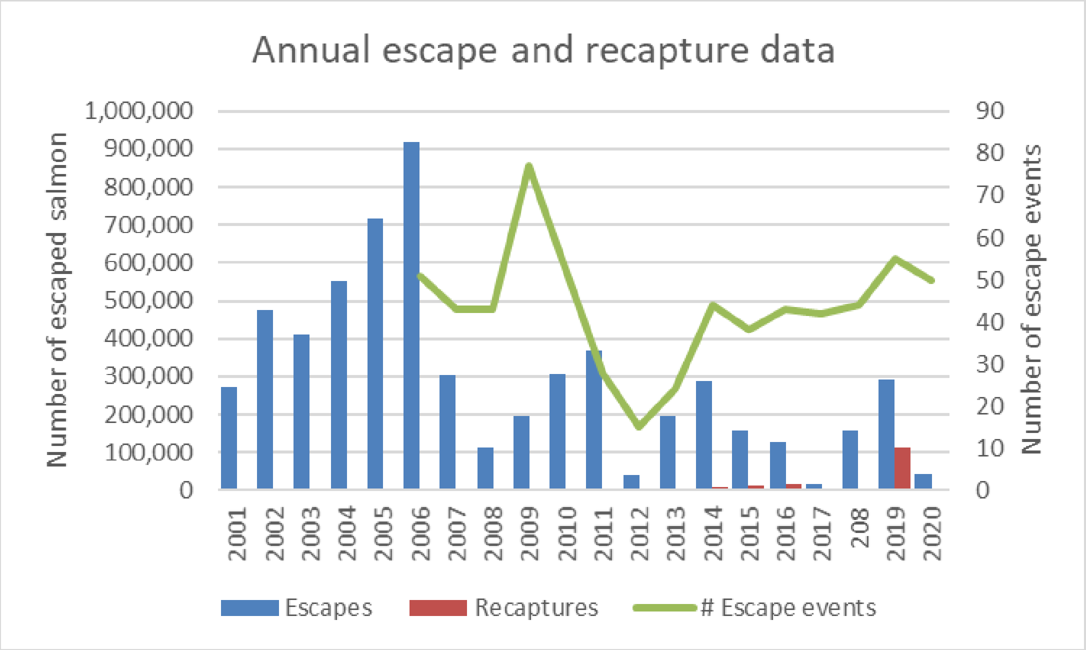

Figure 15: Annual total reported escapes and recaptures in Norway from 2001 to 2020. Data from Fiskeridirektoratet.

The average annual number of escaped fish for the ten-year period 2011 to 2020 is 168,458. The aforementioned interactive mapping tool from the Directorate of Fisheries includes a function to view escapes data; an example of a query is shown in Figure 16, with 2019 escapes selected showing escape events of varying sizes were reported throughout the country.

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[35] http://www.fiskeridir.no/

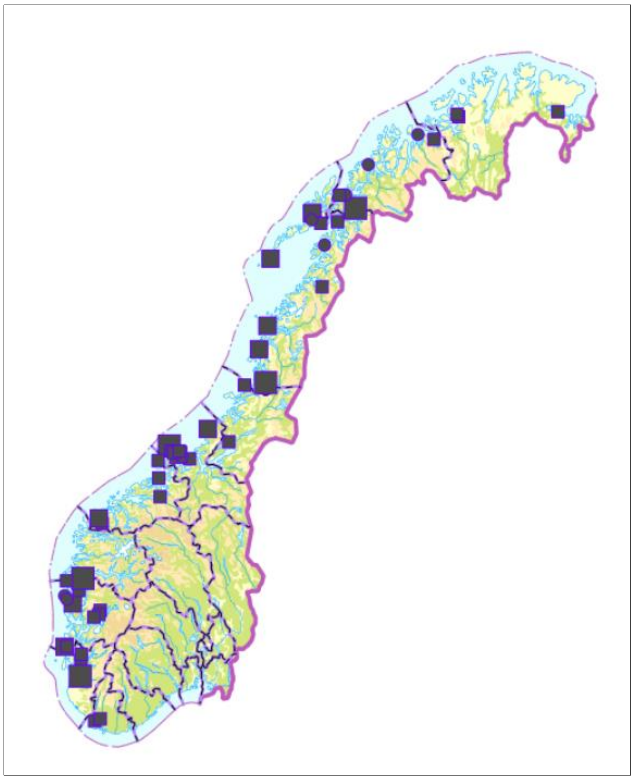

Figure 16: Screenshot of the Fiskeridirektoratet mapping tool database showing 2019 escape events. Purple squares mark the location and scale of escape (circles show the location of escape events that do not yet have confirmed total numbers).

With high escape numbers in the early and mid-2000s, Norway's Ministry of Fisheries and Coastal Affairs established an Aquaculture Escape Commission aimed at minimizing escapes; the resulting implementation of a Norwegian technical standard (NS 9415) for the design, construction, siting, and maintenance of net pen farms in 2004 is associated with the large drop in escapes after 2006, when the standard was implemented (in Figure 15). Nevertheless, large escape events continue to be reported; the Directorate's data show the largest escapes in Norway in 2019 were 179,491 fish (of which 112,793 were reported recaptured) and 49,626 fish (of which 3,337 were recaptured), and the dominant cause of escapes continues to be human error, with 93% of escapes in 2019 caused by operational errors and 6% due to storms (i.e. design and construction errors).

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). While isolated, large-scale catastrophic escape events are clearly limited to a very small proportion of the sites in Norway, the small-scale, so-called 'trickle losses' of tens or dozens of fish can also be significant and (from sites commonly holding a million fish) likely to be undetected and therefore unreported (Taranger et al., 2011). Sistiaga et al. (2020) noted the escape of small smolts through farm cage netting is a major challenge faced by the Norwegian salmon farming industry when the smolts placed in the net pens are smaller than the size estimated by the farmers. Importantly, Skilbrei and Wennevik (2006) note small-scale unreported escape events may make up a large portion of the total escaped farmed fish, and the analysis by Skilbrei et al. (2015) suggests that the total numbers of post-smolt and adult escapees have been two- to four-fold higher than the numbers reported to the authorities.

In conclusion, it is clear from the reported data that the peaks in total escapes in recent years are dominated by infrequent mass-escape events and overall, the reported escape events are limited to a small minority of farms in Norway. Yet, despite the comprehensive technical standard and reduction in reported escapees subsequent to its introduction, a wide variety of sizes of farmed salmon escape throughout the year, significant escape events of approximately 50,000 fish or more have happened almost every year in recent years, and escapes continue to occur largely as a result of human error. Grefsrud et al. (2021a,b) contend that as long as farmed salmon are produced with current technology, which are mainly open cages in the sea, there is a high probability that there will also be major escape episodes in the coming years. Trickle losses are also likely to be substantial yet may not be detected and/or reported. Ultimately, it is clear that Norwegian net pens continue to be vulnerable to both large-scale and small-scale escapes.

Recaptures and mortality

Academic studies (e.g., Skilbrei et al. (2010), Chittenden et al. (2011)) show that up to 80% of escapees within some life stages could eventually be recaptured from enclosed fjord systems in Norway, and Skilbrei and Jorgensen (2010) show that up to 60% of escapees may eventually be recaptured in regional fisheries, but actual recapture efforts and success rates by the farms themselves at the escape site have only been reported since 2014. Recapture success relates to many factors that control the dispersal and movement of escapees, including fish size, time of year, farm location, and prevailing currents (Skilbrei et al., 2015; Skilbrei and Jorgensen, 2010; Olsen and Skilbrei, 2010). For example, Skilbrei et al. (2015) noted that the location and time of year of an escape is important, and they also concluded: “life stage at the time of escape has a profound influence on the survival, dispersal, and potential recapture of the escapees on both short and long timescales.” According to Chittenden et al. (2011), recapture efforts must be immediate and widespread to maximize recovery and mitigate the potential impact of escape events.

The Fiskeridirektoratet recapture data show highly variable success ranging from zero to a notable reported recapture of 58% after the largest 2019 escape of 179,491 fish in July 2019. Based on the reported numbers of escapees and recaptures, the annual average recapture percentages from 2014 to 2020 are shown in Figure 17 (data for 2020 are through the first half of the year) with an average of 9.95% over this period.

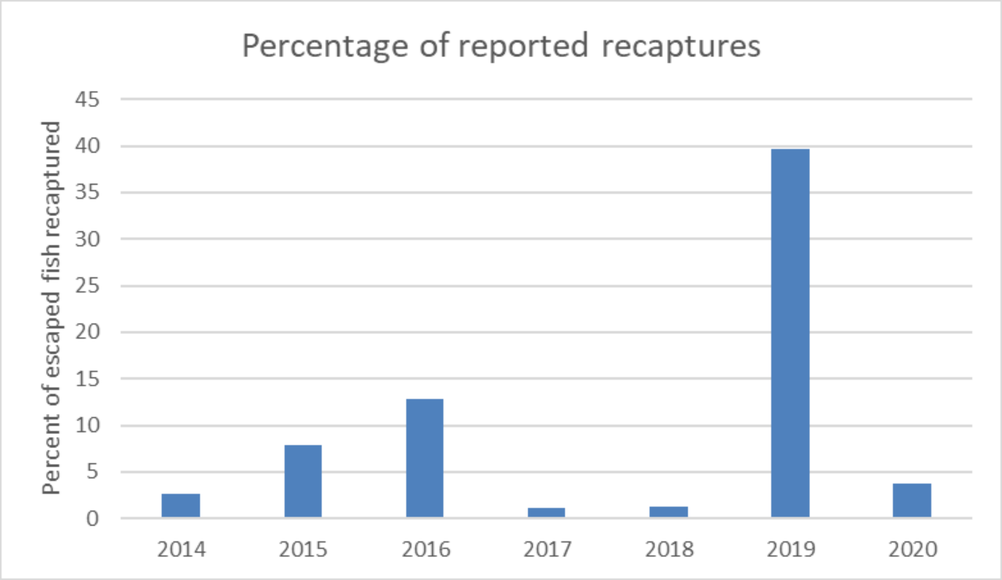

Figure 17: Percentage of recaptures of escaped farmed salmon each year. Data from Fiskeridirektoratet.

The Norwegian government has established an aquaculture-financed fund (OURO) to remove farmed salmon escapees from wild populations in priority rivers, but fishing measures were implemented in 50 to 66 rivers between 2016 and 2019 and caught an average of 692 fish per year (range of 345 to 1,058 per year) (data in Gresfsrud et al., 2021b). These numbers are small in comparison to the direct post-escape recaptures represented in Figure 17.

As the recapture and mortality of escaped farmed salmon are considered in the IMR risk assessment when determining the risk of escaped fish reaching the spawning grounds, a specific recapture score is not applied here, but is taken into account in the final score for Factor 6.1.

Detection and proportions of escaped farmed salmon in rivers

The number of salmon escaping from farms in Norway is probably in excess of the number of wild adult salmon returning to rivers in most years (Glover et al., 2019), and while most escapees disperse into the sea where they are likely to die of starvation, disease, or be eaten by predators, some survive and thousands migrate into Norway's rivers each year (Grefsrud et al., 2021a,b).

Aronsen et al. (2020) noted that the escape history of farmed Atlantic salmon will influence the likelihood of escapees reaching maturity and entering the rivers to spawn (with wild salmon or other escapees). These authors reported escaped farmed salmon caught in coastal waters and fjords in Norway came from multiple escape events over several years, and approximately 50% of the escapees had spent one or more winters at sea after escape (with some spending up to three years at sea). The higher proportion of escapees captured on the coast compared to within fjords suggested there is a reservoir of immature farmed salmon in coastal waters, and individuals may enter rivers to spawn with wild salmon when they reach sexual maturity (Aronsen et al., 2020). Therefore, while predation and starvation will continue to reduce the numbers in this coastal population, when investigating the risk of genetic introgression from escapees to wild salmon populations, Aronsen et al. (2020) note that escape events from the last four years will have to be considered.

A positive correlation has been documented between the observed proportion of escaped farmed salmon in a river over time and the degree of genetic interference, and the proportion of escaped farmed salmon in rivers is the most decisive factor affecting how many escaped farmed salmon there are in the spawning grounds (Grefsrud et al., 2021a,b). Norway's national monitoring program for escaped farmed salmon surveyed 200 rivers in 2019 using a variety of methods and the results show 145 rivers displayed a low frequency of farmed escaped salmon (<4% of the sampled population), 35 rivers had moderate frequency of escaped farmed salmon (between 4% and 10%) and 20 rivers displayed a high frequency of farmed escaped salmon (>10%) (Aronsen et al., 2020). These numbers are consistent with those reported for the 2018 sampling season (in Aronsen et al., 2019). Figure 18 shows the spread of these results across Norway.

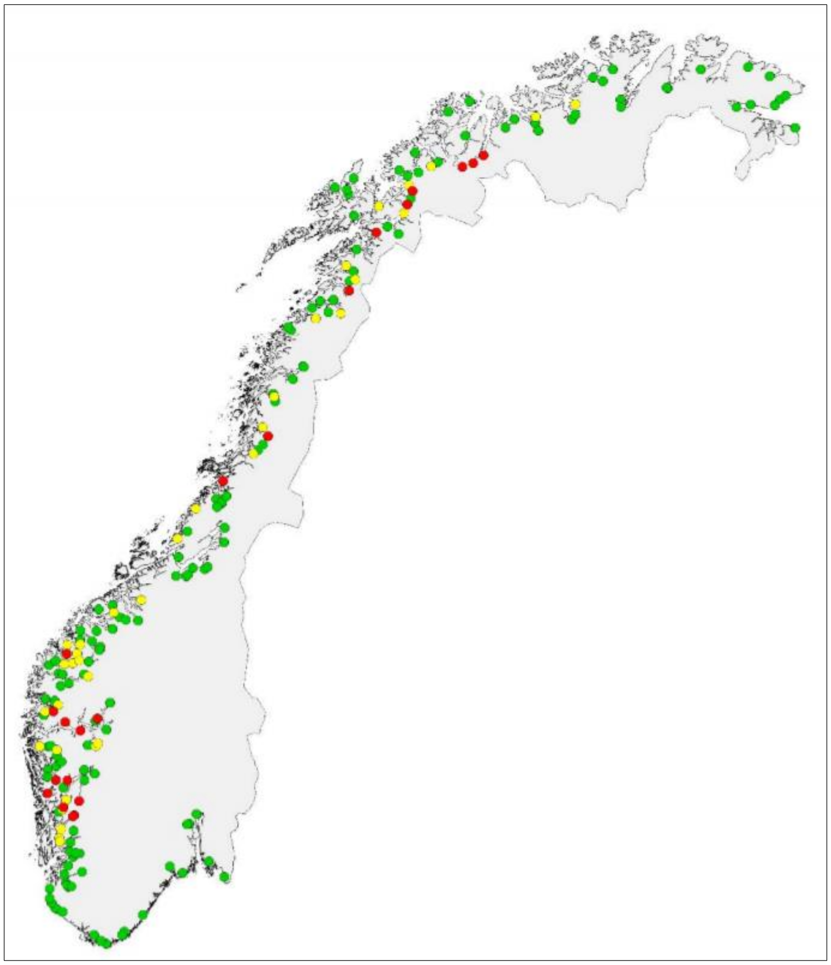

Figure 18: The map shows the location of the rivers where the proportion of escaped farmed salmon amongst the sampled population is considered to be low (<4%, green circles), medium (4 - 10%, yellow circles), or high (>10%, red circles). Image copied from Aronsen et al. (2020)

Since the monitoring program began (in 1989), the proportion of escapees in rivers has declined (noting that the proportion of escaped farmed salmon in a river is also influenced by the number of wild salmon returning from the sea) despite a >6-fold increase in aquaculture production (Glover et al., 2019).

Regional variation and final Seafood Watch scores for Factor 6.1

As noted in Table 5, the IMR risk assessment considers three subfactors in determining the risk of farmed salmon being present among wild salmon in the spawning grounds, and these are shown in Table 6 along with the corresponding Seafood Watch score for Factor 6.1. The IMR knowledge status for each regional risk assessment (in column e) was "Moderate" for all Production Areas except Area 3, for which it was "Good".

The outcomes of the IMR assessment (column e) were used to inform the Seafood Watch score for Factor 6.1 (column f) in each Production Area as follows:

- A "good" risk assessment outcome is considered to indicate only occasional detection of low numbers of escapees in the wild and a score for Factor 6.1 of 6 out of 10. It is not considered to justify a score of 8 out of 10 where escapees are not present in the wild.
- A "moderate" risk assessment is considered to indicate open systems with track record of low escapes or justifiable evidence for a lower level of concern, and a score for Factor 6.1 of 4 out of 10.
- A "poor" risk assessment outcome is considered to indicate that escapees are frequently detected in the wild, and a score for Factor 6.1 of 2 out of 10.

Table 6: Outcomes of the IMR risk assessment for the three factors (columns b,c,d) that determine the risk of farmed salmon being present among wild salmon in the spawning grounds (column e) for each Production Area (column a). The corresponding Seafood Watch score is shown in column f. Note recaptures were not assessed by IMR in Production Area 1.

a	b	c	d	e	f
PA	**Numbers of escapes**	**Proportion of escaped farmed salmon in rivers**	**Recaptures**	**Risk of farmed salmon in the spawning grounds**	**Seafood Watch Factor 6.1 Score (0-10)**
1	Good	Good	n/a	Good	6
2	Good	Good	Moderate	Good	6
3	Poor	Poor	Moderate	Poor	2
4	Poor	Moderate	Moderate	Moderate	4
5	Moderate	Moderate	Moderate	Moderate	4
6	Poor	Moderate	Poor	Moderate	4
7	Poor	Poor	Poor	Poor	2
8	Moderate	Moderate	Moderate	Moderate	4
9	Poor	Poor	Poor	Poor	2
10	Poor	Poor	Poor	Poor	2
11	Good	Poor	Poor	Poor	2
12	Moderate	Moderate	Poor	Moderate	4
13	Good	Good	Poor	Good	6

Factor 6.2. Competitive and Genetic Interactions

In the early 1970s, several breeding lines were established to improve farmed salmon production traits such as growth and sexual maturation, and 50 years later, Norwegian farmed salmon have undergone approximately 15 generations of targeted breeding and are now considered to be partially domesticated and adapted to a life in captivity (Grefsrud et al. 2021a). While it has been documented that escaped farmed salmon have poorer spawning success than wild salmon, some are able to spawn with other farmed salmon or with wild salmon, leading to genetic changes in the wild salmon stocks (Grefsrud et al., 2021a).

Wild salmon stocks that are genetically affected by escaped farmed salmon show changes in important traits such as survival, growth rate, age at migration, sexual maturation and migration pattern, and according to the available knowledge, these are changes that weaken the salmon's adaptations to the natural environment and will lead to increased mortality and reduced production of wild salmon (Grefsrud et al., 2021a,b; NINA, 2020[36]).

In addition to the genetic impacts (for a review, see Glover et al., 2017), escaping farmed salmon can have direct ecological interactions and impacts in the wild. For example, Skaala et al. (2012) concluded the overlap in diet among types of crosses between farmed and wild salmon demonstrates competition, and farm and hybrid progeny therefore will reduce the river's capacity for production of wild salmon. The dispersal, migration, survival, and ecological interactions of escaping salmon has been shown to be complex and varies considerably with the age of escaping fish, the location, and particularly the time of year (Skilbrei, 2010; Hansen and Youngsson, 2010; Olsen and Skilbrei, 2010). While these impacts have been identified in multiple studies, there is little information with which to quantify the impacts. Following the lead of the IMR (in Grefsrud et al., 2021a), the primary concern is therefore focused on the genetic interactions described above.

The genetic status of wild salmon

Glover et al. (2013) demonstrated that the level of genetic introgression in wild Atlantic salmon in Norwegian rivers has been population-specific, and that it is not solely predicted by the frequency or proportion of escapees observed in the population. Grefsrud et al. (2021a,b) now note that interbreeding of escaped farmed salmon with wild salmon has already led to extensive genetic change in many wild salmon stocks. Using studies on the genetic status of 50,000 wild salmon from 239 wild stocks throughout Norway carried out jointly by the Norwegian Institute for Natural Research and the Institute of Marine Research, Diserud et al. (2020) characterize the genetic influence of escaped farmed salmon by classifying the various stocks of wild salmon. Table 7 shows their conclusion that that 33.5% of sampled stocks have "very good to good" genetic status (no genetic changes observed), 29.0% have "moderate" status (weak genetic changes have been detected), 9.0% have "poor" status (moderate genetic changes have been detected), and 28.5% have “very poor” status (major genetic changes have

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[36] At the launch of the NINA report (Diserud et al., 2020), co-author Dr Hindar reportedly described these characteristics and reduced production (www.aquablogg.no).

been detected). Figure 19 shows populations in the different categories along the Norwegian coast. The IMR risk assessment used these results to determine their categorization of the genetic status of wild populations in each Production Area (column c in Table 9 below).

Table 7: Genetic status of 239 wild Atlantic salmon populations in 2020. Data from Diserud et al. (2020).

Category of genetic status	2020 Percentage per catageory
Green – very good to good	33.5%
Yellow - moderate	29.0%
Orange – poor	9.0%
Red – very poor	28.5%

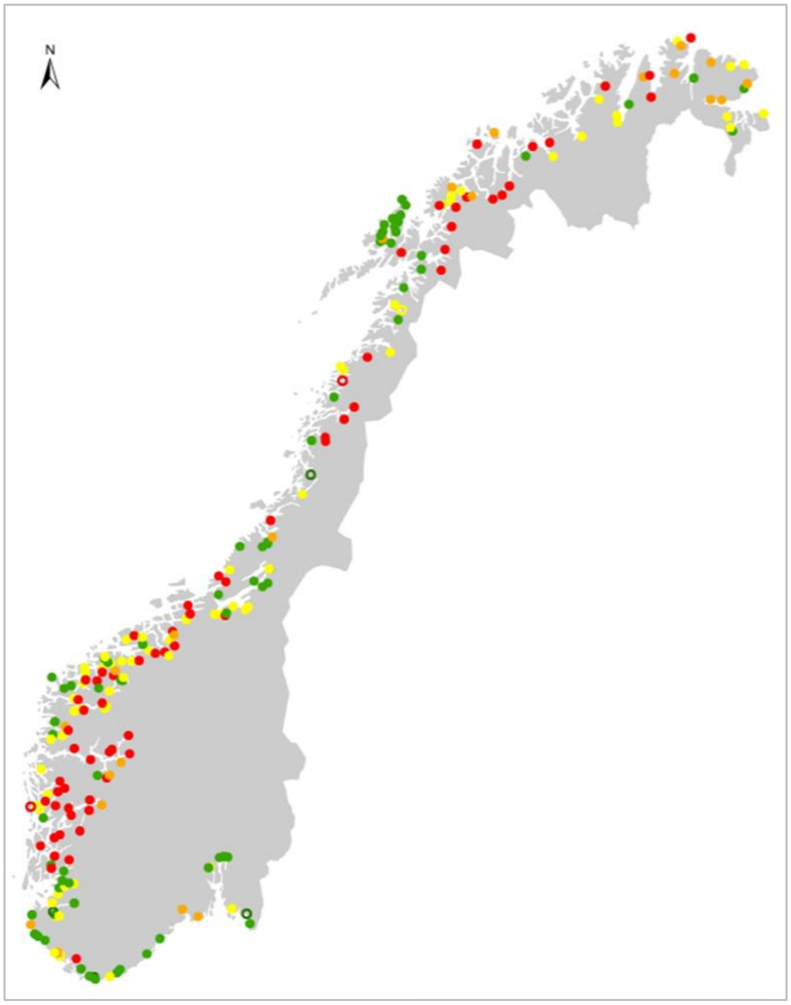

Figure 19: Genetic status of 239 salmon populations in Norway. Green (condition very good to good): No genetic changes observed; Yellow (condition moderate): Weak genetic changes indicated; Orange (condition poor): Moderate genetic changes have been detected; Red (condition very poor): Major genetic changes have been detected. Image copied from Diserud et al., (2020).

Table 8 shows the temporal change in the results of this NINA/IMR monitoring program from 2015 to 2020 for 48 of the 53 National Salmon Rivers[37]. It shows that while there has been a minor increase in the green (very good to good) category, there have been markedly larger increases in the orange (poor) and red (very poor) condition categories over this period.

Table 8: Comparison of genetic status across the 48 sampled Norwegian National salmon rivers from 2015 to 2020. Data from Diserud et al. (2020).

Genetic Status	**2015**	**2020**	**Percent change**
Green – very good to good	27.1%	28.3%	+4.43%
Yellow - moderate	43.8%	28.3%	–35.39%
Orange – poor	10.4%	18.9%	+81.73%
Red – very poor	18.8%	24.5%	+30.32%

Thorstad et al. (2020) note that wild salmon stocks face many challenges, and while there have been some improvements in important areas such as the occurrence/impact of acid rain and the parasite *Gyrodactylus*, the number of (wild) Norwegian salmon in the sea has more than halved since the 1980s. While impacts from fishing have decreased, the catch in 2019 was 136,000 fish (of which 21,000 were released alive), and this was the second lowest catch since 1980. Impacts from hydropower, pollution, and others are also important, but in their Report from the Scientific Council for salmon management (Vitenskapelig råd for lakseforvaltningon[38]) on the status of Norwegian salmon stocks in 2020, Thorstad et al. (2020) consider escaped farmed salmon and salmon lice (see Criterion 7 – Disease) to be the biggest threats to wild salmon populations.

Population status of wild salmon in Norway.

Wild salmon populations have declined across the Atlantic (and Pacific) Ocean, and while human impacts such as dams, pollution or marine overexploitation were responsible for some stock declines in the past, adult returns to river and hatchery stocks with no obvious local impacts have also declined or collapsed since 1985 leading to the extirpation or extinction of many stocks (Dadswell et al. (2021).

Wild salmon stocks that reach their spawning stock target[39] and have a high production potential[40] are considered to be more robust against genetic introgression from escaped farmed salmon than wild stocks that have little production potential and/or do not reach the spawning stock target (Grefsrud et al., 2021b). The IMR risk assessment thus uses the

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[37] National Salmon Rivers and National Salmon Fjords are areas where the salmon stocks are particularly important and where they are given special protection. No new aquaculture sites may be established in them, and in the case of 14 of the National Salmon Fjords, no aquaculture facilities at all are permitted. Further information here: https://miljostatus.miljodirektoratet.no/tema/ferskvann/laks/nasjonale-laksevassdrag-og-laksefjorder/

[38] https://www.vitenskapsradet.no/

[39] The spawning stock target is the amount of spawning salmon (kilograms of female salmon) needed to utilize the river's production potential

[40] A river’s production (or harvest) potential is the biomass of salmon present in excess of those needed to reach a river’s spawning stock target.

achievement of spawning stock targets and harvesting potential for each stock calculated annually by the Scientific Council for Salmon Management as an indicator of the wild salmon stock's robustness against increasing genetic introgression from escaped farmed salmon in each Production Area (for details, see Table 4.4 in Grefsrud et al. (2021b). The proportion of the total number of spawning stocks in Norway for which spawning stock targets and harvest potentials have been calculated is 79.4% on average for Norway as a whole, and is taken into account in each Production Area's risk assessment by the IMR.

The results of the IMR assessment of the population status of wild salmon in each Production Area (based on a 2015 to 2019 timeframe) are categorized as "Good", "Moderate" or "Poor" and shown in Table 9 below (column b)

Regional variation and final Seafood Watch scores for Factor 6.2

As noted in Table 5, the IMR risk assessment combines two subfactors to determine the resilience of wild salmon stocks against new genetic introgression (the wild salmon population status and their genetic status), and these are shown in Table 9 (columns b and c) along with the IMR risk assessment outcome (column d). For all Production Areas, the IMR knowledge status was "Moderate".

Table 9: Outcomes of the IMR risk assessment for the two sub-factors (columns b and c) that determine the resilience of wild salmon stocks to new genetic introgression (column d) for each Production Area (column a). The corresponding Seafood Watch score for Factor 6.2 is shown in column e.

a	b	c	d	e
PA	**Wild salmon population status**	**The genetic status of wild salmon**	**Resilience of wild stocks to new genetic introgression**	**Seafood Watch Factor 6.2 Score (0-10)**
1	Moderate	Moderate	Moderate	4
2	Good	Moderate	Good	6
3	Poor	Poor	Poor	0
4	Poor	Poor	Poor	0
5	Moderate	Poor	Moderate	2
6	Moderate	Moderate	Moderate	4
7	Moderate	Moderate	Moderate	4
8	Poor	Poor	Poor	0
9	Poor	Moderate	Poor	0
10	Poor	Poor	Poor	0
11	Poor	Poor	Poor	0
12	Good	Moderate	Good	6
13	Moderate	Moderate	Moderate	4

The outcomes of the IMR risk assessment (column d) are used to inform the Seafood Watch score for Factor 6.2 (column e) for each Production Area as follows:

- A "good" risk assessment outcome is considered to indicate escaping farmed salmon are genetically distinct from their wild conspecifics and introgression has had some impact on the genetic status of wild populations, but the degree of impact and current resilience of those populations to further genetic change lowers the overall risk, resulting in a score for Factor 6.2 of 6 out of 10.

- A “moderate” risk assessment is considered to indicate competition, predation, disturbance or other impacts to wild species, habitats or ecosystem may occur, but are not considered likely to affect the population status of the wild species, and a score for Factor 6.2 of 4 out of 10. An exception to this case has been made for PA 5 which has a “poor” genetic status.
- A “poor” risk assessment outcome is considered to indicate evidence of population-level impacts to wild species through genetic interactions, competition, predation or other disturbance, and a score for Factor 6.2 of 0 out of 10.

Genetic changes in wild cleaner fish populations

Due to widespread movements of various species of wrasse used as cleaner fish (see Criterion 8X – Source of Stock), Grefsrud et al. (2021a,b) report that there have been genetic changes in local stocks in Trøndelag (in Production Area 3), and the probability of ongoing genetic change in Area 3 is considered high as a result of escaping imported wrasse. This is noted here for future reference but does not currently affect the scoring of this criterion which focuses on salmon.

Conclusions and Final Score

Salmon continue to escape from Norwegian farms in both large-scale events and in small-scale trickle losses. As a result of escapees interbreeding with wild Atlantic salmon, only 33% of wild populations in Norway have good or very good genetic status; 27% have poor or very poor status and 30% have moderate status. The most recent annual risk assessment on salmon farming (2021 publication) conducted by the Institute of Marine Research (IMR) concluded that this has led to a reduced production of wild salmon, as well as changes in important biological properties in wild stocks such as age at sexual maturity and migration time for smolts. The IMR notes regional variations in the risk of these impacts and uses two primary factors in risk assessments for each of the 13 Production Areas: 1) the occurrence of escaped farmed salmon in the spawning grounds, and 2) the robustness of the wild stocks against new genetic introgression, and combines them to give an assessment of the risk of further genetic change in the wild populations. These two IMR factors (and their sub-factors which include recaptures) closely mirror the two Seafood Watch Escape Criterion Factors 6.1 and 6.2, and the IMR risk assessment (accompanied by a comprehensive Status of Knowledge report) has largely been used to inform the Seafood Watch scores in Table 10 below. Due to subtle differences in the IMR and Seafood Watch factors and subfactors, and due to the translation of factor scores to a final numerical Seafood Watch scores for this criterion, there are some minor variations in the outcomes of the IMR risk assessment and the Seafood Watch scores in some Production Areas.

Table 10: Final Seafood Watch scores for each Production Area for Criterion 6 – Escapes (column g – where green is a low concern, yellow is moderate, red is high, and black is a Critical conservation concern), along with the two IMR risk factor results (columns b and d), the two Seafood Watch factor results (columns c and e), and the overall IMR risk assessment results for the further risk of genetic change in wild salmon (column f – resulting from columns b and d).

a	b	c	d	e	f	g

PA	IMR Risk of farmed salmon in spawning grounds	Seafood Watch Factor 6.1 Score (0-10)	IMR Robustness of wild stocks	Seafood Watch Factor 6.2 Score (0-10)	IMR Risk of further genetic change in wild salmon	Seafood Watch Criterion 6 – Escapes Final score (0-10)
1	Good	6	Moderate	4	Good	4
2	Good	6	Good	6	Good	6
3	Poor	2	Poor	0	Poor	0
4	Moderate	4	Poor	0	Poor	1
5	Moderate	4	Moderate	2	Moderate	3
6	Moderate	4	Moderate	4	Moderate	4
7	Poor	2	Moderate	4	Poor	3
8	Moderate	4	Poor	0	Poor	1
9	Poor	2	Poor	0	Poor	0
10	Poor	2	Poor	0	Poor	0
11	Poor	2	Poor	0	Poor	0
12	Moderate	4	Good	6	Moderate	5
13	Good	6	Moderate	4	Good	4

The final Seafood Watch scores for Criterion 6 – Escapes show escaping farmed salmon are a critical conservation concern in Production Areas 3, 4, 8, 9, 10 and 11 (scores of 0 and 1 out of 10), and a high concern in Areas 5 and 7 (score 3 out of 10). These Seafood Watch results largely reflect the “Poor” outcomes of the IMR risk assessment in these Areas. Production Areas 1, 2, 6, 12 and 13 have moderate scores of 4 out of 10 (PA 1 and 6), 5 out of 10 (PA 12) and 6 out of 10 (PA 2) and largely reflect the presence of a “Moderate” outcome in either one of the IMR risk assessment factors. Overall, the IMR risk assessment had a moderate “knowledge status” in all Production Areas (except Area 3, where it was good) and the application of the Seafood Watch Aquaculture Standard produced slightly more conservative results compared to those of the IMR (e.g., in PA 2). It is also of interest to note that genetic changes have also been observed in wild wrasse populations due to the escape of imported cleaner fish, but these have not currently affected the scores in this assessment. See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations.

Criterion 7: Disease; pathogen and parasite interaction

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

Evidence-based assessment

C7 Disease	Final Score (0-0)	Rating	Critical
Production Areas 1, 11-13	4	Yellow	No
Production Areas 8-10	2	Red	No
Production Areas 2-7	0	Critical	Yes

Brief Summary

The detection of bacterial and viral pathogens in wild salmonids in Norway is low, and while farms can still act as chronic reservoirs of pathogens, the focus of this Disease Criterion is on parasitic sea lice. While the industry typically keeps lice below regulatory levels at individual farms, the cumulative dispersal of sea lice from the industry creates a substantial infection pressure in coastal waters that can infect and affect wild salmon migrating past farms and/or those species spending longer periods of time in coastal waters such as sea trout. The "traffic light" system in Norway is the most important regulatory tool with regard to annual sea lice impacts on juvenile wild salmon in each of the Production Areas. As such, the findings of the traffic light expert working group are important, but with a consideration of a longer-term dataset and cumulative impacts (from 2012 to 2020), and particularly the full inclusion of impacts to sea trout (and Arctic char), the results of the IMR risk assessment are the focus here. The IMR assesses two primary factors in each of the Production Areas which are combined to determine the risk of lice-induced mortality for juvenile salmon and sea trout. The first factor is the risk that wild fish will be infected by sea lice from farms, which is informed by the environmental conditions for lice, the emissions of lice from farms, and the overlap between wild fish and lice in time and space. The second factor is the wild fish's tolerance to sea lice infection, which mainly considers the fish size at the potential time of infection. The IMR risk assessment is also supported by a separate comprehensive knowledge status review, and the Evidence-Based Assessment method has been used in the Seafood Watch standard.

The IMR's "low" risk of sea lice induced mortality in juvenile wild salmon or sea trout typically results from either low emission of lice from farms or from little overlap in the timing of lice emissions and the presence of wild salmon or sea trout (such that there is a low probability that they will be infected with lice). Nevertheless, mortality may be moderate in some rivers in some years, and the "low" IMR category allows annual mortality of up to 10%. With consideration of this potential level of lice-induced mortality, the score for Criterion 7 – Disease in Production Areas with a “low” IMR outcome is 4 out of 10, as sea lice can cause mortality but are not considered to have a population-level impact. Conversely, a “high” risk of mortality (high lice emissions and high overlap), indicating greater than 30% annual mortality of wild fish, is associated with population-level impacts to wild salmon or sea trout, and the score for Criterion 7 – Disease is 0 and a “Critical” conservation concern due to the vulnerable nature of wild salmon and sea trout populations in Norway. For the intermediate “moderate” risks of mortality to wild salmon and sea trout (with a 10% to 30% annual mortality range), the final score for Criterion 7 – Disease is 2 out of 10, as sea lice are considered to negatively impact the affected species’ population size or its ability to recover. The Seafood Watch Aquaculture Standard scoring therefore takes a more precautionary approach to the mortality categories used by both the traffic light system and the IMR risk assessment, and in summary, Production Areas 1 and 11-13 have a final score for Criterion 7 – Disease of 4 out of 10, Production Areas 8-10 have a score of 2 out of 10, and Production Areas 2-7 have a “Critical” final score for Criterion 7 – Disease.

Justification of Rating

The open nature of net pen salmon farms means the fish are vulnerable to infection by pathogens from the surrounding waterbody, from wild fish, or from other natural infection routes, and farms can act as a temporally unnatural reservoir for a variety of pathogens and parasites that have the potential to be transmitted or re-transmitted to wild resident organisms, including native salmon species (Hammell et al., 2009). The escape of mobile and potentially migratory infected farmed fish (see Criterion 6 – Escapes) can also result in the wider distribution of pathogens, including into rivers (Grefsrud et al., 2021a,b).

It is known that significant amounts of pathogens can be spread from infected farmed fish, and the consequences of the spread of infection from farmed to wild salmon may vary from few or none to serious epidemics with the potential to eradicate populations (Grefsrud et al., 2021a,b). The extent to which this happens will vary depending on a complex suite of variables such as the properties of the different viruses and the salmon's ability to resist them, in addition to many environmental parameters that affect the interaction between salmon and the pathogens (Grefsrud et al., 2021a,b).

Acknowledging that pathogen detection alone is insufficient to allow inferences about health issues in wild fish and requires the context of host susceptibility, virulence of pathogen strains, and environmental conditions (Jia et al., 2020), the expansion of salmon aquaculture has brought conservation concerns into regions where the areas occupied by salmon farms are important for wild salmon (e.g., Peacock et al., 2014).

The primary source of information on fish diseases in aquaculture in Norway is the comprehensive Norwegian Veterinary Institute’s review in their annual Fish Health Report (only available in Norwegian for the 2020 report; Sommerset et al., 2020). In addition, the annual risk assessments from the Institute of Marine Research and associated Knowledge Status reports (e.g., Grefsrud et al., 2021a,b) provide important reviews (the 2020 report focused only on the concerns regarding sea lice). Annual reports on health monitoring of wild anadromous salmonids in Norway are available (e.g., Madhun et al., 2020) and included in the review of the status of Norwegian salmon stocks (Thorstad et al., 2020). While detailed site-specific information regarding on-farm disease is also available from Barents Watch, this Seafood Watch assessment has focused on the key review documents mentioned above, and particularly on the IMR risk assessment which itself relies on a review of the available information in Norway. Given the substantial amount of research conducted in Norway and readily available reports and risk assessments, the Evidence-Based Assessment method has been used[41].

Mortality rates

The Directorate of Fisheries and the Veterinary Institute publish data on losses during production[42] and Sommerset et al. (2021) have presented annual mortality data as a percentage of stocked fish (Figure 20). These figures show minor annual variability of approximately 2%, but it is important to note firstly that the 2019 value was increased due to large mortalities caused by algal blooms, and secondly that mortality rates in individual production cycles or Production Areas can be highly variable. For example, Sommerset et al. (2021) report that the 2020 percentage mortality ranging from 6.7% (in Production Area 13 in the far north) to 27.2% (in Production Area 4 in western Norway).

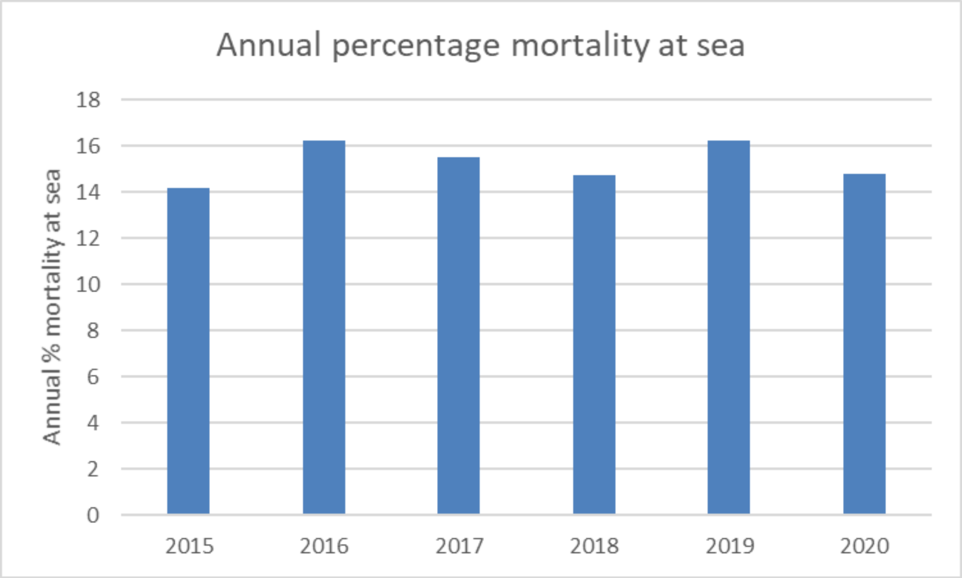

Figure 20: Annual average percentage mortality during growout at sea. Data from Sommerset et al. (2021).

The data sources do not differentiate the cause of mortality beyond a category of "dead fish", but when considering the complexities associated with the inclusion of mortalities from algal blooms or losses due to other causes, Sommerset et al. (2021) conclude the mortality rate due

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[41] The data score for disease in Criterion 1 – Data is 7.5 out of 10 allowing either the Evidence-Based or Risk-Based assessment method to be used.

[42] The Veterinary Institute statistics on production losses and mortality are here: http://apps.vetinst.no/Laksetap/

to disease has been stable over this time period (2015 to 2020). It must also be noted that due to the presence of non-clinical infections, the use of therapeutic treatments and/or natural recovery, the on-farm mortality rate is an imperfect indicator to evaluate the potential transfer of pathogens to wild fish throughout the pathogen cycle.

Bacterial diseases

Sommerset et al. (2021) consider the consumption of antibacterial agents to be a good indicator of the occurrence of bacterial diseases, and with a very low number of prescriptions written in recent years (13 in 2019; see Criterion 4 – Chemical Use), bacterial pathogens are considered a lesser concern compared to viral pathogens and lesser again to parasites.

Viral diseases

Viral diseases continue to cause the greatest losses when considering infectious diseases in Norwegian aquaculture, and Table 11 shows that these specific diseases have varied in importance over time. In 2020, like the previous six years, pancreatic disease (PD), heart and skeletal muscle inflammation (HSMI), and cardiomyopathy syndrome (CMS) have dominated diagnosed cases (Sommerset et al., 2021).

Table 11: Incidence of various viral diseases in salmonids in fish farming (as numbers of diagnosed cases) during the period 2009–2019. ISA: infectious salmon anemia; PD: pancreas disease; HSMI: heart and skeletal muscle inflammation; IPN: infectious pancreatic necrosis; CMS: cardiomyopathy syndrome. Data from Sommerset et al. (2020, 2021).

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
ISA	10	7	1	2	10	10	15	12	14	13	10	23
PD	48	88	89	137	99	142	137	138	176	163	152	158
CMS	62	49	74	89	100	107	105	90	100	101	82	150
HSMI	139	131	132	142	134	181	135	101	93	104	79	161
IPN	223	198	154	119	56	48	30	27	23	19	23	22

Salmon farms as reservoirs of pathogens and transfer to wild salmonids

With consideration of the transfer of these viral pathogens to wild salmonids in Norway, the Institute of Marine Research began extensive mapping activities of viral pathogens in wild salmonids in 2012, and this has become part of the institute's long-term monitoring activities (Grefsrud et al., 2021a,b). An "Annual report on health monitoring of wild anadromous salmonids in Norway" is published annually (e.g., Madhun et al., 2021) but focuses on a limited number of viruses (just two viruses in the 2021 report (ISA virus[43] and SAV[44]). They report the absence or low prevalence of viral infections in the tested migrating smolts in 2019 and note this is consistent with previous findings in wild salmonids that showed no apparent relationship to the fish farming intensity or the frequency of disease outbreaks. Madhun et al. (2021) conclude with a suggestion that wild salmon are exposed to a low infection pressure from fish farming.

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[43] Infectious Salmon Anemia Virus, causing ISA in Table 11

[44] Salmonid Alpha Virus, causing Pancreas Disease (PD) in Table 11

The IMR Risk Assessment (Grefsrud et al., 2021a,b) considers the risk of a change in the disease incidence of wild fish as a result of pathogens from aquaculture using several factors associated with the infection pressure on wild salmon and the consequences of infection, but was run for the same two viruses (ISA virus and SAV). The risk was considered to be moderate to low in all Production Areas. Madhun et al. (2020) also note the possibility that infection may lead to rapid disappearance, altered behavior, or biased sampling of the infected fish, and while Grefsrud et al. (2021b) provide examples of mass deaths of fish in the wild (usually caused by novel introduced pathogens or special environmental conditions), studying disease in wild populations is exceedingly complex; that is, mortality events are rarely observed, sampling efforts solely capture live fish, and weak and dying fish are probably predated before the disease progresses to mortality (Miller et al. 2014).

Grefsrud et al. (2021b) also provide a theoretical scenario in Figure 21 showing how migrating salmon may be affected after passing through an area of infection such as a farm, and also caution that a) the presence of a pathogen does not mean infection, b) infection does not mean the development of disease or the spread of infection, and c) illness does not mean death.

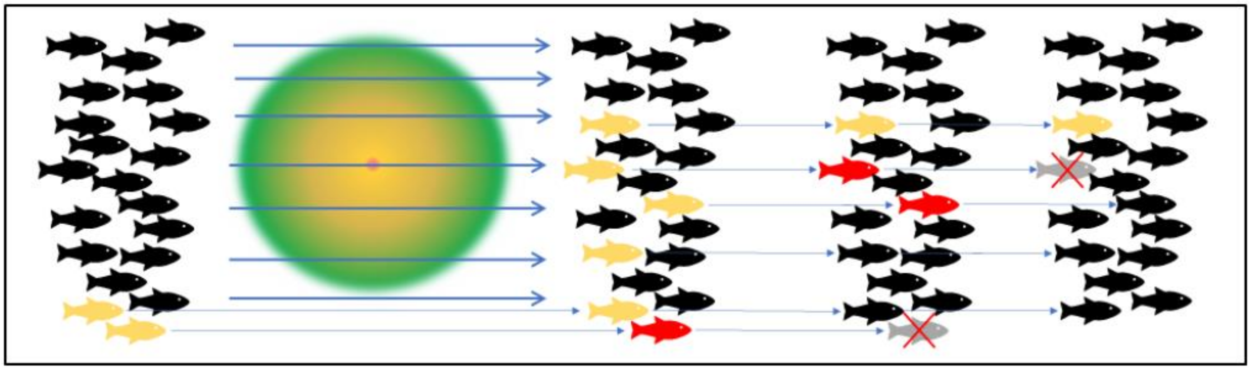

Figure 21: A theoretical scenario of migrating salmon smolts or sea trout in a fjord passing through areas with infection from farming. In such an area the exposure varies a lot. Upon exposure, some individuals may become infected (yellow fish). Some infected individuals may become ill (red fish). Some sick fish may die (grey fish), some may recover, and some may become chronically infected (carriers). Some of the wild fish may be naturally infected regardless of farming, and some of them may also become ill and die. Image copied from Grefsrud et al. (2021b)

Given the limited concern regarding the risk of impacts of bacterial and viral pathogens in key studies such as Madhun et al (2021) and Grefsrud et al. (2021a,b), the focus of this Seafood Watch assessment is on sea lice.

Sea lice

Parasitic sea lice (*Lepeoptheirus salmonis* and *Caligus elongatus*) are a major production problem for Norwegian salmon farms (and in other countries), resulting in losses of production (e.g. reduced growth rates), increased susceptibility to secondary infections, direct animal welfare concerns, and costly treatments (that have their own welfare issues to the salmon and cleaner fish) (Grefsrud et al., 2021a,b; Sommerset et al., 2021). In addition, wild salmonids can be infected by lice discharged from net pen salmon farms, and many studies in different salmon regions indicate substantial impacts are expected in some years (Shephard and Gargan, 2021).

In the well-studied situation in Norway for example, sea lice are currently considered to be the biggest (and expanding) threat to wild salmon populations (Thorstad et al., 2020; Grefsrud et al., 2021).

It has been shown that a number of factors can be linked to the infection of wild salmonids with lice from farms and their consequent mortality (Grefsrud et al., 2021a,b); for example, the timing and number of lice emanating from farms, temperature and salinity in the fjord and coastal areas, migration time, and migration route to the post-smolt environments are considered the most important influencing factors for the degree of infection pressure. These factors vary between coastal areas and from year to year and thus affect the acute and longer-term risk to salmon populations and sub-populations.

There are large amounts of data and analysis on sea lice in Norway, and the importance of the potential impacts of sea lice to wild salmonids is such that the industry's scale of operation in each of the 13 Production Areas is dictated by the results of the "traffic light system" which predicts the sea lice-induced mortality of wild salmon populations (Vollset et al. 2020). The IMR risk assessment and comprehensive Knowledge Status reports also provide comprehensive reviews and assessments of the risk of mortality to migrating post smolts of salmon, and importantly sea trout, as a result of sea lice emissions from salmon farms (Grefsrud et al., 2021a,b). Some background information is provided below, but given the complexity and expertise required to assess the impacts to wild salmonids, the findings and conclusions of the expert working group on the traffic light system (e.g., Vollset et al., 2020) and the IMR risk assessment are relied upon here to inform the Seafood Watch scoring.

Sea lice on Norwegian salmon farms and in coastal waters

Sea lice counts for every stocked salmon farm in Norway are available on the Barents Watch database[45]. Sexually mature sea lice on farmed salmonids release planktonic lice larvae that are dispersed by water currents and can subsequently infect wild salmon, sea trout, and char that live along the coast (Karlsen et al., 2020b). Figure 22 shows an example of the estimated number of sea lice eggs released per hour from salmon farms in four Production Areas in southern Norway from 2019 to 2020 and show considerable variation by region and year. These data show the efforts made by the industry to reduce lice numbers during the outmigration period of wild salmon to adhere to the regulated sea lice treatment thresholds on farms[46] (the time at which 50% of wild salmon are considered to have migrated in each region is shown by a green line in Figure 22). The egg production shows a rapid increase immediately after this time, and therefore an increased infection pressure over the latter half of the outmigration period, and potentially for periods of importance to sea trout which remain in coastal waters for longer periods.

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[45] https://www.Barents Watch.no/

[46] The lice limit is normally 0.5 adult female lice per fish. In 2017, the regulation changed so that the limit was lowered to 0.2 adult female lice per fish from weeks 16-21 for southern Norway and weeks 21-26 for Nordland, Troms and Finnmark in northern Norway.

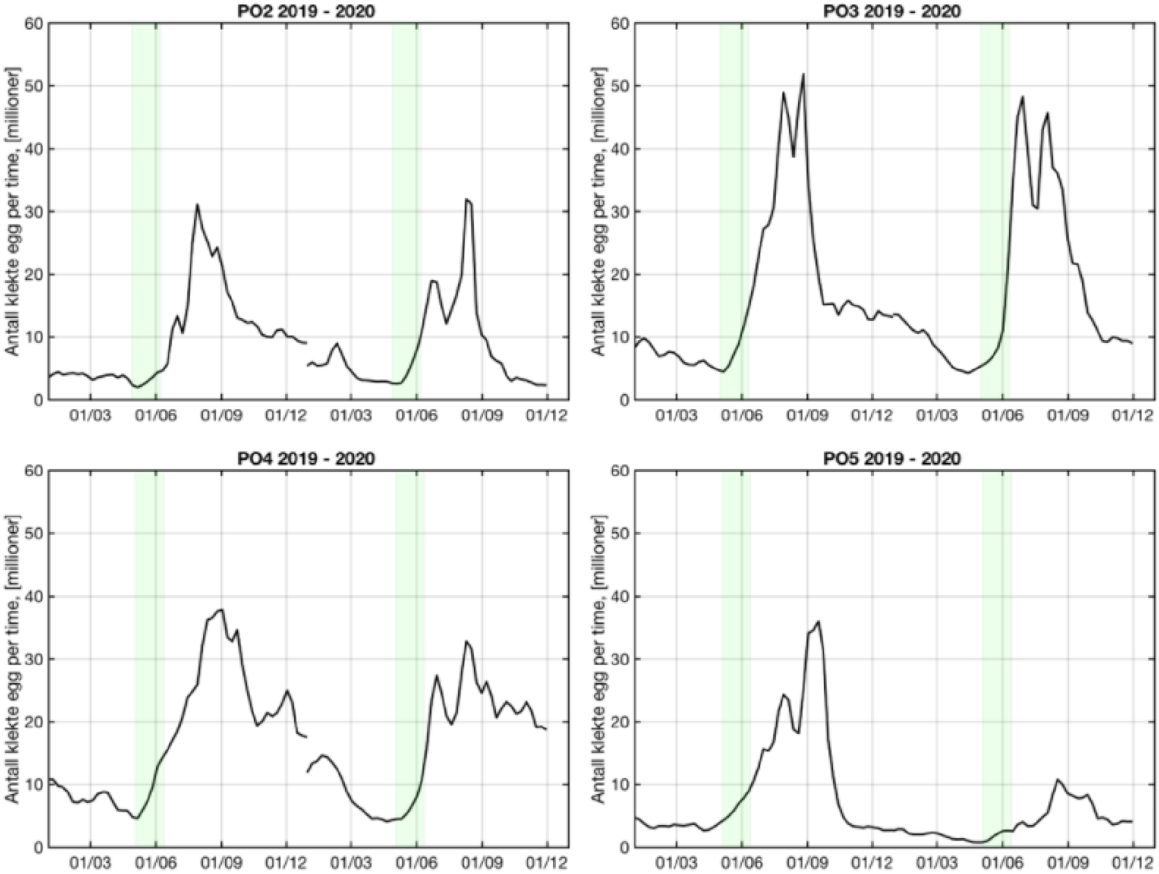

Figure 22: An example of sea lice egg production in millions of eggs per hour for four Production Areas in southern Norway in 2019 and 2020. The migration period of wild salmon is shown by the green lines in each region. Graphs copied from Grefsrud et al. (2021b).

Using these data and others, the Institute of Marine Research produces a mapped database[47] of sea lice infection pressure. Figure 23 shows two example screenshots of part of Production Area 4 in week 19 (May 5, 2020) and week 28 (July 4, 2020). This area was selected as an example of high infection pressures, and the images show that while the farms control lice levels below the regulatory limits (blue dots), the cumulative infection pressure in coastal areas (orange shading) increases dramatically over this period (note that week 28 is after the period of the lower permitted lice thresholds covering the peak outmigration period of wild salmon, but potentially not for sea trout). Grefsrud et al. (2020) note the migration of salmon from the rivers in this region mainly takes place in weeks 17 to 25, but the later period is still important for sea trout; see further discussion on sea trout below.

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[47] https://www.hi.no/forskning/marine-data-forskningsdata/lakseluskart/html/lakseluskart.html

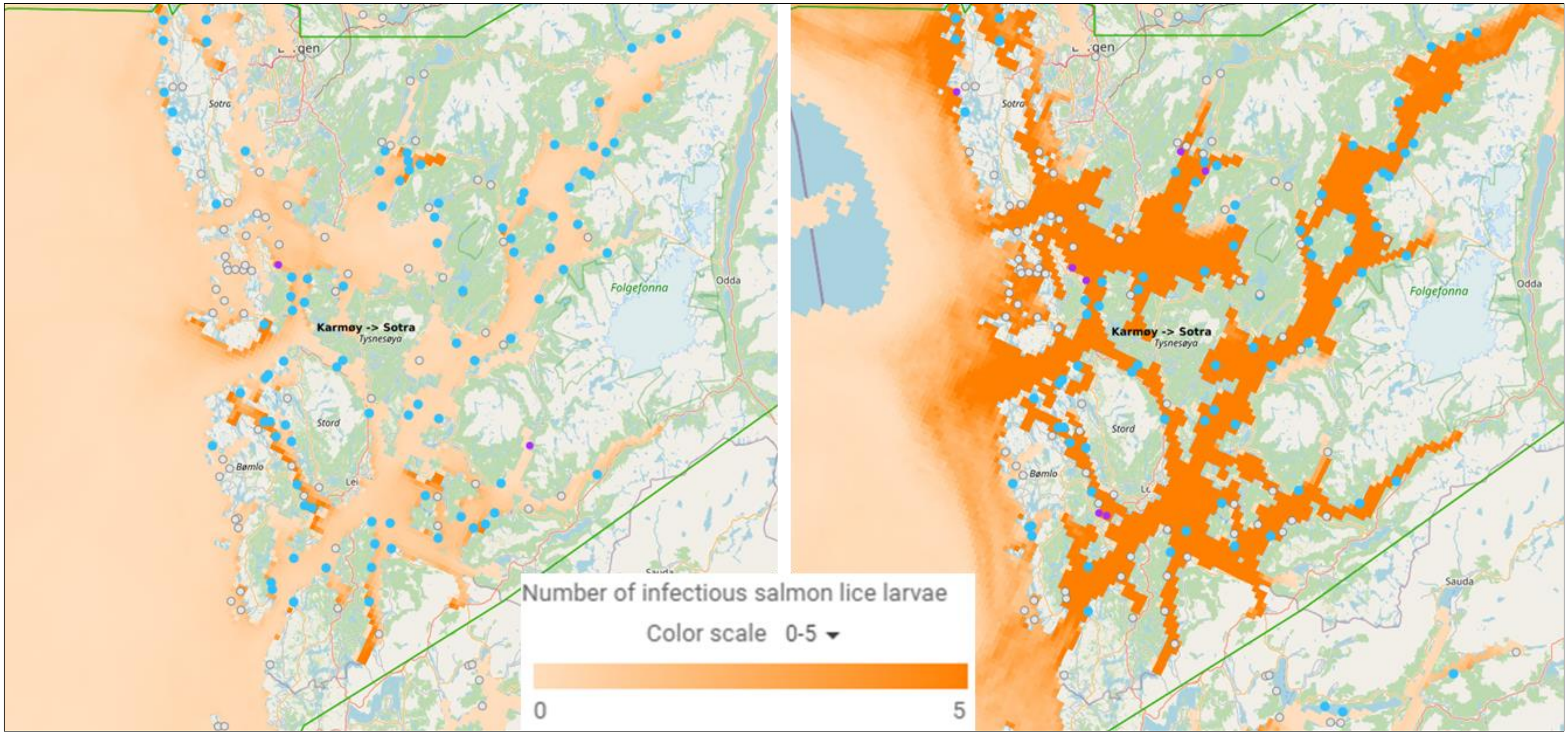

Figure 23: Screenshots from the IMR Lakseluskart showing Production Area 4 in week 19 (May 5th, 2020) in the left image and week 28 (July 4th 2020) in the right. Blue dots represent salmon farms operating below the sea lice limits, and purple dots represent sites above the limits. Orange shading represents the sea lice infection pressure in lice per square meter of water.

Figure 24 shows similar results from the sea lice dispersion models for the country as a whole over a similar period (weeks 21 and 27) from Nilsen et al. (2020). Figure 25 shows a closer view of the western Norway and Trøndelag regions in week 27, and these regions are discussed further in the following sections. It can be seen that in nearly all the inshore areas (in western Norway and Trøndelag) and particularly in the fjords, that there are high levels of infectious sea lice in these periods (i.e., the period of importance for out-migrating salmon and sea trout).

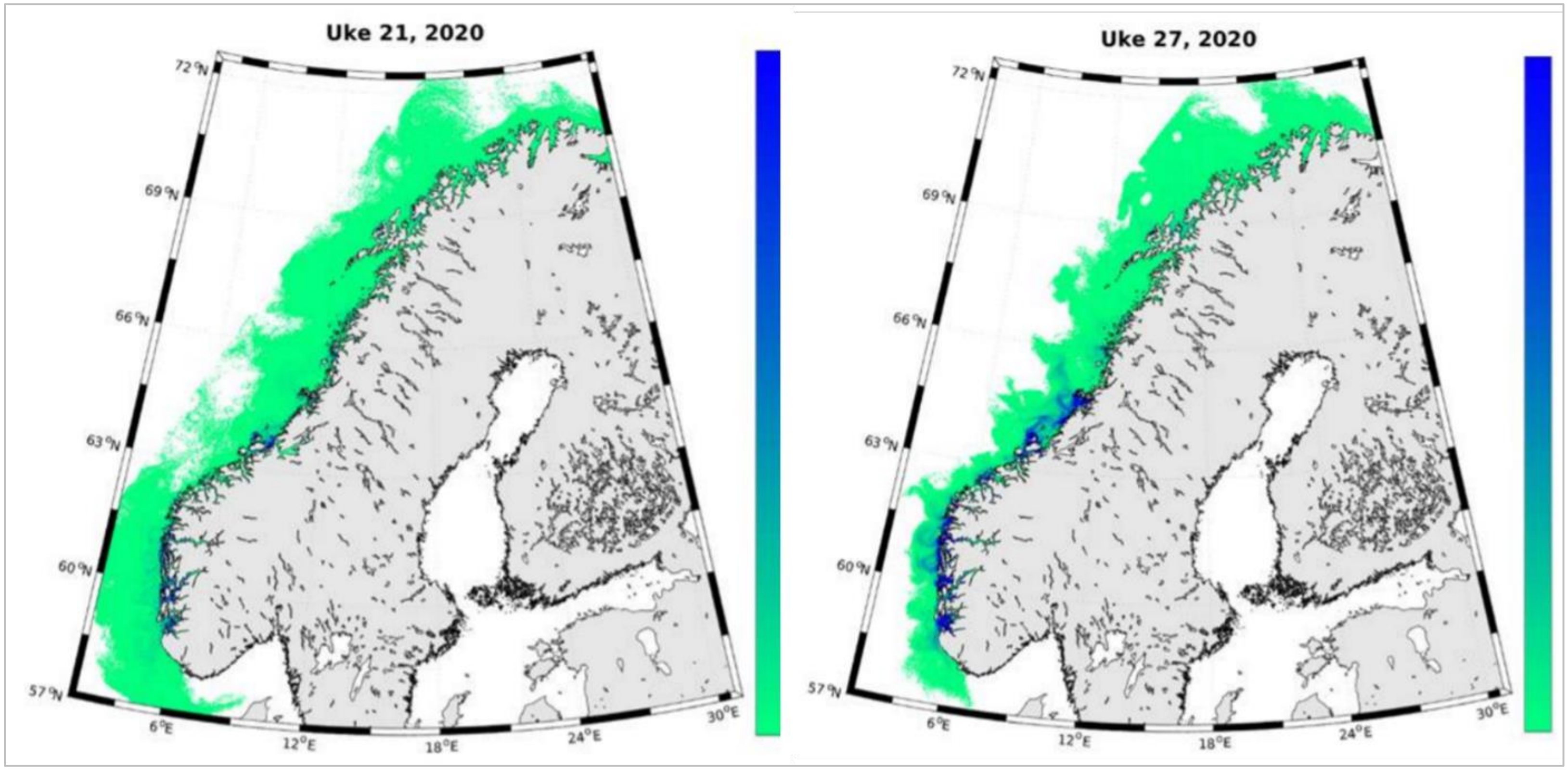

Figure 24: Modelling results showing the density of infectious sea lice stages along the Norwegian coast in week 21 (mid-May: left image) and week 27 (late June: right image). The green color indicates a low density and darker blue is high density or infection pressure. Image copied from Nilsen et al. (2020).

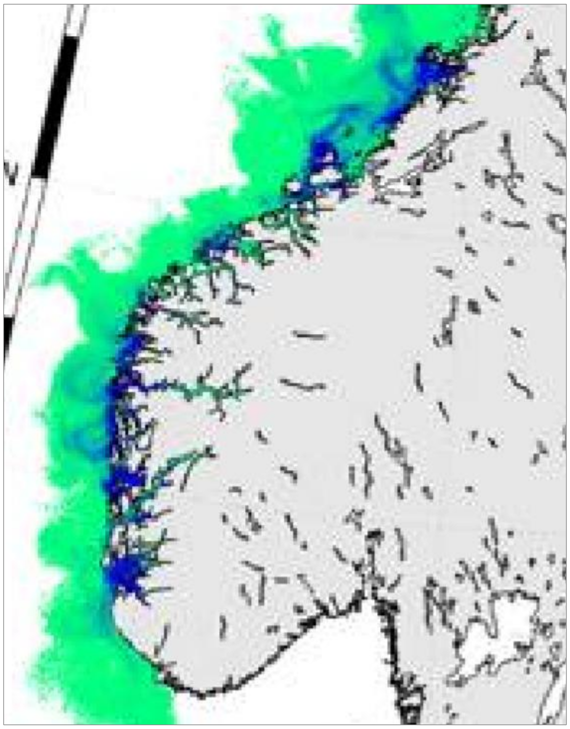

Figure 25: Close up view of the right image (week 27) in Figure 24 showing the high density of infectious sea lice in the inshore waters of western Norway and Trøndelag. Image copied from Nilsen et al. (2020).

Monitoring of lice on wild salmonids

The national monitoring program for salmon lice on wild salmonids (Nasjonalt Overvåkningsprogram for Lakselus - NALO) surveys and reports annually (e.g., Nilsen et al., 2020a). Note this is monitoring for lice levels on out-migrating juvenile salmonid smolts rather than on adult fish. These data are reviewed in many other publications such as Karlsen et al. (2020a, 2020b), and reported in other annual reviews such as the annual fish health report in Sommerset et al. (2020).

The NALO reports provide detailed results for sea lice counts on juvenile wild salmon and sea trout smolts for each of the 13 Production Areas along the coast during the spring outmigration period from April to July. Sampling data are presented for each locality, week, number of fish and weight, and the lice infestation data are presented as prevalence (defined as the proportion of the examined fish that are found with one or more salmon louse and is stated as a percentage), average intensity (defined as the average number of salmon lice on the fish that have lice present), and the relative number of lice (defined as the proportion of fish with more than 0.1 lice per gram of fish weight). With consideration of many other studies and datasets, the annual NALO data can be analyzed to give indications of impact to wild salmonid populations, and Norway's new "traffic light system" is the focus here and discussed below.

Assessing impacts – the “traffic light” system

In 2017, the Norwegian government ratified a new regulation, commonly referred to as the traffic-light system, in which farmed salmon production tonnage is governed (by the Ministry of Trade and Industry) by a single indicator on the predicted salmon lice-induced mortality in migrating juvenile wild salmonids (Vollset et al., 2020). Under directives from the Ministry of Trade and Industry (NFD), a steering committee from the Institute of Marine Research (IMR), the Veterinary Institute (VI) and the Norwegian Institute for Natural Research (NINA) established an expert working group of ten experts from Norwegian research institutions.

More specifically, the group was tasked with calculating the mortality on migrating salmon post-smolts, first-time migrating sea trout and char post-smolts, and on grazing sea trout and char as a consequence of infection with salmon lice from fish farms (since the latter two species stay on the coast and in the fjords throughout the marine phase, they are potentially affected by salmon lice from fish farms for a much longer period than migrating salmon).

Simplistically (see Vollset et al., 2020, for a full review – in Norwegian) the group categorized mortality of wild salmonids into four levels based on the number of sea lice per gram of fish weight (e.g., if a 50 g smolt has five lice, it has 0.1 lice per gram of fish weight) such that:

- 100% of individuals with >0.3 lice per gram of fish weight will die.
- 50% of individuals with 0.2-0.3 lice per gram of fish weight will die.
- 20% of individuals with 0.1–0.2 lice per gram of fish weight will die.
- 0% of individuals with <0.1 lice per gram of fish weight will die.

Using several complex models from different institutions in Norway, the traffic light system calculates the risk of mortality to wild salmon (but not yet specifically to trout or charr as discussed below) in each Production Area and uses it to regulate the biomass of fish held in farms in each Production Area, where:

- If the mortality of wild salmon is considered small (<10%), industry growth is permitted.
- If the mortality is between 10-30%, increased production is not permitted.
- If the mortality is most likely >30%, the farmed production must be reduced.

Noting that juvenile wild salmon have a high natural mortality rate, the traffic light system is thereby aiming at a mortality rate of migrating wild salmon due to lice infection from farms of between 10% and 30% each year. Recognizing the complexity of their assessments, Vollset et al. (2020) extensively describe the assumptions and uncertainties, and these are not discussed further here with two important exceptions. First, it is important to note that one of the main challenges is that the effect of lice on wild salmonids is context-sensitive; that is, the effect of lice is directly correlated with the overall survival in the ocean, so that in years of poor survival the effect of lice is large, while in years of good survival the effect of lice is almost not measurable (Vollset et al., 2015, 2019b, Bøhn et al., 2020). The limit values must therefore be regarded as lethal in a probable context (conditions in the sea). Second, it is important to note that the impacts are highly variable by locality (e.g., individual rivers and fjords) and year, and

Vollset et al. (2020) recognize the challenges of drawing conclusions over an entire production area. Similarly, Bøhn et al. (2020) highlight that timing is crucial. In years with little overlap between lice blooms and Atlantic salmon smolt migration, only minor effects can be expected; conversely, in years with a strong overlap in timing, serious mortality effects can be expected.

Vollset et al. (2020) present the results of the traffic light system from 2016 to 2020 for each Production Area (Table 12). These results show that 9 out of 13 Production Areas in 2020 were considered to have a low risk, indicating less than 10% estimated mortality of wild salmon due to sea lice from salmon farms. Two regions were moderate risk (10-30% mortality of wild salmon) and two were high risk (more than 30% mortality of wild salmon).

Table 12: Results of the expert group of the “traffic-light” system, from 2016 to 2019, for each of thirteen Production Areas (PA, from #1 in the south to #13 in the north of Norway). Low risk corresponds to <10 percent salmon lice-induced mortality in wild salmon smolt, moderate risk corresponds to 10-30 percent mortality, and high risk corresponds to >30 percent salmon lice-induced mortality in wild salmon smolts. Data are from Vollset et al. (2020).

Area	**Annual “traffic light” results**				
	2016	**2017**	**2018**	**2019**	**2020**
1	Low	Low	Low	Low	Low
2	Mod	Low	Mod	Low	High
3	High	High	High	Mod	High
4	Mod	High	Mod	High	Mod
5	Mod	Mod	Mod	High	Low
6	Mod	Low	Low	Low	Low
7	Mod	Low	Mod	Low	Mod
8	Low	Low	Low	Low	Low
9	Low	Low	Low	Low	Low
10	Low	Low	Low	Mod	Low
11	Low	Low	Low	Low	Low
12	Low	Low	Low	Low	Low
13	Low	Low	Low	Low	Low

The Norwegian Food Safety Authority (Mattilsynet) noted[48] that the results of the monitoring program indicate a good fit between the traffic light system’s models predicting the spread of lice and the results of the monitoring of sea lice in Norway, but given the uncertainties and assumption noted above (in Vollset et al. 2020) it is somewhat inevitable that the results have been challenged. In 2021, 25 salmon farming companies in Production Area 4 challenged the traffic light system in court (for being too ‘conservative’ and considering the predicted impact

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[48] https://www.mattilsynet.no/fisk_og_akvakultur/fiskehelse/fiske_og_skjellsykdommer/lakselus/ny_rapport_oppsummerer_overvaakningsprogrammet_for_lakselus_i_2020.41374

to be higher than they believed it to be) but lost on all the points made in their case and the results of the system were upheld[49].

Vollset et al. (2020) stress that the traffic light system does not assess the lice-induced mortality of wild sea trout or Arctic char; these two salmonid species stay on the coast and in the fjords throughout the marine phase and are thus affected by salmon lice from fish farms for a much longer period than migrating salmon smolts. It has also been shown that these species have a potential behavioral response to salmon lice infestations that result in premature return to fresh water or areas with low salinity; for example, uninfected sea trout spent an average of 100 days at sea, whereas infested fish returned to freshwater after only 18 days at sea at the probable cost of reduced growth opportunities and compromised future fitness (Serra-Llinares et al., 2020). It can also be argued that the ability to return to freshwater to remove sea lice will reduce the lice-induced mortality in these species.

Assessing impacts – the IMR risk assessment

The IMR risk assessment (Grefsrud et al., 2021a) assessed the risk associated with mortality in outgoing post-smolt salmon as a result of discharges of sea lice from fish farming. Importantly, it also separately assessed the risks associated with negative effects on sea trout and Arctic char. It is also important to note that in contrast to the single year assessments of the traffic light system, the IMR risk assessment considered cumulative impacts over a longer timeframe using data from 2012 to 2020. The risk assessment considered two primary factors, of which one had three secondary factors as shown in Table 13. While the second factor (tolerance) does not have specific secondary factors, it mostly considers the size of wild fish at the potential time of lice infection. The two factors are then combined to give the risk of mortality on migrating post-smolt salmon as a result of discharges of sea lice from salmon farming. The IMR use the same annual mortality categories as the traffic light system described above (from Vollset et al., 2020) to determine the final risk assessment outcomes for "low" mortality (<10%), "moderate" (10 to 30%) and "high" (>30%)

Table 13: Factors and secondary factors used in the IMR risk assessment to determine the risk associated with mortality in outgoing post-smolt salmon or sea trout as a result of discharges of salmon lice from fish farming in each of the 13 Production Areas. The two primary factors are combined to give the risk of mortality on migrating post-smolt salmon as a result of discharges of sea lice from salmon farming.

Primary Factor	**1: Wild fish are infected by salmon lice**	**2: The wild fish's tolerance to sea lice**
Secondary Factors	1a: Environmental conditions	No secondary factors here
	1b: Emissions of salmon lice larvae from farms	
	1c: Overlap between fish and lice in time and space	

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[49] https://www.fishfarmingexpert.com/article/norway-salmon-farmers-lost-traffic-light-court-fight/

The outcomes of the risk assessment for each species and each Production Area are shown in Table 14, along with the assessment of the knowledge strength for each one of those outcomes. In comparison to the annual results of the traffic light system (Table 12), the risk assessment with consideration of cumulative impacts using multi-year data from 2012 to 2020 has a higher number of red outcomes with a "high" risk or mortality to wild salmon (four Production Areas) and also a lower number of green outcomes with a "low" risk of mortality (six Production Areas) (Table 14). For sea trout (and char) the risk assessment outcomes are worse, with six production Areas (2-7) having a high risk of mortality to these species, and only four Areas with a low risk of mortality (1, 11-13).

Table 14: Outcomes of the IMR risk assessment to determine the risk associated with mortality in outgoing post-smolt salmon or sea trout as a result of discharges of salmon lice from fish farming in each of the 13 Production Areas. The knowledge strength for each species and production area is also provided. Data from Grefsrud et al. (2021a).

Area	**2012-2020 Salmon**	Knowledge strength	**2012-2020 Sea Trout**	Knowledge strength
1	Low	Good	Low	Good
2	High	Moderate	High	Moderate
3	High	Good	High	Moderate
4	High	Good	High	Moderate
5	High	Poor	High	Moderate
6	Moderate	Poor	High	Moderate
7	Moderate	Poor	High	Moderate
8	Low	Moderate	Moderate	Moderate
9	Low	Good	Moderate	Moderate
10	Moderate	Poor	Moderate	Moderate
11	Low	Good	Low	Good
12	Low	Good	Low	Good
13	Low	Good	Low	Good

With consideration of the factors in the IMR risk assessment (Table 12), the variability in these results is primarily due to differences in the emissions of lice larvae from farms and in the overlap in timing of those discharges and the outmigration period of salmon (and the longer coastal period for sea trout). As such, "low" risks of mortality in Table 14 typically result from a low emission of lice or little overlap in timing, such that there is a low probability that salmon or sea trout will be infected with lice. Conversely, a "high" risk of mortality typically means a high emission of lice and a longer overlap in timing, such that the probability that salmon or sea trout will be infected is high. In these scenarios, the longer residence period of sea trout in coastal waters increases the potential for a significant overlap with higher lice emissions.

The knowledge strength is variable for salmon, but is moderate to good in all Production Areas for sea trout and char. Nevertheless, Grefsrud et al. (2021a) note it is crucial that decision-makers and others who use the results of these risk assessments understand that incomplete information, insufficient knowledge, hypotheses and assumptions are part of, <u>and largely characterize</u>, such an analysis (underlining added here for emphasis).

To quantify the scale of these mortalities, the Norwegian Scientific Advisory Committee for Atlantic Salmon (Thorstad et al., 2020) estimated the annual loss of adult wild salmon returning to Norwegian rivers due to salmon lice[50] at 39,000 adult salmon in 2019 (noting that the corresponding number of out-migrating salmon smolts killed by sea lice will be much larger than this number of returning adult salmon). To give context to the 39,000 figure, catch data from Statistics Norway[51] show 131,258 salmon (and 34,857 sea trout and Arctic char) were caught and killed by anglers in Norwegian rivers in 2019, with a further 32,189 (all species) caught and released. The total weight of salmon killed by anglers in 2019 was 348.1 mt (the salmon farming industry harvested 1.3 million mt in 2019). However, while it appears fishing pressure has a greater numerical impact, the reality is that with robust fishery regulations, the angling catch is strictly limited to those rivers where there are sufficient numbers of returning salmon to support a capture fishery; fishing, for example, is currently closed in 110 rivers due to reduced populations and restricted in others (Thorstad et al., 2020).

As discussed in Criterion 6 – Escapes (and shown in Figure 14), according to the Norwegian Scientific Advisory Committee for Atlantic Salmon, sea lice and escaped farmed salmon have the greatest negative impact on wild salmon in Norway and are regarded as an expanding population threat, which means they are affecting populations to the extent that populations may be critically endangered or lost in nature and that have a high likelihood of causing even further reductions (Thorstad et al., 2020). The results of both the traffic light system and the IMR risk assessment allow for more nuance based on the results in each Production Area.

<u>Status of wild salmonid populations in Norway</u>
Adult returns to many Atlantic salmon wild and hatchery stocks of the North Atlantic have been in a long-term decline, but although there has been an approximate decline of 50% in adult returns since 1985, Norway is among the few countries with the least decline in adult return abundance (Dadswell et al., 21021).

Atlantic salmon in Europe is listed by the IUCN as Vulnerable[52] but the IUCN currently refers to a 2001 analysis showing the populations of wild salmon were healthy in 47% of Norwegian rivers, vulnerable in 3%, endangered in 23%, critical in 8%, and extinct in 9% (with 10% unknown; WWF, 2001). This is consistent with the Norwegian Ministry of the Environment who considered wild salmon stocks had disappeared from about 45 Norwegian rivers, and that about one-quarter to one-third of the stocks in the remaining 401 rivers were threatened or vulnerable[53]. Globally, Atlantic salmon is listed by the IUCN as Least Concern but is currently

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[50] The loss is estimated by comparing the number of adult salmon returning in practice to the predicted number of returns had their out-migrating juveniles experienced only natural background lice levels.
[51] https://www.ssb.no/en/jord-skog-jakt-og-fiskeri/statistikker/elvefiske
[52] https://www.iucnredlist.org/species/19855/2532398
[53] https://www.regjeringen.no/no/dokumenter/stprp-nr-32-2006-2007-/id442061/?ch=1

being reclassified[54]. The North Atlantic Salmon Conservation Organization (to which Norway is signatory party) describes Atlantic salmon as a species in crisis with the number declining by more than a half from 1983 to 2016 despite a large drop in fishing mortality over the same period.

The IUCN does not separate migratory sea trout from the larger brown trout populations which are listed as Least Concern[55], and Arctic char are also listed as Least Concern[56]. Anon (2019) classified the condition of 430 Norwegian sea trout stocks, showing only 20% of the stocks were considered to be in good or very good condition (85 stocks). Almost half of the stocks were in poor or very poor condition (208 stocks), and the other 137 stocks were in moderate condition. By far the largest negative impact on sea trout was salmon lice, which affected very many of the assessed stocks, but hydropower regulation and agriculture also had a major negative effect on many stocks, with also transport and hunting being important influences.

Conclusions and Final Score

The detection of bacterial and viral pathogens in wild salmonids in Norway is low, and while farms can still act as chronic reservoirs of pathogens, the focus of this Disease Criterion is on parasitic sea lice. While the industry typically keeps lice below regulatory levels at individual farms, the cumulative dispersal of sea lice from the industry creates a substantial infection pressure in coastal waters that can infect and affect wild salmon migrating past farms and/or those species spending longer periods of time in coastal waters such as sea trout. The “traffic light” system in Norway is the most important regulatory tool with regard to annual sea lice impacts on juvenile wild salmon in each of the Production Areas. As such, the findings of the traffic light expert working group are important, but with a consideration of a longer-term dataset and cumulative impacts (from 2012 to 2020), and particularly the full inclusion of impacts to sea trout (and Arctic char), the results of the IMR risk assessment are the focus here. The IMR assesses two primary factors in each of the Production Areas which are combined to determine the risk of lice-induced mortality for juvenile salmon and sea trout.. The first factor is the risk that wild fish will be infected by sea lice from farms, which is informed by the environmental conditions for lice, the emissions of lice from farms, and the overlap between wild fish and lice in time and space. The second factor is the wild fish’s tolerance to sea lice infection, which mainly considers the fish size at the potential time of infection. The IMR risk assessment is also supported by a separate comprehensive knowledge status review, and the Evidence-Based Assessment method has been used in the Seafood Watch standard.

The IMR’s “low” risk of sea lice induced mortality in juvenile wild salmon or sea trout typically results from either low emission of lice from farms or from little overlap in the timing of lice emissions and the presence of wild salmon or sea trout (such that there is a low probability that

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[54] The reassessment is expected to be completed by the end of 2021. https://salmon-trout.org/atlantic-salmon-iucn-red-list-review/

[55] https://www.iucnredlist.org/species/19861/9050312

[56] https://www.iucnredlist.org/species/19877/136593662

they will be infected with lice). Nevertheless, mortality may be moderate in some rivers in some years, and the "low" IMR category allows annual mortality of up to 10%. With consideration of this potential level of lice-induced mortality, the score for Criterion 7 – Disease in Production Areas with a "low" IMR outcome is 4 out of 10, as sea lice can cause mortality but are not considered to have a population-level impact. Conversely, a "high" risk of mortality (high lice emissions and high overlap), indicating greater than 30% annual mortality, is associated with population-level impacts to wild salmon or sea trout, and the score for Criterion 7 – Disease is 0 and a critical conservation concern due to the vulnerable nature of wild salmon and sea trout populations in Norway. For the intermediate "moderate" risks of mortality to wild salmon and sea trout (with a 10 to 30% annual mortality range), the final score for Criterion 7 – Disease is 2 out of 10, as sea lice are considered to negatively impacts the affected species' population size or its ability to recover. The Seafood Watch Aquaculture Standard scoring therefore takes a more precautionary approach to the mortality categories used by both the traffic light system and the IMR risk assessment, and the results of the IMR risk assessment for both salmon and sea trout, and the final scores for Criterion 7 – Disease for each of the production regions are shown in Table 15.

Table 15: IMR risk assessment results from 2012 to 2020 for the risk of lice-induced mortality to wild salmon and sea trout, and the corresponding Seafood Watch score for Criterion 7 – Disease. The IMR categories are defined as: "low" risk of lice induced mortality = <10% annual mortality, "moderate" = 10 to 30% annual mortality, and "high" risk of lice induced mortality = >30% annual mortality.

Production Area	IMR 2012-2020 Salmon	IMR 2012-2020 Sea Trout	C7 - Disease Final Score (0-10)
1	Low	Low	4
2	High	High	Critical
3	High	High	Critical
4	High	High	Critical
5	High	High	Critical
6	Moderate	High	Critical
7	Moderate	High	Critical
8	Low	Moderate	2
9	Low	Moderate	2
10	Moderate	Moderate	2
11	Low	Low	4
12	Low	Low	4
13	Low	Low	4

In summary, for Criterion 7 – Disease, Production Areas 1 and 11-13 have a final score of 4 out of 10, Production Areas 8-10 have a final score of 2 out of 10, and Production Areas 2-7 have a Critical final score.

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

Impact, unit of sustainability and principle

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

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

Criterion 8X Summary

C8X Source of Stock – Independence from wild fish stocks			
Production Areas	**Percent of production dependent on wild sources (%)**	**Score (0 to -10)**	**Critical**
Production Areas 1, 2	53	-5	No
Production Areas 3, 4, 6, 7, 8	11 to 18	-1	No
Production Areas 5	37	-3	No
Production Areas 9-13	0	-0	No

Brief Summary

As is common throughout the global salmon aquaculture industry, Norwegian salmon farming production is based on hatchery-raised broodstocks selectively bred over many generations. As such, the industry is considered to be independent of wild salmon fisheries for broodstock, eggs, or juveniles. With increasing use of non-chemical alternatives to sea lice treatment, the use of cleaner fish (which can eat the sea lice parasites) is now substantial. In 2020, 51.5 million cleaner fish were used in Norway, of which 17.4 million (33%) were wild caught, consisting primarily of four species of wrasse. The wrasse fishery established a quota of 18 million fish in 2018 alongside other management measures, but there is still a high potential for local stocks to be overfished. Approximately 65% to 70% of Norwegian salmon farms use cleaner fish (i.e., both wild and farmed), but the use (particularly of wild-caught sources) varies across the 13 Production Areas. Only Areas 1 to 8 are considered to use wild caught wrasse with relatively higher use in the southern Areas (which are also the focus of the wild capture fisheries in Norway and geographically closer to the fishing areas in Sweden). The final scores for Criterion 8X – Source of Stock are based on the proportion of farmed salmon production that is dependent on the use of wild caught fish, in this case wrasse. As such, it is estimated here that 53% of salmon farming production in Areas 1 and 2 (using the number of sites as a proxy for production) is dependent on wild caught wrasse, 18% in Areas 3 and 4, 37% in Area 5, and 11% in Areas 6 and 7. Given that Grefsrud et al (2021a) note the use of wild caught wrasse extends in to Area 8, the same 11% of production is also considered to be dependent on them. These values result in final scores for Criterion 8X – Source of Stock of a deduction of -5 out of -10 for

Production Areas 1 and 2, -1 out of -10 for Production Areas 3, 4, 6, 7, and 8, and -3 out of -10 for Production Area 5.

Justification of Rating

Source of Atlantic salmon

Atlantic salmon aquaculture has seen a multi-decadal establishment of breeding programs, aimed at selection for traits advantageous to farming (e.g., fast growth and disease resistance), which has been integral to the rapid growth of the industry (Asche et al., 2013; Heino et al., 2016; Gutierrez et al., 2016). As such, of the finfish species farmed for food, Atlantic salmon is among those that have been subject to the longest and most intense domestication regimes (Skaala et al., 2019). Norwegian farmed salmon have undergone approximately 15 generations of targeted breeding and are now considered to be partially domesticated and adapted to a life in captivity (Grefsrud et al., 2020). Due to the industry-wide use of domesticated broodstocks globally, 100% of eggs, juveniles and smolts are considered to be independent of wild salmon populations.

Source of cleaner fish

Following laboratory trials in the late 1980s, several species of wrasse and lumpsuckers were confirmed as a “cleaner fish”, eating parasitic sea lice on farmed salmon (see Criterion 7 – Disease and Criterion 4 – Chemical Use). Various species of cleaner fish have now become an established part of sea lice control in Norway (Figure 26) and are now defined as aquaculture animals and subject to the same regulations as other farming organisms in Norway; facilities with cleaner fish are thus considered multi-species cultures (polycultures) (Grefsrud et al., 2021a).

A commercial fishery for wrasse began in the 1990s, but the use of wrasse decreased from 1998 to 2005 when effective chemical treatments for lice control were developed and applied (Skiftesvik et al., 2014). In 2007-2008, the development of resistance to chemicals by sea lice triggered a renewed interest and an increased demand for cleaner fish; the targeted wrasse fishery expanded, and the estimated use of wrasse surpassed 10 million fish in 2010 (Skiftesvik et al., 2014). Wrasse tend to become inactive in winter, but an alternative species, the lumpfish *Cyclopterus lumpus*, continue to feed on sea lice at low temperatures, and in 2020, the number of (all species of) cleaner fish stocked into Norwegian salmon farms exceeded 51.5 million, of which lumpfish were 66% (data from the Directorate of Fisheries[57]). Overton et al. (2020) reported 65% of salmon farms in Norway used cleaner fish in 2018 and given the increasing use of non-chemical alternatives to sea lice treatments (see Criterion 4 – Chemical Use), it is likely this figure continues to be relevant, and may even have increased. Barret et al. (2020) reported 70% of sites used cleaner fish from 2016 to 2018.

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[57] https://www.fiskeridir.no/Akvakultur/Tall-og-analyse/Akvakulturstatistikk-tidsserier/Rensefisk

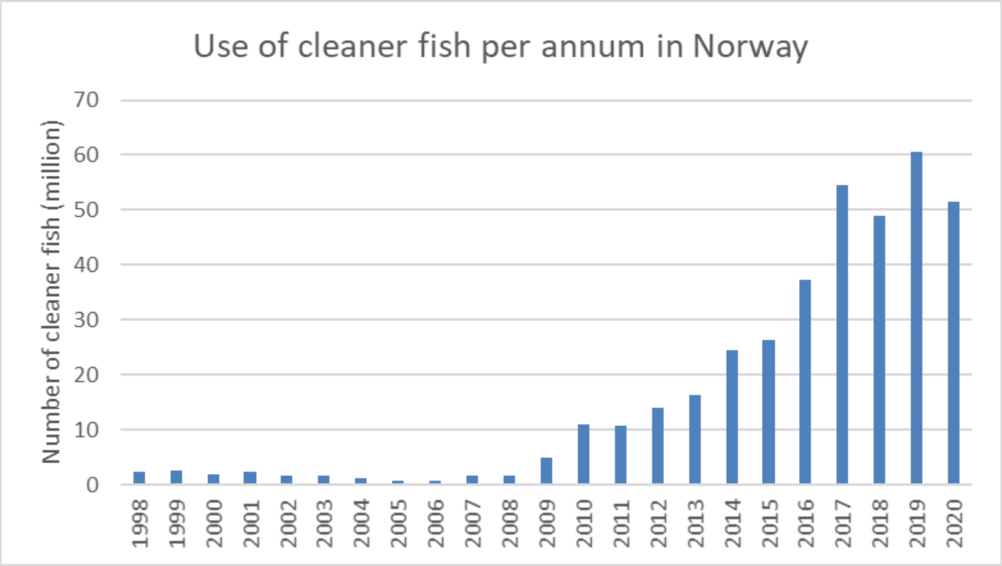

Figure 26: Total number of cleaner fish (farmed and wild) stocked each year into Norwegian salmon farms. Data from the Directorate of Fisheries.

Figure 27 shows that approximately 60% of the cleaner fish used were wild caught in 2015, but as hatchery production increased, the percentage of wild caught fish reduced to 33% in 2020. At the peak of wild fish use in 2017, nearly 24 million wild caught fish were used. This declined to 17.4 million in 2020. There were 25 companies with 51 licenses producing hatchery-raised cleaner fish in Norway in 2019 (Directorate of Fisheries data).

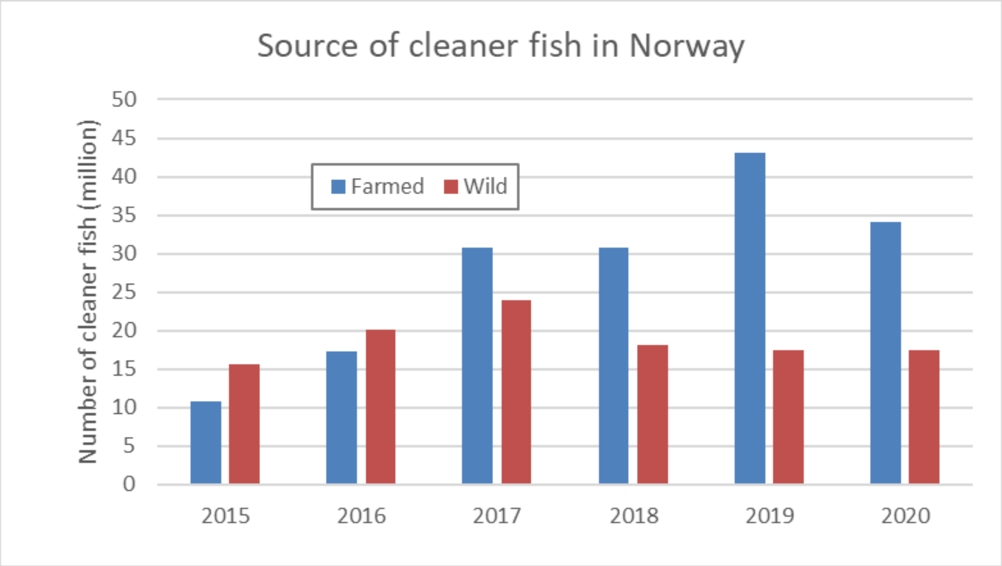

Figure 27: Source of cleaner fish – farmed or wild caught. Data from the Directorate of Fisheries.

The Directorate of Fisheries publishes data on cleaner fish (numbers of fish, wild versus farmed, and species) but publishes it by Norwegian county (or groups of counties), therefore the cleaner fish use per Production Area must be approximated based on the geographical overlap of the two. Where a single county (or county group) covers more than one Production Area the numbers of wrasse were allocated based on the number of sites in each Area.

The data show there is considerable variation in wrasse use amongst the Production Areas along the Norwegian coast (Figure 28). Importantly, this shows wild caught cleaner fish were not used in the north of Norway in 2020 (the most recent being some minor use in 2017). Figure 28 largely agrees with the findings of Grefsrud et al. (2021a) who noted extensive use of wild caught wrasse in the western part of Area 1 and in Areas 2-8 (noting the Directorate of Fisheries data shown in Figure 28 does not allocate any use of wild caught wrasse in Nordland which includes Areas 8 and 9. To allow for this inconsistency, some use of wild wrasse in Production Area 8 is allocated in Figure 29 below).

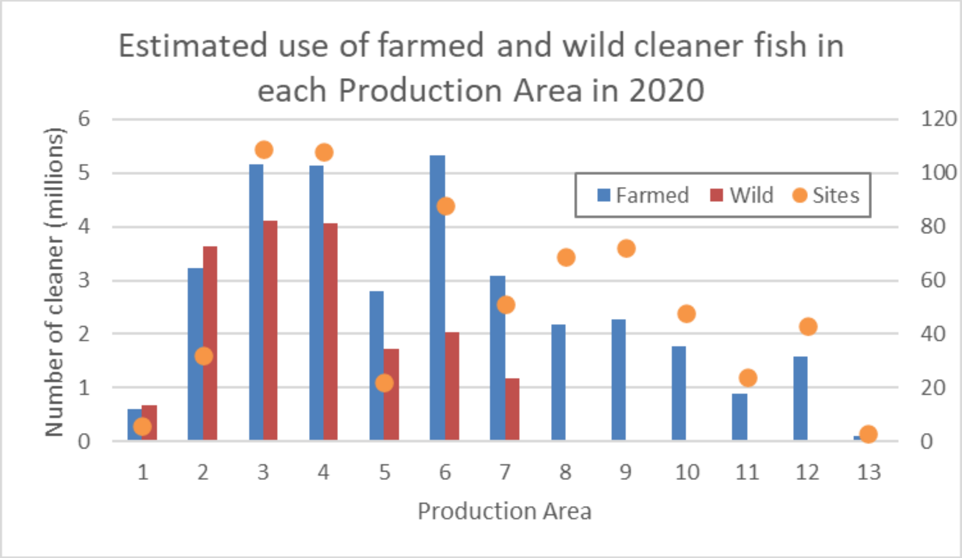

Figure 28: Approximate number of farmed (blue) and wild (red) cleaner fish stocked by salmon farms in each Production Area in 2020. Values are calculated from the Directorate of Fisheries data which are reported by county (or groups of counties) and split here into Production Areas. The number of sites per Area are from Barents Watch.

Barrett et al. (2020) reported an average of 90,300 cleaner fish per site, and if the number of active sites per Production Area (from Barents Watch) is used as a proxy for farmed salmon production in each Area, then the estimated numbers of wild caught wrasse used per Area in 2020 (from Department of Fisheries data and information in Grefsrud et al., 2021a,b) can be used to estimate the proportion of farmed salmon production in each Area that is dependent on the use of wild caught wrasse. For example, Area 2 had a relatively low number of active sites in 2020 (32), but relatively high use of wild caught cleaner fish (approximately 3.6 million), whereas Area 3 has many more sites (109) but a similar use of wild wrasse (approximately 4.1 million in 2020). If 65% to 70% of all sites in Norway use cleaner fish of either farmed or wild origin (Overton et al., 2020; Barrett et al., 2020), it is apparent that Production Area 2 uses substantially more cleaner fish than the national average. Similarly, other Areas (particularly in the far north) use less than the average. In Area 2 it is therefore assumed that cleaner fish were used on every site in 2020, and as 53% of the cleaner fish used were wild caught, then 53% of production in Area 2 would be considered to be dependent on wild caught wrasse. As such, it is estimated here that 53% of farmed salmon production in Production Areas 1 and 2 is dependent on wild caught wrasse, and by making similar calculations based on the numbers of wild caught cleaner fish, the number of sites, and the information in Grefsrud et al. (2021a), 18% of farmed salmon production is considered dependent on wild wrasse in Areas 3 and 4, 37% in Area 5, and 11% in Areas 6 and 7. Given that Grefsrud et al (2021a) note the use of wild caught wrasse extends into Area 8, the same 11% of production is also considered to be dependent on them. Figure 29 provides an overview of these figures.

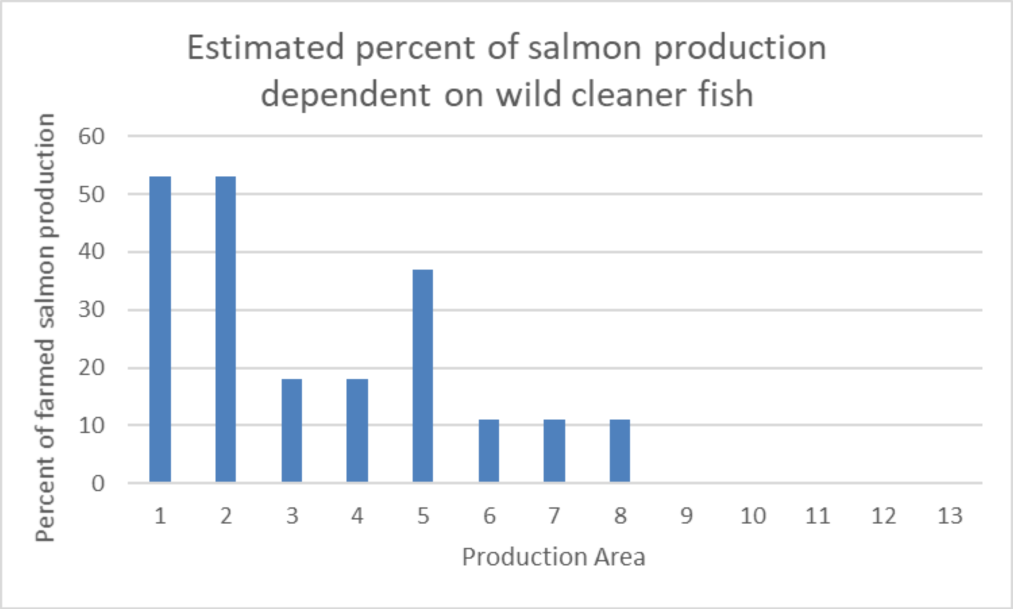

Figure 29: Estimated percentage of farmed salmon production dependent on wild cleaner fish. Data analyzed from the Directorate of Fisheries, DFO, and Grefsrud et al. (2021a).

Species of cleaner fish

Five different types of cleaner fish were stocked in 2020, of which lumpfish were 66% of the total. Of these lumpfish, 94% were hatchery-raised and 6% wild caught. Table 16 shows the same data for the other species.

Table 16: Types of cleaner fish used in 2020 and their source. Data from the Directorate of Fisheries

Common name	Percent of total	Percent Farmed	Percent wild
Lumpfish	66	94	6
Ballan wrasse	6	56	44
Goldsinny wrasse	14	0	100
Corkwing wrasse	12	0	100
Rock cook wrasse	1	0	100

Fisheries for wild-caught cleaner fish

Skiftesvik et al. (2014, 2015) reported there was an intense fishery for wrasse along the Norwegian coast and elsewhere (particularly Sweden). At that time, there was no apparent management of the stocks and the fishery in many areas proved insufficient to meet the demand of local salmon farms. This resulted in wrasse being transported over long distances by trucks fitted with water tanks or by boats (Skiftesvik et al., 2014).

More recent information is summarized by Grefsrud et al. (2021a,b) and relates to the most commonly fished species of wrasse used by the salmon farming industry. Fishing activity and the use of wrasse vary across coastal areas of Norway, and due to the ever-increasing catch, a quota of 18 million individuals was introduced in 2018 which is allocated in three fishing zones along the Norwegian coast. Each quota covers total catches of all species combined and is 4, 10 and 4 million fish for the three zones (from south to north) respectively. In Figure 27, the data show that of the cleaner fish stocked in farms, 18.1 million, 17.6 million and 17.4 million fish were caught from the wild in 2018-2020 (i.e., the quota was exceeded slightly in its first year but has been adhered to since). The primary catch data from the Directorate of Fisheries shows slightly higher total catches of 18.5 million, 19.0 million and 18.1 million in the same 2018-2020 years. In addition to catches along the Norwegian coast, wrasse are also imported from Sweden, and permission has also been granted for the import of more than two million wrasse from Denmark, though a targeted fishery for wrasse has not yet been established in Denmark (Sommerset et al., 2020). Therefore, there is some discrepancy in the total catch data and the numbers stocked into farms. Both datasets are from the Directorate of Fisheries, but perhaps the discrepancy is not surprising if some fish are not of high enough quality, or die during transport, in addition to an uncertain number imported from either Sweden or Denmark.

In addition to the quota, Grefsrud et al. (2021a,b) report the government has also introduced other regulations and measures that, to varying degrees, have reduced the assumed impact of fishing on wild wrasse stocks; for example, selection grids have reduced the catch of undersized fish and by-catch, and species-specific minimum sizes and spawning time protection are important measures to prevent fishing from affecting reproduction and recruitment directly.

While the establishment of controls is undoubtedly a positive development, Grefsrud et al. (2021a,b) note the minimum size measures are poorly adapted to the biology and life history of some of the species which are sequential hermaphrodites (changing sex at large size). They also note wrasse are highly site-specific and have specific habitat preferences, so that density is greatly affected by spatial variation in environmental conditions. Fishing for wrasse usually takes place by fishing intensively at locality by locality, so that a locality is "fished down", whereupon the fishing effort moves to the next locality, which is then "fished down". Although catch per unit of effort shows no or moderate reduction, fishing can have a dramatic effect on small, local and often geographically isolated stocks. The same authors note it is also probable that the intensive fishing could lead to some change in the species, size and sex distribution in the wrasse communities along the coast, but this is not expected to persist if the wrasse fishing ceases.

Grefsrud et al. (2021a,b) conclude that none of the larger stocks show clear signs of decline but acknowledge that the current database for the catch is deficient in several areas and there is a lack of knowledge about the natural variation of the stock sizes. They note that fishing can have a clear impact on local wrasse populations. In their risk assessment, catches of wrasse are considered moderate for all three fishing zones. Overall, the recent introduction of quotas and other management measures is encouraging, but they are perhaps as yet unproven (as emphasized by the large knowledge gaps articulated by Grefsrud et al., 2021a,b). As such, the use of wild-caught cleaner fish is considered in the scoring of this Seafood Watch assessment (i.e., they do not come from demonstrably sustainable fisheries).

Conclusions and Final Score

As is common throughout the global salmon aquaculture industry, Norwegian salmon farming production is based on hatchery-raised broodstocks selectively bred over many generations. As such, the industry is considered to be independent of wild salmon fisheries for broodstock, eggs, or juveniles. With increasing use of non-chemical alternatives to sea lice treatment, the use of cleaner fish (which can eat the sea lice parasites) is now substantial. In 2020, 51.5 million cleaner fish were used in Norway, of which 17.4 million (33%) were wild caught, consisting primarily of four species of wrasse. The wrasse fishery established a quota of 18 million fish in 2018 alongside other management measures, but there is still a high potential for local stocks to be overfished. Approximately 65% to 70% of Norwegian salmon farms use cleaner fish (i.e., both wild and farmed), but the use (particularly of wild-caught sources) varies across the 13 Production Areas. Only Areas 1 to 8 are considered to use wild caught wrasse with relatively higher use in the southern Areas (which are also the focus of the wild capture fisheries in Norway and geographically closer to the fishing areas in Sweden). The final scores for Criterion 8X – Source of Stock are based on the estimated proportion of farmed salmon production that is dependent on the use of wild caught fish; in this case wrasse. By considering the numbers of wild caught and farmed cleaner fish (from the Directorate of Fisheries), the number of sites per Area (from Barents Watch), and the information on wrasse use in the IMR risk assessment and other academic studies, it is estimated here that 53% of salmon farming production in Areas 1 and 2 (using the number of sites as a proxy for production) is dependent on wild caught wrasse, 18% in Areas 3 and 4, 37% in Area 5, and 11% in Areas 6 and 7. Given that Grefsrud et al. (2021a) note the use of wild caught wrasse extends in to Area 8, the same 11% of production is also considered to be dependent on them. These values result in final scores for Criterion 8X – Source of Stock of a deduction of -5 out of -10 for Production Areas 1 and 2, -1 out of -10 for Production Areas 3, 4, 6, 7, and 8, and -3 out of -10 for Production Area 5.

Criterion 9X: Wildlife Mortalities

Impact, unit of sustainability and principle

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

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

Criterion 9X Summary

All Production Areas

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		**-4**
Critical?	No	Yellow

Brief Summary

Harbor seals are the most likely marine mammals to interact with salmon pens in Norway, and Norwegian regulations for the control of seals allow them to be killed if they damage fishing gear or farm infrastructure at sea when "reasonable efforts and other measures to avert damage" have failed. Other than three companies reporting (zero mortalities) through GSI, there are no robust mortality (lethal control or entanglement) data. GSI also report a low number of bird entanglements (average of 2.1) per site each year, but again, further data are not available. The Norwegian Marine Mammal Scientific Advisory Board describes the regulations and management measures in place for marine mammals, and many species continue to be hunted to some extent in Norway. Information on the status of the harbor seal population indicates any mortalities on salmon farms are unlikely to affect the population status. With mortality numbers unknown, the Risk-Based Assessment method was used and the final score for Criterion 9X – Wildlife Mortalities is -4 out of -10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Justification of Rating

Without a robust understanding of the impact that predator control at salmon farms has on wild species in Norway, the corresponding Criterion 1 – Data score is 5 out of 10. As such, the Risk-Based Assessment method was used.

The presence of farmed salmon in net pens at high densities inevitably constitutes a powerful food attractant to opportunistic coastal marine mammals, seabirds, and fish that normally feed on native fish stocks (Sepulveda et al., 2015). Harbor seals (*Phoca vituline*) are the most likely to interact with salmon pens in Norway, or to be affected by the industry (K. Nilssen, IMR, pers. comm., 2020), and take quotas for this species are set annually by the Directorate of Fisheries. According to Regulation J-36-2014 “Regulation of seals on Norwegian coast”, it is prohibited to catch, chase, kill, or harm seals; however, an exception allows seals to be killed if they damage fishing gear or fish farms at sea when “reasonable efforts and other measures to avert damage” have failed.

It is therefore permitted to shoot seals that interact with fish farms (and fisheries) and these removals are supposed to be reported to the Directorate of Fisheries, but there do not appear to be any official data available on the numbers killed. In the past, there have been indications that not all cases are reported (Nilssen et al., 2010) and this situation is believed to continue today (K. Nilssen, IMR, pers. comm., 2020). GSI has wildlife mortality data for three salmon farming companies in Norway for the period 2014-2019, showing an average of 2.1 birds were killed per site per year, and zero marine mammals. While it is likely that birds and other coastal marine animals such as common seals or otters are also attracted to other (i.e., non-GSI reporting) salmon farms in Norway, and may be subject to lethal control or entanglement, there are no further data available. The GSI data for three companies cannot robustly be extrapolated to represent the whole industry.

The Norwegian Marine Mammal Scientific Advisory Board was established in 2009 and their most recent annual report (Bjørge et al., 2020) describes the management measures for the many species of marine mammals in Norway, many of which continue to have some level of hunting mortality managed by quotas and size or seasonal restrictions under the concept of Potential Biological Removal. For harbor seals, Bjørge and Nilssen (2019) indicate that the catch (i.e., reported catch, primarily from licensed hunters) in recent years has been lower than the total quota (450 individuals) and the seal population is slightly higher than the target management plan. As such, despite the limited data and potential for unreported mortalities, the status of the population indicates the regulations or management are broadly effective and any interactions with salmon farms are unlikely to significantly affect the population’s status.

Conclusions and Final Score

Harbor seals are the most likely marine mammals to interact with salmon pens in Norway, and Norwegian regulations for the control of seals allow them to be killed if they damage fishing gear or farm infrastructure at sea when “reasonable efforts and other measures to avert damage” have failed. Other than three companies reporting (zero mortalities) through GSI, there are no robust mortality (lethal control or entanglement) data. GSI also report a low number of bird entanglements (average of 2.1) per site each year, but again, further data are not available. Many species continue to be hunted to some extent in Norway, and information on the status of the harbor seal population indicates any mortalities on salmon farms are unlikely to affect the population status. With mortality numbers unknown, the Risk-Based Assessment method was used and the final score for Criterion 9X – Wildlife Mortalities is -4 out of -10 for all Production Areas (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

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

Production Areas 3, 4, 6-13: Score based on salmon movements.

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	50.0	4
Biosecurity score of the source of animal movements (0-10)		8
Biosecurity score of the farm destination of animal movements (0-10)		0
Species-specific score 10X Score		-1.2
Multi-species assessment score if applicable (cleaner fish)		-0.0 or -1.0
C10X Introduction of Secondary Species Final Score		**-1.2**
Critical?	No	Green

Production Areas 2 and 5: Score based on cleaner fish movements.

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	27.0	7
Biosecurity score of the source of animal movements (0-10)		0
Biosecurity score of the farm destination of animal movements (0-10)		0
Species-specific score 10X Score		-3.0
Multi-species assessment score if applicable (salmon)		-1.2
C10X Introduction of Secondary Species Final Score		**-3.0**
Critical?	No	Green

Production Area 1: Score based on cleaner fish movements.

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	13.2	8
Biosecurity score of the source of animal movements (0-10)		0
Biosecurity score of the farm destination of animal movements (0-10)		0
Species-specific score 10X Score		-2.0
Multi-species assessment score if applicable (salmon)		-1.2
C10X Introduction of Secondary Species Final Score		**-2.0**
Critical?	No	Green

Brief Summary

Movements of live fish are a characteristic of the Norwegian salmon farming industry, with shipments of smolts from freshwater hatcheries to open net pen farms, fish for slaughter from net pens to slaughter facilities, and shipments of cleaner fish from wild fisheries to net pen salmon farms. Assessing the risk of introducing a non-target species during those movements is complex given the characteristics of the different source and destination. The industry's reliance on movements of live salmon across different waterbodies was estimated to be 50% of production (Factor 10Xa score of 4 out of 10), but the freshwater hatcheries that are the primary source of movements have good biosecurity and a low risk of introducing secondary species at the source (Factor 10Xb score 8 out of 10). This was considered to be consistent across all Production Areas and resulted in a final score for Criterion 10X of -1.2 out of -10 (i.e., a small deduction) for the movements of salmon in all Production Areas.

Data from the Directorate of Fisheries show the use of wild caught cleaner fish (mostly four species of wrasse) is highly variable across Production Areas, and the IMR risk assessment on the risk of spreading infection during movements of these fish describes the typical movements into and out of the fishing zones and salmon farming Production Areas. Based on the proportions of farmed salmon production in each Area that are dependent on the use of wild wrasse (calculated in Criterion 8X – Source of Stock), between 8% and 26% of farmed salmon production in different Areas are considered to be dependent on wild wrasse that have been moved across waterbodies (and that therefore represent a risk of unintentionally transporting secondary species). Factor 10Xa scores therefore range from 7 out of 10, to 10 out of 10. The movements of wild caught wrasse are considered to have minimal biosecurity at both the source and destination (Factor 10Xb score of 0 out of 10).

Factor 10Xa (the reliance on movements of live fish) and 10Xb (the biosecurity of those movements) combine as follows to give a final score for Criterion 10X – Escape of Secondary Species. For Production Areas 3, 4, and 6-13 the final score is a deduction of -1.2 out of -10 based on salmon movements. Production Areas 2 and 5 have a final score of -3 out of -10 based on movements of wild caught cleaner fish, and Area 1 has a final score -2 out of -10, also based on movements of wild cleaner fish. For reference, these results do not match the outcomes of the IMR assessment on the risk of infection spread due to the use of wild wrasse (which was considered to be low in Area 1, moderate in Areas 2-4, and high in Areas 5-8). This is due the use here of data on the numbers of farmed and wild caught cleaner fish in each Production Area for this Seafood Watch assessment, combined with the number of farming sites in each Area. This is considered to more closely reflect the proportion of farmed salmon in each Area that is dependent on wild cleaner fish use.

Justification of Rating

This criterion provides a measure of the escape risk (introduction to the wild) of alien species <u>other than the principal farmed species</u> unintentionally transported during animal shipments.

According to the UN FAO (2012), the expanded and occasionally irresponsible global movements of live aquatic animals have been accompanied by the transboundary spread of a wide variety of pathogens. In some instances, these pathogens have caused serious damage to aquatic food productivity and resulted in serious pathogens becoming endemic in culture systems and the natural aquatic environment. In Norway, transfers of live material, including smolts, fish for slaughter and cleaner fish, are regarded as one of the most serious risk factors for spreading disease (Sommerset et al., 2021, Grefsrud et al., 2021a,b).

Factor 10Xa International or trans-waterbody live animal shipments

Movements of Atlantic salmon

Norway is a notably large exporter of salmon eggs (ova); suppliers in Norway are the only ones permitted to export ova to Chile, and Scotland annually imports large numbers of eggs from Norway (Munro & Wallace, 2019). Therefore, while there are no direct import data, there is also no evidence that Norway imports live salmon or their gametes with regard to this assessment. However, eggs are commonly transported from breeding centers to hatcheries and/or smolt producers (Lillehaug et al., 2015).

Transporting fish over long distances is common within Norway when smolts are produced in one area and stocked for growout in another, and when fish for harvesting are transported from growout sites to central slaughtering and processing facilities (Sommerset et al., 2021). Well-boats are virtually the only means of transport used for live fish, and while movements within Norway are not “international”, they can be considered “transwaterbody” when there is the potential to move infectious agents (including novel strains) or other organisms into new areas.

There is little specific information on smolt movements, but one indicator is provided by the difference in smolts produced and smolts stocked in each Norwegian county where a substantial difference between the two indicates either the “import” of smolts into that county or the “export” of surplus production into another county; for example, the county of Trøndelag stocked 1.77 times as many salmon smolts as were produced in the county’s hatcheries (Sommerset et al., 2020). It should be noted that these are not necessarily movements between ecologically distinct waterbodies but analyzing the data in Sommerset et al. (2020) shows approximately 50% of total smolt production may move between counties in Norway.

Sommerset et al. (2021) also indicate that the movement of fish for harvest from growout sites to slaughtering/processing facilities represents a risk of unintentionally transferring non-target organisms. There are no data available to indicate what proportion of fish are transported in this way, over what distances, or whether these movements are between ecologically distinct regions of Norway, but Sommerset et al. (2021) note again that as of January 2021, both intake and discharge water must be disinfected. Overall, the information provided by Sommerset et al. (2021) indicates that the Norwegian salmon industry is heavily reliant on the intra-national movement of fish, and that these movements have the potential to transfer secondary organisms into waterbodies where they previously were not present. For the purposes of this assessment, it is assumed that cross-county movements of smolts are trans-waterbody movements that carry the risk of introducing novel pathogens, and the 50% of smolt movements (i.e., 50% of farmed salmon production is considered dependent on cross-county movements) results in a score for Atlantic salmon of 4 out of 10 for Factor 10Xa for all Production Areas.

Movements of cleaner fish

As a result of the increased demand for wrasse and lumpsuckers as cleaner fish to control parasitic sea lice, the fisheries in many areas of Norway have proved insufficient to meet the demand of local salmon farms (see Criterion 8X – Source of Stock). This has resulted in cleaner fish (mostly four species of wrasse) being transported over long distances by trucks fitted with water tanks or by boats, including international movements of fish caught in Sweden and the Baltic Sea and transported to Production Areas in Norway (Sommerset et al., 2021). Wild-caught cleaner fish have an unknown disease history and could be carriers of a number of infectious agents; Grefsrud et al. (2021a,b) provide examples of known infectious agents that have been detected in wrasse including viral (e.g., VHS virus, NNV (nodavirus)), bacterial (e.g., *Aeromonas salmonicida* (causing furunculosis), Pasteurella sp.), and parasitic (e.g., *Paramoeba perurans* (causing AGD)) pathogens. While these examples do not necessarily represent pathogens (or strains) that are not already present in most or all salmon farming locales in Norway, they do represent the risk of introducing such organisms.

As discussed in Criterion 8X – Source of Stock, the use of wild caught cleaner fish is variable across the 13 Production Areas and it is challenging to estimate the proportion of these fish that are transported across ecologically distinct waterbodies. Grefsrud et al. (2021a,b) note the transport varies along the coast; for example, a lot of wrasse are caught in the far south of Norway (where there is lower production of farmed salmon), and they are therefore transported north, but many areas also use locally caught fish. As part of assessing the environmental impact of using wild caught wrasse, and specifically assessing the spread of infection during their movements, the IMR risk assessment (Grefsrud et al. 2021a) reviews the movement of wrasse between areas and notes the following (note this is based on the analysis of three fishing zones and salmon farming Production Areas may overlap two zones:

- In the eastern part of Production Area 1 there is a large catch of wrasse, but low use of wrasse (in terms of the number of fish[58]) as the number of sites and production of farmed salmon is low in the area. There is only considered to be transport of wrasse out of this Area. The risk of movements contributing to infection spread into this area is low (green).
- In Production Areas 2-4 (plus the western part of Production Area 1) there is a lot of movement and transport of wrasse, but most of the wrasse are caught within this zone. The risk of movements contributing to infection spread into this area is moderate (yellow)

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[58] Criterion 8X – Source of Stock shows that while the absolute number of wrasse may be relatively low, the dependency of farmed salmon production on wild caught wrasse is relatively high).

- In Production Areas 5-8 there is frequent transport of wrasse into this region, and it is assumed that a large proportion of these fish originates far away such as southern Norway or Sweden. The risk of movements contributing to infection spread into this area is high (red).

According to these categories from Grefsrud et al. (2021), a small proportion (25%) of the wild wrasse used in Production Area 1 are considered here to be moved across waterbodies. In Areas 2 to 4, a moderate proportion (50%) of the wild wrasse are considered here to be moved, and a high proportion (75%) in Areas 5 to 8. Using the proportions of farmed salmon in each Production Area that are estimated to be dependent on the use of wild wrasse in Criterion 8X – Source of Stock, the scores for Factor 10Xa for cleaner fish movements can be calculated. For Production Areas 9 to 13 (with no use of wild wrasse) the score for Factor 10Xa is 10 out of 10; for Areas 3, 4, 6, 7 and 8, the score is 9 out of 10; for Area 1, the score is 8 out of 10; for Areas 2 and 5 the score is 7 out of 10.

Factor 10Xb Biosecurity of source/destination

Biosecurity of Atlantic salmon movements

As noted in Factor 10Xa, there are movements of live salmon in the form of eggs from breeding centers to freshwater hatcheries or smolt units, then from smolt units to marine net pens for growout, and from there to harvest locations for slaughter. Lillehaug et al. (2015) describe the biosecurity aspects of the farmed salmon system and consider movements of fertilized eyed eggs from specialized broodfish producers to be of low risk as the eggs are disinfected immediately after fertilization and sometimes again before delivery.

For fry and smolts, the important feature from a biosecurity perspective is the containment aspect where for tank-based systems on land (and often inside physical structures), the primary biosecurity risk is the water source (Lillehaug, 2015). The risk may be reduced significantly by employing water disinfection systems such as UV light or ozone that reduce the infectious load substantially, but no water treatment systems have the capacity to eliminate microorganisms completely. Lillehaug (2015) consider that a smolt farm on land can be mostly isolated in a biosecurity sense but note the biosecurity risk varies according to the transmission characteristics of the different pathogens. Smolt movements are accompanied by health certificates describing the health status of the fish, but the destination of smolt movements is net pens which are open to the surrounding water and have a less-controllable reality (Lillehaug, 2015).

For harvest-ready fish, the source of movements is the same net pen containment system, open to the local environment, but the destination is slaughter/processing facilities for which biosecurity is a lower concern (as long as wastewater is appropriately treated).

The primary concern therefore is the movement of smolts from freshwater hatcheries to marine growout sites. Domestic fish transports in Norway are managed in the “Regulations for transport of aquaculture animals” (updated in 2016). Requirements regarding technical equipment for the disinfection of transportation water, the enabling of transport boats to be tracked, and to register when water intakes have been opened are now included. Requirements that apply to tracking and registration came into effect in 2016 and for water disinfection of incoming and outgoing water in 2021 (Sommerset et al., 2021). The scoring is therefore based on the source, and the higher biosecurity of the tank-based hatcheries, and results in a score of 8 out of 10 for Factor 10Xb for Atlantic salmon.

<u>Biosecurity of cleaner fish movements</u>
For the movement of cleaner fish, there is no evidence of fish health diagnostic or screening procedures or regulations prior to movements, and the source of the fish is open coastal fisheries. Although wild-caught cleaner fish are defined as aquaculture animals (at the time they are caught), most of the transport takes place via small boats and tankers, and there is little or no treatment of the transport water before it is emptied into the reception area (Grefsrud et al., 2021). The destination of movements (i.e., net pen salmon farms) is also an open system. Therefore, with little or no biosecurity, the source and destination of cleaner fish movements is considered here to score 0 out of 10 for Factor 10Xb.

Conclusions and Final Score

Movements of live fish are a characteristic of the Norwegian salmon farming industry, with shipments of smolts from freshwater hatcheries to open net pen farms, fish for slaughter from net pens to slaughter facilities, and shipments of cleaner fish from wild fisheries to net pen salmon farms. Assessing the risk of introducing a non-target species during those movements is complex given the characteristics of the different source and destination. The industry’s reliance on movements of live salmon across different waterbodies was estimated to be 50% of production (Factor 10Xa score of 4 out of 10), but the freshwater hatcheries that are the primary source of movements have good biosecurity and a low risk of introducing secondary species at the source (Factor 10Xb score 8 out of 10). This was considered to be consistent across all Production Areas and resulted in a final score for Criterion 10X of -1.2 out of -10 (i.e., a small deduction) for the movements of salmon in all Production Areas.

Data from the Directorate of Fisheries show the use of wild caught cleaner fish (mostly four species of wrasse) is highly variable across Production Areas, and the IMR risk assessment on the risk of spreading infection during movements of these fish describes the typical movements into and out of the fishing zones and salmon farming Production Areas. Based on the proportions of farmed salmon production in each Area that are dependent on the use of wild wrasse (calculated in Criterion 8X – Source of Stock), between 8% and 26% of farmed salmon production in different Areas are considered to be dependent on wild wrasse that have been moved across waterbodies (and that therefore represent a risk of unintentionally transporting secondary species). Factor 10Xa scores therefore range from 7 out of 10 to 10 out of 10 (see Table 17 below). The movements of wild caught wrasse are considered to have minimal biosecurity at both the source and destination (Factor 10Xb score of 0 out of 10). Table 17 shows the scores for Factors 10Xa and 10Xb for movement of both salmon and cleaner fish, and the final score for Criterion 10X.

Table 17: Final Seafood Watch scores for Criterion 10X – Escape of Secondary Species for salmon and cleaner fish movements for each Production Area

PA	Salmon Movements			Cleaner fish Movements			Criterion 10X Final score (0 to -10)
	Factor 10Xa (0-10)	Factor 10Xb (0-10)	Final C10X Score (0 to -10)	Factor 10Xa (0-10)	Factor 10Xb (0-10)	Final C10X Score (0 to -10)	
1	4	8	-1.2	8	0	-2	-2.0
2	4	8	-1.2	7	0	-3	-3.0
3	4	8	-1.2	9	0	-1	-1.2
4	4	8	-1.2	9	0	-1	-1.2
5	4	8	-1.2	7	0	-3	-3.0
6	4	8	-1.2	9	0	-1	-1.2
7	4	8	-1.2	9	0	-1	-1.2
8	4	8	-1.2	9	0	-1	-1.2
9	4	8	-1.2	10	0	0	-1.2
10	4	8	-1.2	10	0	0	-1.2
11	4	8	-1.2	10	0	0	-1.2
12	4	8	-1.2	10	0	0	-1.2
13	4	8	-1.2	10	0	0	-1.2

In summary, Factor 10Xa (the reliance on movements of live fish) and 10Xb (the biosecurity of those movements) combine as follows to give a final score for Criterion 10X – Escape of Secondary Species. Production Areas 3, 4, and 6-13 have a final score of -1.2 out of -10 based on salmon movements. Production Areas 2 and 5 have a final score of -3 out of -10 based on movements of wild caught cleaner fish, and Area 1 has a final score -2 out of -10, also based on movements of wild cleaner fish. For reference, these results do not match the outcomes of the IMR assessment on the risk of infection spread due to the use of wild wrasse (which was considered to be low in Area 1, moderate in Areas 2-4, and high in Areas 5-8). This is due the use here of data on the numbers of farmed and wild caught cleaner fish in each Production Area for this Seafood Watch assessment, combined with the number of farming sites in each Area. This is considered to better reflect the proportion of farmed salmon in each Area that is dependent on wild cleaner fish use.

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

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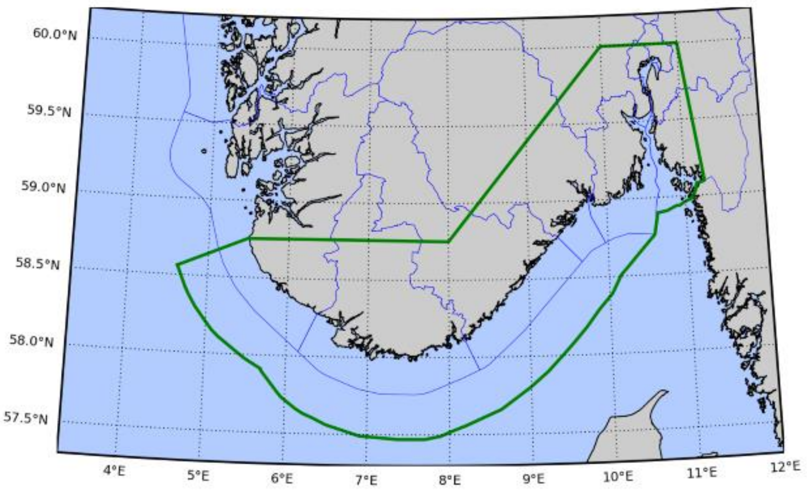
Appendix 1 – Maps of Norway’s Production Areas

The following maps and boundary information are copied from the Regulations on production areas for aquaculture of food fish in the sea of salmon, trout and rainbow trout (production area regulations) (Anon, 2017a)[59].

Locations of every Norwegian aquaculture site are also available from the Directorate of Fisheries mapped database (https://kart.fiskeridir.no/akva) which can be translated online.

Area 1: The Swedish border to Jæren



Production area 1 is delimited by the Norwegian economic zone up to 30 nautical miles from the baseline and the following lines:

1. Svinesund by the Svinesund Bridge, N 59 ° 05.64 ′ Ø 11 ° 15.12 ′
2. Jærens reef at Søre Revtangen, N 58 ° 45.12 ′ Ø 5 ° 29.34 ′ to open sea N 58 ° 33.60 ′ Ø 4 ° 37.20 ′

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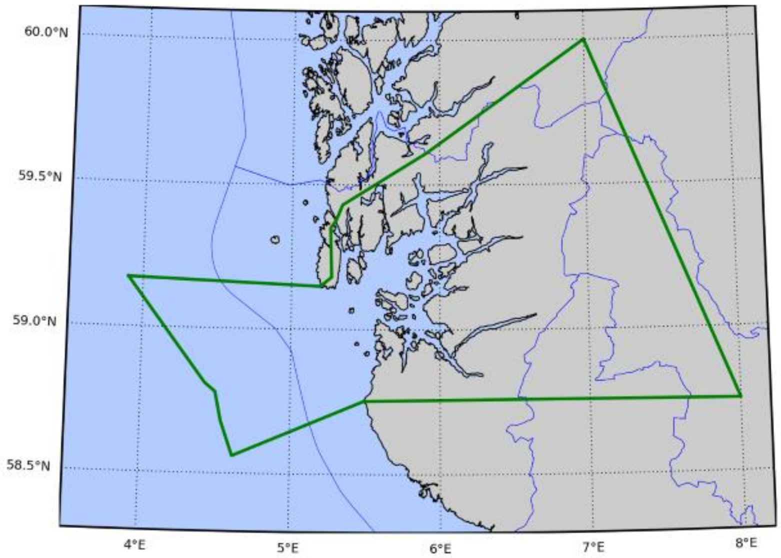
[59] https://lovdata.no/dokument/SF/forskrift/2017-01-16-61

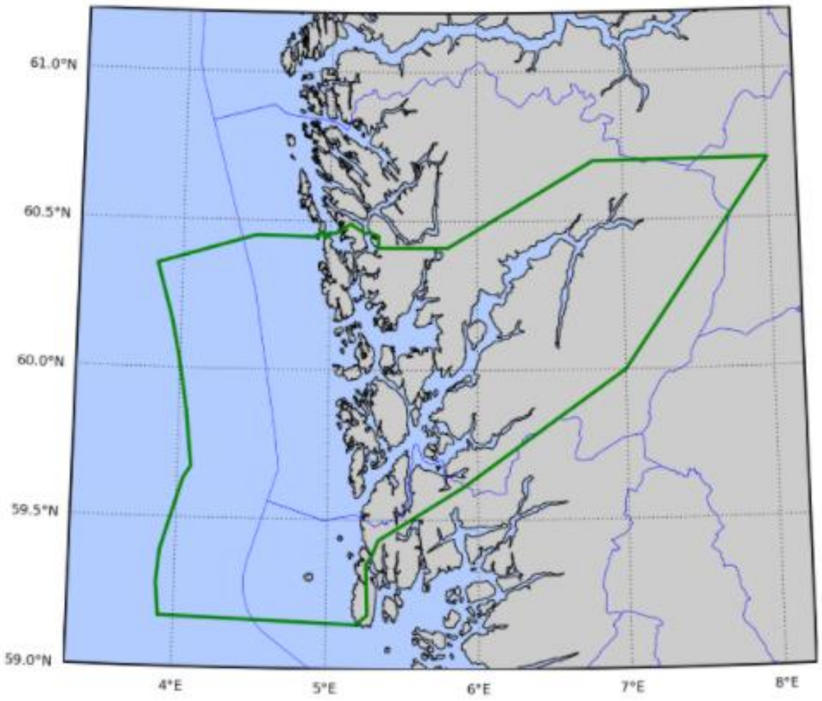
Area 2: Ryfylket



Production area 2 is bounded at 30 nautical miles from the baseline and the following lines:

1. Jærens reef at Søre Revtangen, N 58 ° 45.12 ′ Ø 5 ° 29.34 ′ to open sea N 58 ° 33.60 ′ Ø 4 ° 37.20 ′
2. Karmsundet by Karmsund bridge, N 59 ° 22.50 ′ Ø 5 ° 17.76 ′
3. Karmøy by Syreneset, N 59 ° 08.88 ′ Ø 5 ° 11.58 ′ to open sea N 59 ° 10.20 ′ Ø 3 ° 54.00 ′.

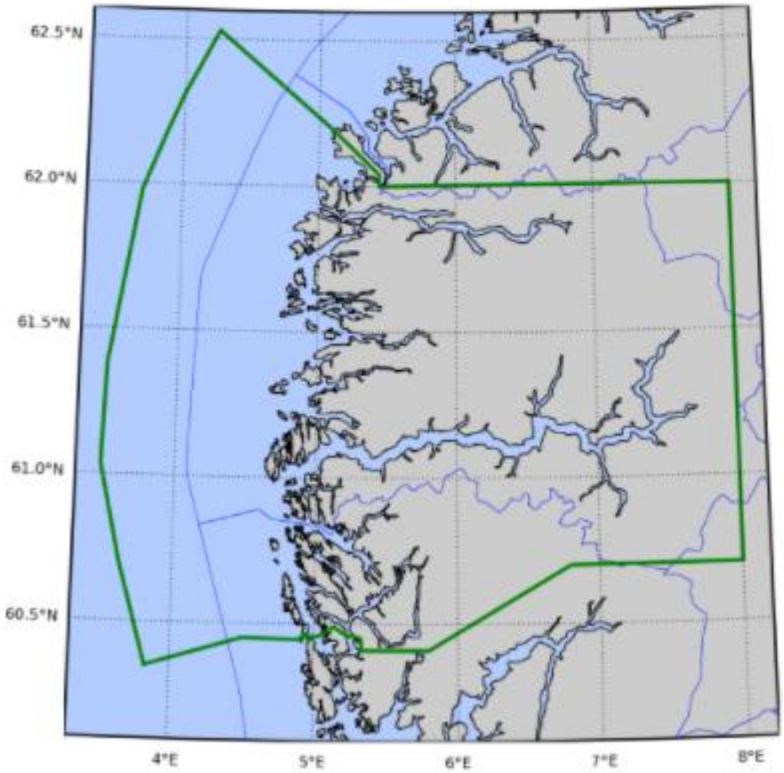
Area 3: Karmøy to Sotra



Production area 3 is bounded at 30 nautical miles from the baseline and the following lines:

1. Karmøy by Syreneset, N 59 ° 08.88 ′ Ø 5 ° 11.58 ′ to open sea N 59 ° 10.20 ′ Ø 3 ° 54.00 ′
2. Karmsundet by Karmsund bridge, N 59 ° 22.50 ′ Ø 5 ° 17.76 ′
3. Herdlefjorden, from Tertnes N 60 ° 27.60 ′ Ø 5 ° 16.32 ′ to Strømsnes N 60 ° 27.54 ′ Ø 5 ° 14.10 ′
4. Hjeltefjorden, from Kalvsøyna N 60 ° 27.54 ′ Ø 5 ° 02.22 ′ to Vindeneskvarven N 60 ° 27.36 ′ Ø 4 ° 59.28 ′
5. Solsviksundet by Solsviksundet bridge, N 60 ° 26.46 ′ Ø 4 ° 57.96 ′
6. Svelgen by Svelgen bridge, N 60 ° 27.42 ′ Ø 4 ° 57.30 ′
7. Søndagsholmen by Turøy N 60 ° 26.76 ′ Ø 4 ° 54.24 ′ to open sea N 60 ° 27.00 ′ Ø 4 ° 30.00 ′.

Area 4: Nordhordland to Stadt



Production area 4 is bounded at 30 nautical miles from the baseline and the following lines:

1. Søndagsholmen by Turøy N 60 ° 26.76 ′ Ø 4 ° 54.24 ′ to open sea N 60 ° 27.00 ′ Ø 4 ° 30.00 ′
2. Svelgen by Svelgen bridge, N 60 ° 27.42 ′ Ø 4 ° 57.30 ′
3. Solsviksundet by Solsviksundet bridge, N 60 ° 26.46 ′ Ø 4 ° 57.96 ′

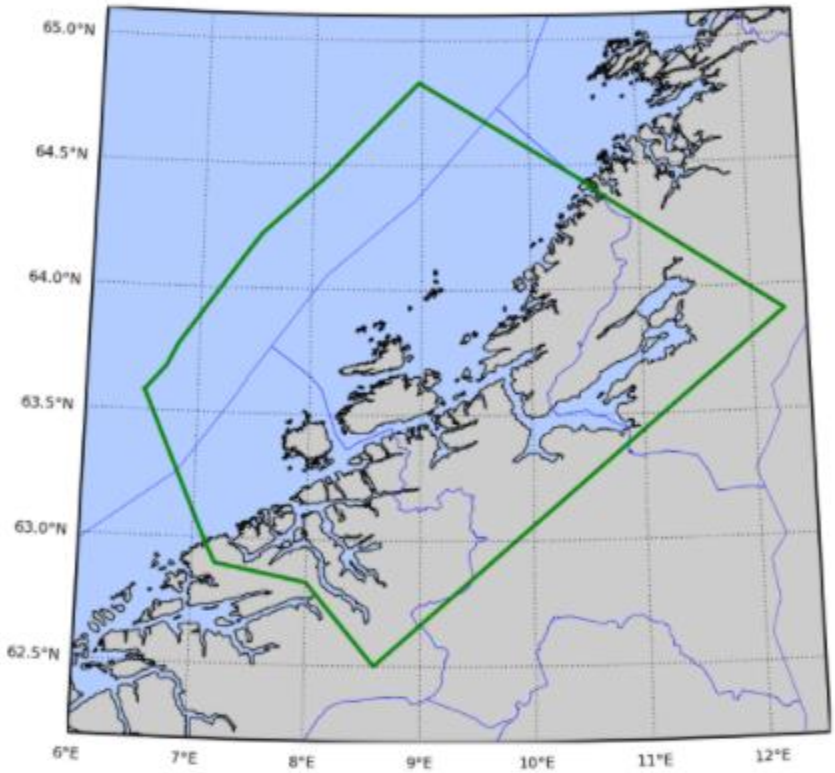
4. Hjeltefjorden, from Kalvsøyna N 60 ° 27.54 ′ Ø 5 ° 02.22 ′ to Vindeneskvarven N 60 ° 27.36 ′ Ø 4 ° 59.28 ′
5. Herdlefjorden, from Tertnes N 60 ° 27.60 ′ Ø 5 ° 16.32 ′ to Strømnes N 60 ° 27.54 ′ Ø 5 ° 14.10 ′
6. Nobba (Stadt) N 62 ° 11.64 ′ Ø 5 ° 06.06 ′ to open sea N 62 ° 31.80 ′ Ø 4 ° 15.00 ′.

Area 5: Stadt to Hustadvika

Production area 5 is bounded at 30 nautical miles from the baseline and the following lines:

1. Nobba (Stadt) N 62 ° 11.64 ′ Ø 5 ° 06.06 ′ to open sea N 62 ° 31.80 ′ Ø 4 ° 15.00 ′
2. Taskneset (Fræna) N 62 ° 59.28 ′ Ø 7 ° 06.30 ′ to open sea N 63 ° 34.80 ′ Ø 6 ° 31.20 ′.

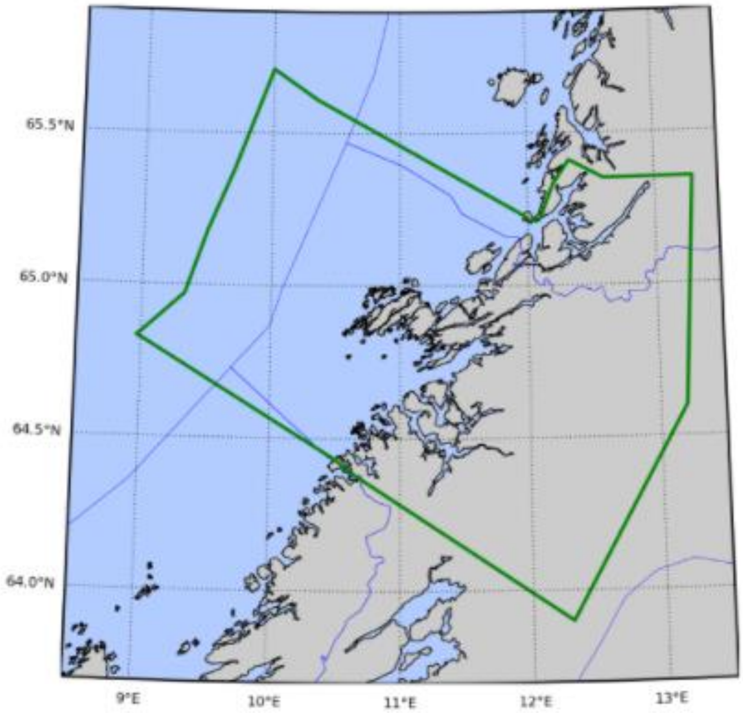
Area 6: Nordmøre and Sør-Trøndelag



Production area 6 is bounded at 30 nautical miles from the baseline and the following lines:

1. Taskneset (Fræna) N 62 ° 59.28 ′ Ø 7 ° 06.30 ′ to open sea N 63 ° 34.80 ′ Ø 6 ° 31.20 ′
2. County boundary at Skjemta, Flatanger, N 64 ° 25.74 ′ Ø 10 ° 30.60 ′ to open sea N 64 ° 49.80 ′ Ø 8 ° 58.20 ′.

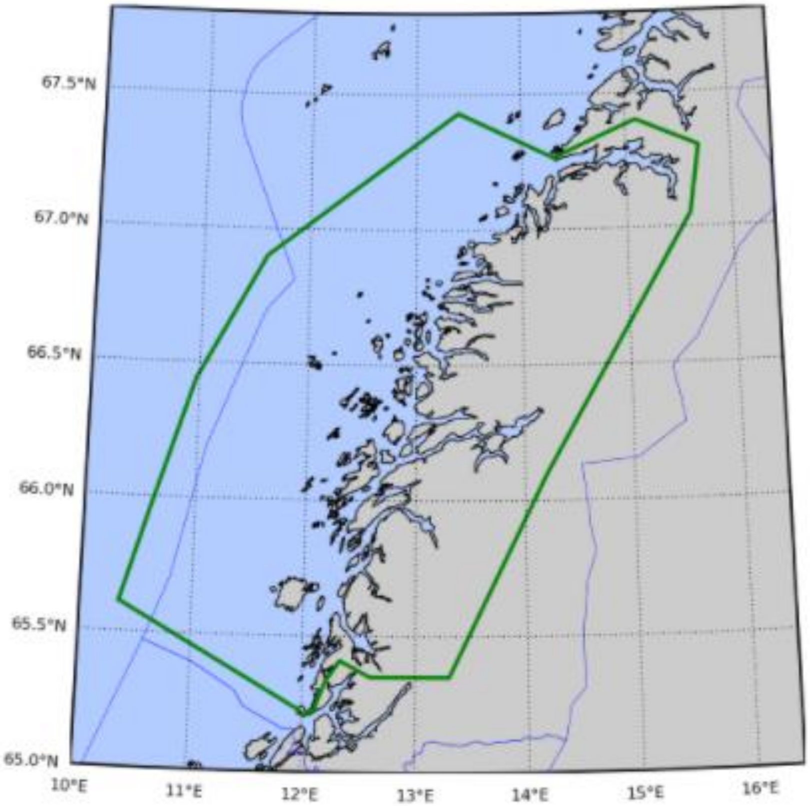
Area 7: Nord-Trøndelag and Bindal



Production area 7 is bounded at 30 nautical miles from the baseline and the following lines:

1. County boundary at Skjemta, Flatanger, N 64 ° 25.74 ′ Ø 10 ° 30.60 ′ to open sea N 64 ° 49.80 ′ Ø 8 ° 58.20 ′
2. Langøya by Kvaløya (Sømna) N 65 ° 13.86 ′ Ø 11 ° 57.78 ′ to open sea N 65 ° 36.60 ′ Ø 10 ° 21.00 ′.

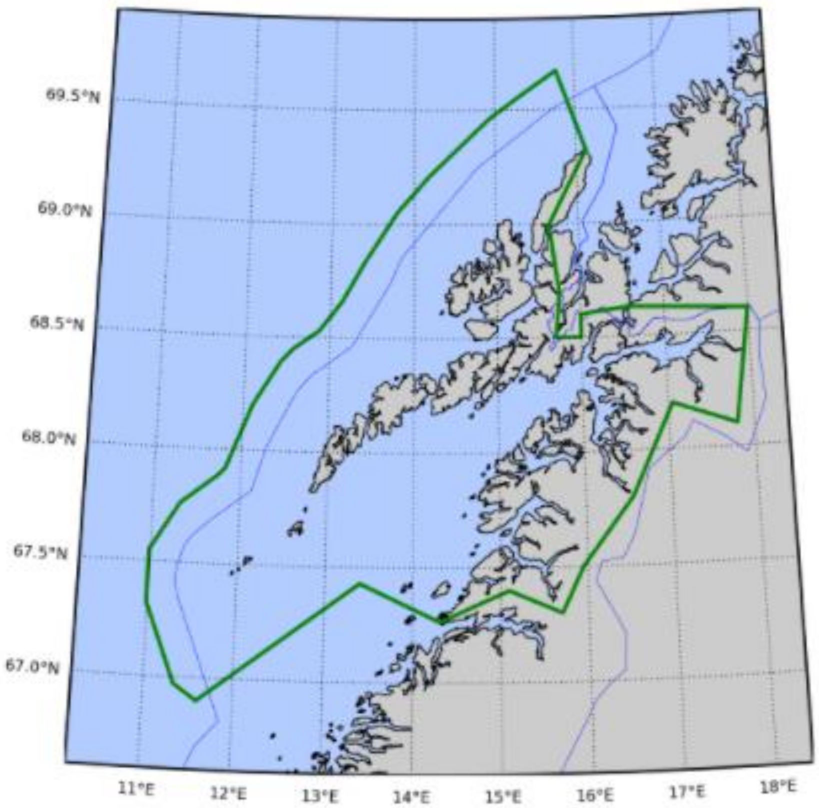
Area 8: Helgeland to Bodø



Production area 8 is bounded at 20 nautical miles from the baseline and the following lines:

1. Langøya by Kvaløya (Sømna) N 65 ° 13.86 ′ Ø 11 ° 57.78 ′ to open sea N 65 ° 36.60 ′ Ø 10 ° 21.00 ′
2. Ytre Hernesskagen at Bodø Airport N 67 ° 15.84 ′ Ø 14 ° 18.60 ′ to the junction in the Vestfjord N 67 ° 25.80 ′ Ø 13 ° 24.00 ′.

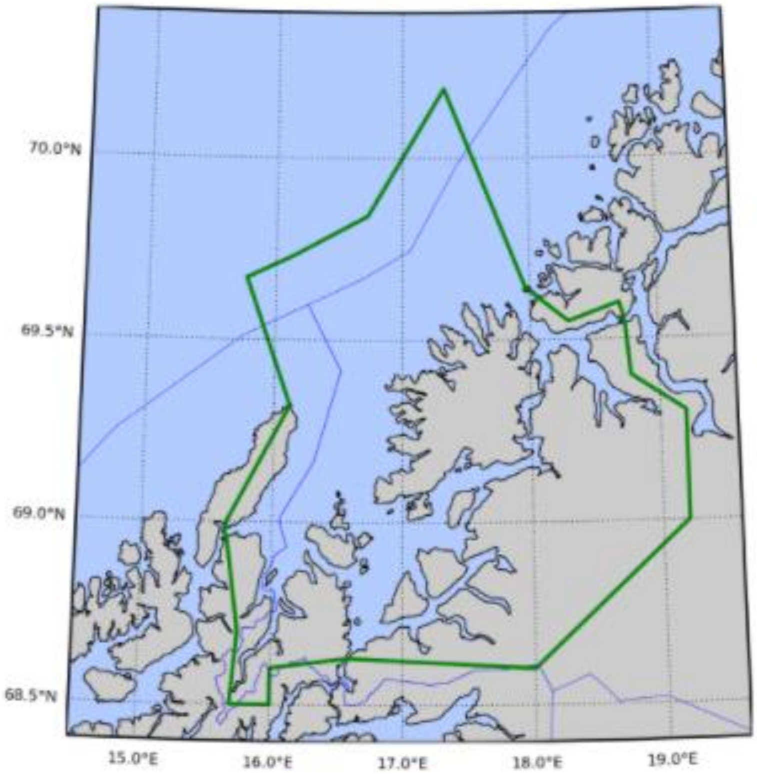
Area 9: Vestfjorden and Vesterålen



Production area 9 is bounded at 20 nautical miles from the baseline and the following lines:

1. Ytre Hernesskagen at Bodø Airport N 67 ° 15.84 ′ Ø 14 ° 18.60 ′ to junction in Vestfjorden N 67 ° 25.80 ′ Ø 13 ° 24.00 ′
2. Tjeldsundbrua N 68 ° 37.68 ′ Ø 16 ° 34.68 ′
3. Risøysundet from Litle Risøya N 68 ° 57.66 ′ Ø 15 ° 39.18 ′ to N 68 ° 58.02 ′ Ø 15 ° 38.04 ′
4. Andenes N 69 ° 19.20 ′ Ø 16 ° 07.32 ′ to open sea N 69 ° 40.20 ′ Ø 15 ° 46.20 ′.

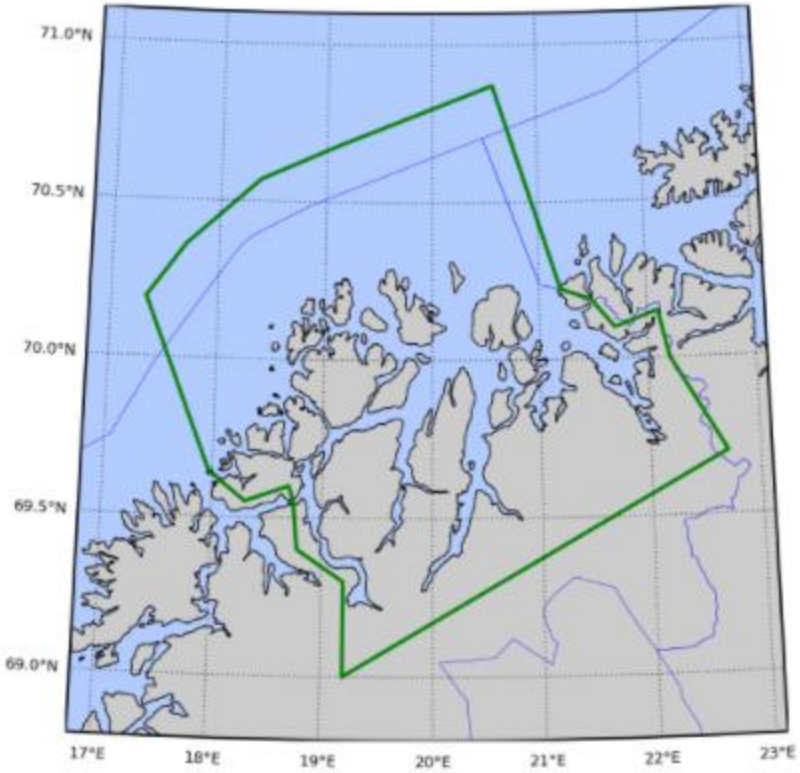
Area 10: Andøya to Senja



Production area 10 is bounded at 20 nautical miles from the baseline and the following lines:

1. Andenes N 69 ° 19.20 ′ Ø 16 ° 07.32 ′ to open sea N 69 ° 40.20 ′ Ø 15 ° 46.20 ′
2. Risøysundet from Litle Risøya N 68 ° 57.66 ′ Ø 15 ° 39.18 ′ to N 68 ° 58.02 ′ Ø 15 ° 38.04 ′
3. Tjelsundbrua N 68 ° 37.68 ′ Ø 16 ° 34.68 ′
4. Straumfjorden from Andstraumneset N 69 ° 32.64 ′ Ø 18 ° 44.52 ′ to Hella N 69 ° 33.48 ′ Ø 18 ° 44.04 ′
5. Hillesøya N 69 ° 38.58 ′ Ø 17 ° 57.96 ′ to open sea N 70 ° 11.40 ′ Ø 17 ° 19.80 ′.

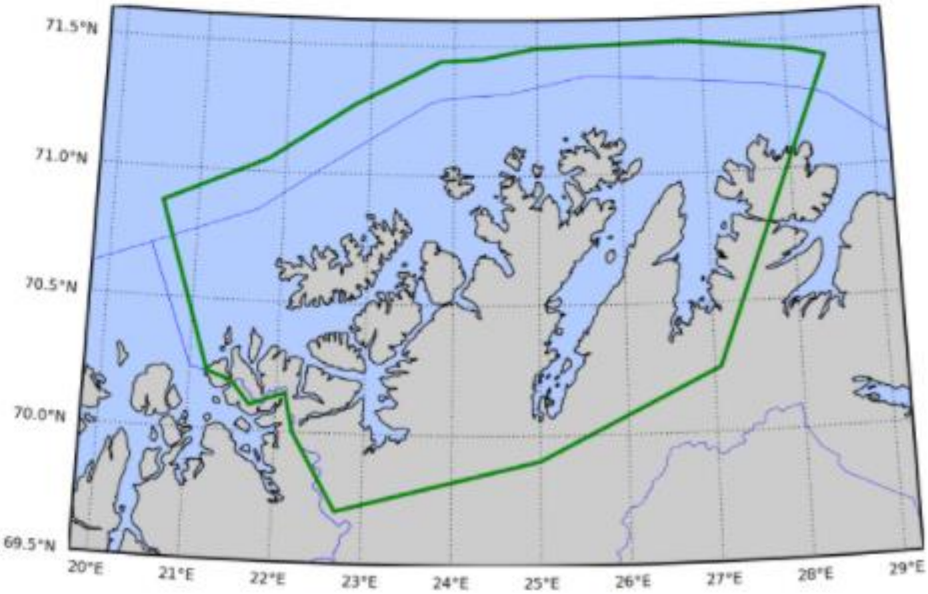
Area 11: Kvaløya to Loppa



Production area 11 is bounded at 20 nautical miles from the baseline and the following lines:

1. Hillesøya N 69 ° 38.58 ′ Ø 17 ° 57.96 ′ to open sea N 70 ° 11.40 ′ Ø 17 ° 19.80 ′
2. Straumfjorden from Andstraumneset N 69 ° 32.64 ′ Ø 18 ° 44.52 ′ to Hella N 69 ° 33.48 ′ Ø 18 ° 44.04 ′
3. County boundary south of Andsnes, N 70 ° 13.38 ′ Ø 21 ° 12.00 ′ to open sea N 70 ° 52.20 ′ Ø 20 ° 34.80 ′

Area 12: West Finnmark



Production area 12 is bounded at 20 nautical miles from the baseline and the following lines:

1. County boundary south of Andsnes, N 70 ° 13.38 ′ Ø 21 ° 12.00 ′ to open sea N 70 ° 52.20 ′ Ø 20 ° 34.80 ′
2. Bishop at Gamvik, N 71 ° 05.28 ′ Ø 28 ° 03.36 ′ to open sea N 71 ° 25.80 ′ Ø 28 ° 29.40 ′.

Area 13: East Finnmark

Production area 13 is bounded by the Norwegian economic zone up to 20 nautical miles from the baseline and the following lines:

1. Bishop at Gamvik, N 71 ° 05.28 ′ Ø 28 ° 03.36 ′ to open sea N 71 ° 25.80 ′ Ø 28 ° 29.40 ′
2. Border with Russia, southeast of Sjærgårdsneset, N 69 ° 47.22 ′ Ø 30 ° 49.20 ′ to open sea N 69 ° 58.80 ′ Ø 31 ° 06.00 ′.

Appendix 2 - Data points and all scoring calculations

All Production Areas

Criterion 1: Data	
Data Category	**Data Quality**
Production	10.0
Management	10.0
Effluent	7.5
Habitat	5.0
Chemical Use	7.5
Feed	5.0
Escapes	7.5
Disease	7.5
Source of stock	7.5
Wildlife mortalities	5.0
Escape of secondary species	5.0
C1 Data Final Score (0-10)	**7.045**
	Green

All Production Areas

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

All Production Areas

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

Production Areas 1,5,7-12

Criterion 4: Chemical Use	
Single species assessment	Data and Scores

Chemical use initial score (0-10)	4.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0-10)	**4.0**
Critical?	No

Production Areas 2,6,13

Criterion 4: Chemical Use	
Single species assessment	Data and Scores
Chemical use initial score (0-10)	6.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0-10)	**6.0**
Critical?	No

Production Areas 3,4

Criterion 4: Chemical Use	
Single species assessment	Data and Scores
Chemical use initial score (0-10)	2.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0-10)	**2.0**
Critical?	No

All Production Areas

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 %	11.700
Fishmeal from byproducts, weighted inclusion %	2.800
Byproduct fishmeal inclusion (@ 5%)	0.140
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	8.250
Fish oil from byproducts, weighted inclusion %	2.750
Byproduct fish oil inclusion (@ 5%)	0.138
Fish oil yield value, weighted %	5.000
eFCR	1.300
FFER Fishmeal value	**0.684**
FFER Fish oil value	**2.181**
Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	5.000
Critical Source fisheries?	No
SFW "Red" Source fisheries?	No

FFER for red-rated fisheries	n/a
Critical (SFW Red and FFER >=1)?	No
Final Factor 5.1 Score	**2.100**

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

5.3 Feed Footprint	**Data and Scores**
CCI (kg CO2-eq kg-1 farmed seafood protein)	**7.324**
Contribution (%) from fishmeal from whole fish	14.812
Contribution (%) from fish oil from whole fish	3.545
Contribution (%) from fishmeal from byproducts	7.316
Contribution (%) from fish oil from byproducts	2.439
Contribution (%) from crop ingredients	71.888
Contribution (%) from land animal ingredients	0.000
Contribution (%) from other ingredients	0.000
Factor 5.3 score	**8**
C5 Final Feed Criterion Score	**3.8**
Critical?	**No**

Production Areas 1 to 7

Criterion 6: Escapes	PA1	PA2	PA3	PA4	PA5	PA6	PA7
F6.1 System escape risk	6	6	2	4	4	4	2
Percent recaptured (%)	0	0	0	0	0	0	0
F6.1 Recapture adjustment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F6.1 Final escape risk score	6	6	2	4	4	4	2
F6.2 Invasiveness score	4	8	0	0	2	4	4
C6 Escape Final Score (0-10)	4	6	0	1	3	4	3
Critical?	No	No	Yes	Yes	No	No	No

Production Areas 8 to 13

Criterion 6: Escapes	PA8	PA9	PA10	PA11	PA12	PA13
F6.1 System escape risk	4	2	2	2	4	6
Percent recaptured (%)	0	0	0	0	0	0
F6.1 Recapture adjustment	0.0	0.0	0.0	0.0	0.0	0.0

F6.1 Final escape risk score	0	0	0	0	8	4
F6.2 Invasiveness score	1	0	0	0	5	4
C6 Escape Final Score (0-10)	4	6	0	1	3	4
Critical?	Yes	Yes	Yes	Yes	No	No

Production Areas 1, 11-13

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

Production Areas 2-7

Criterion 7: Disease	**Data and Scores**
Evidence-based or Risk-based assessment	Evidence
Final C7 Disease Criterion score (0-10)	**Critical**
Critical?	Yes

Production Areas 8-10

Criterion 7: Disease	**Data and Scores**
Evidence-based or Risk-based assessment	Evidence
Final C7 Disease Criterion score (0-10)	**2**
Critical?	No

Production Areas 1,2

Criterion 8X Source of Stock	**1,2**	**3,4**	**5**	**6,7,8**	**9-13**
% production dependent on wild sources	53	18	37	11	0
Initial Source of Stock score (0-10)	-5	-1	-3	-1	-0
Use of ETP or SFW "Red" fishery sources	No	No	No	No	No
Lowest score if multiple species farmed (0-10)	n/a	n/a	n/a	n/a	n/a
C8X Source of stock Final Score (0-10)	**-5**	**-1**	**-3**	**-1**	**-0**
Critical?	No	No	No	No	No

All Production Areas

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

All Production Areas – Atlantic salmon

Criterion 10X: Introduction of Secondary Species	**Data and Scores**
Production reliant on transwaterbody movements (%)	50

Factor 10Xa score	4
Biosecurity of the source of movements (0-10)	8
Biosecurity of the farm destination of movements (0-10)	0
Species-specific score 10X score	-1.200
Multi-species assessment score if applicable	-1.200
C10X Introduction of Secondary Species Final Score	**-1.200**
Critical?	n/a

All Production Areas – Wrasse

Criterion 10X: Introduction of Secondary Species	**1**	**2**	**4,4**	**5**	**6-8**	**9-13**
Production reliant on transwaterbody movements	13.2	26.5	8.8	27.6	8.1	0
Factor 10Xa score	8	7	9	7	9	10
Biosecurity of source of movements (0-10)	0	0	0	0	0	0
Biosecurity of destination of movements (0-10)	0	0	0	0	0	0
Species-specific score 10X score	-2	-3	-1	-3	-1	0
Multi-species assessment score if applicable	-2	-3	-1.2	-3	-1.2	-1.2
C10X Introduction of Secondary Species Final Score	-2	-3	-1.2	-3	-1.2	-1.2
Critical?	n/a	n/a	n/a	n/a	n/a	n/a