Monterey Bay Aquarium
Seafood Watch®

Atlantic salmon
Salmo salar

Image © Monterey Bay Aquarium

Norway
Net pens

March 31 2014

Peter Bridson – Seafood Watch

Seafood Watch and Seafood Reports are made possible through a grant from the David and Lucile Packard Foundation.

Final Scores and Seafood Recommendation

Norwegian farmed salmon has a final score of 3.6 at the low end of the yellow range, but has three red criteria (chemical use, escapes and disease) and, therefore, results in a final overall red "Avoid" recommendation.

Criterion	Score (0-10)	Rank	Critical?
C1 Data	6.7	GREEN	
C2 Effluent	4.0	YELLOW	NO
C3 Habitat	6.0	YELLOW	NO
C4 Chemicals	1.0	RED	NO
C5 Feed	5.2	YELLOW	NO
C6 Escapes	2.0	RED	NO
C7 Disease	0.0	RED	NO
C8 Source	10.00	GREEN	
C9X Wildlife mortalities	-6.00	YELLOW	NO
C10X Introduced species escape	0.00	GREEN	
Total	**29.0**		
Final score	**3.6**		

OVERALL RANKING

Final Score	3.6
Initial rank	YELLOW
Red criteria	3
Interim rank	RED
Critical Criteria?	NO
Final Rank	**AVOID/RED**

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

Executive Summary

Norway is currently the world's largest farmed salmon producer, harvesting 1.24 million metric tons (mt) of Atlantic salmon in 2012 from a farm population of approximately 366 million fish. Approximately one thousand production sites along the coast are owned by a small number of large vertically-integrated companies. Production intensity has increased dramatically with average production-per-license increasing from 26 mt in 1980 to 1,130 mt in 2010 and, while this assessment demonstrates that the industry has made (and continues efforts to make) significant improvements to many aspects of production, all stakeholders agree that the still-ubiquitous floating net pen farming production system continues to present challenges from an environmental perspective.

Norway's largest fjord, the Hardangerfjord, produces 70-80,000 mt of farmed salmon alone, and was the subject of a 2014 special publication in the journal Marine Biology Research. The editors stated, "With high human activity in the coastal zone, the fast expansion of salmon farming along the Norwegian coast and particularly in the Hardangerfjord, the reports of massive salmon lice infection on anadromous brown trout, disease problems in many salmon farms and numerous escapees in salmon rivers, there has been a strong concern among the public and management authorities for the wild salmon, sea trout and the environment of the Hardangerfjord."

This Seafood Watch assessment involves a number of different criteria covering impacts associated with: effluent, habitats, wildlife and predator interactions, chemical use, feed production, escapes, introduction of non-native organisms (other than the farmed species), disease, the source stock, and general data availability[1].

Compared to many global aquaculture sectors, Norway generally has good data availability for its salmon farming industry and there is significant ongoing scientific research on its impacts; however, government statistics are typically aggregated, they have some important gaps in public availability on key topics such as chemical use, benthic monitoring and escapes, and are often based on industry self-reported data. Within these limitations, there are generally sufficient data available from various institutions and scientific publications to give good confidence that the industry's operations and impacts are generally well understood within the current limitations of scientific understanding. Score 6.7 out of 10.

As a result of the linear input of nutrients into the net pens as feeds and the direct output of nutrients as untreated excretory wastes, salmon farming represents a large loss of the ecologically expensive ingredients provided in the feed. Although the industry has improved feeding efficiency and reduced waste output, as much as 70%, 62% and 70% of the carbon, nitrogen and phosphorous, respectively, provided in the feed is lost to the environment as

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

soluble and particulate effluents, which have the potential to cause local and cumulative impacts in the water column and seabed habitats.

Although the floating net pens themselves have a minimal direct habitat impact, the operational impacts from settling wastes (primarily feces) on the benthic habitats within the farm boundary have the potential to be profound. Results of mandatory seabed inspection in Norway, however, show that 70% of farm sites tested are in “excellent” condition and only a few sites were severely overloaded. The impacts where present are also reversible over a relatively short timeframe and the ecosystem services provided are, therefore, considered to be maintaining functionality. Although Norway’s Auditor General raises some concerns about regulatory enforcement, the management effectiveness in Norway in terms of avoiding cumulative habitat impacts is considered to be moderate-good, and overall the Habitat Criterion score for the floating farms is 6.1 out of 10.

Considering effluent waste impacts beyond the farm site, although there is some disagreement in the figures for the total waste produced in Norway, there is agreement that it can be considered relatively minor compared to the natural influx of coastal nutrients. Norway’s Institute for Marine Research (IMR) considers the risk of regional eutrophication in the pelagic zone in all counties to be low, and even in the most heavily impacted areas, the farm wastes are considered to cause a minimal increase in primary productivity beyond the farm. Nevertheless, uncertainties regarding the effective monitoring and the potential for impacts on seaweeds up to 1 km from farms necessitate an ongoing precautionary approach. Monitoring of particulate wastes impacts within the farm boundary indicate they are likely to have a significant impact beyond the farm area in only a small proportion of sites. Therefore, data are considered to show only occasional, temporary or minor evidence of effluent impacts beyond the farm; the Effluent Criterion score is 4 out of 10.

Antibiotic use in Norway is generally considered to be low, however, the total 1.5 mt used in 2012 was a large (nearly 300%) increase on 2011 and was dominated (88%) by antibiotics considered by the World Health Organization (WHO) to be critically important to human health. There are no regulations in place to limit the total antibiotic use should a disease outbreak occur. Pesticide use is substantial (6.5 mt of active ingredient in 2010, not including hydrogen peroxide) and increasing year on year. Increasingly, toxic alternatives have been introduced due to antibiotic overuse and the development of resistance by parasitic sea lice to historically effective treatments. Resistance to multiple sea lice treatments is evidence of over-use and poor management and there is some evidence of impacts on a variety of non-target species distant to the farm. Additionally, there is a somewhat unknown potential for cumulative impacts from coordinated treatments at multiple farms. Overall, the Chemical Use criterion score is 1 out of 10.

Feeding practices in salmon farming represent a linear input/output feedlot system with substantial net losses of feed resources that have been grown and/or harvested on a global scale. Feed conversion ratios have improved considerably (1.2 to 1.3 tonne of (dry) feed are now used to produce one tonne wet weight of salmon) and it can be demonstrated that salmon is relatively more efficient at converting feed nutrients than intensive terrestrial livestock, yet Norwegian salmon farming still represents a 40% to 50% net loss of edible protein, uses nearly a quarter of the global supply of fish oil and uses an area of land equivalent to half of Norway's total cropland to produce the terrestrial ingredients increasingly used to replace fishmeal and fish oil in feeds.

On a per-tonne-of-production basis, Norwegian salmon farming has made large reductions in the use of wild fish. By using increasing amounts of terrestrial crop ingredients and using fishmeal and oil made from fishery processing byproducts rather than potentially edible whole fish, the "wild fish use" is now considered to be moderate. From first principles (i.e., ignoring other uses of associated fishmeal), approximately 1.8 pounds of wild fish would need to be caught to supply the fish oil needed to grow one pound of farmed salmon. Most of the source fisheries used are generally considered to be well managed and, although the impacts of producing ingredients for salmon feeds occur globally, Norway is considered to have a moderate footprint in terms of the area of ocean and land needed to supply these ingredients on a per tonne of production basis. With moderate scores for the three factors (fish in: fish out ratio, net protein gain or loss, and feed footprint), the overall feed criterion score is a moderate 5.2 out of 10.

The impacts of salmon farming on wild salmonid species (salmon, sea trout and char) are widely acknowledged to be the greatest ongoing environmental concern in Norway. A recent survey of 481 wild Atlantic salmon populations in Norway suggests that escaped farmed salmon, salmon lice and hydroelectric power are the three major factors that impact production; 340 populations are believed to be negatively affected by escaped farmed salmon and 187 by salmon lice, and hydroelectric power production affects 110 populations.

Norway has the world's largest wild stock of Atlantic salmon, yet there are between 250 and 700 times as many salmon in farms in Norway as there are wild salmon. Although, Norway has designated 29 fjords and 52 rivers as "Salmon Fjords" in order to prevent the infection of important populations of wild salmonids with salmon lice from farms, significant escapes and/or farm disease outbreaks have a substantial potential to affect the relatively small wild populations when and where they interact.

While improvements to net pen design and farm management have led to commendable reductions in reported escapes in Norway, with low escapes reported in both 2012 and 2013, nevertheless, over 300,00 fish escaped in 2011 and it is likely that official reported figures substantially underestimate the actual ongoing escape numbers. Large escape events still occur (for example, 175,000 fish from one site in February 2011), and despite improvements to net pen design, human error is still a major cause. A small portion of escapees are recaptured and significant direct mortality is expected, but data on both are limited and the substantial number of escaped farmed salmon documented in Norwegian rivers is evidence of their survival to maturity in the wild.

Norway has over 200 rivers supporting native Atlantic salmon populations. Many of those populations have displayed moderate to high frequencies of domesticated farmed escapees on the spawning grounds for two decades or more. After multiple generations of selective breeding, farmed salmon are genetically differentiated from their wild counterparts and interbreeding of escapees and wild salmon has led to highly significant genetic differences in a number of Norwegian wild salmon populations. The resulting interactions led Norway's Auditor General to state, "*A goal of reducing impacts that threaten the genetic diversity of salmon to a non-harmful level by 2010 has not been achieved due to persistently high figures for escaped fish,"* and that *"several rivers and watercourses have a high proportion of farmed fish among wild fish that, in some areas, has already affected the genetic distinctiveness of wild salmon.*" The escape criterion score is 2 out of 10.

A variety of bacterial, viral, and parasitic pathogens represent a primary cause of inefficiency in the Norwegian salmon farming industry and also indicate a potential for severe impacts on wild salmon and other salmonids. Although a number of viral pathogens are the leading problem from a production perspective, they are generally thought to be of low risk to wild fish populations. The greatest concern for wild fish (and a significant production problem and cause of pesticide use) are parasitic sea lice and, while the industry is making significant efforts to control them, the evidence of increasing resistance to widely used chemical treatments indicates the ongoing challenges to control their numbers. Recent meta-analyses conclude that sea lice have a moderate population regulatory effect on wild salmon populations in the NE Atlantic and, while the use of wrasse for biological control has increased markedly and may offer at least a partial alternative to chemical use, based on 2010 survey the IMR concluded there is a moderate to high likelihood that salmon lice from farms have a population regulating effect on wild salmonids, particularly sea trout, in eight out of ten of Norway's coastal regions.

Total sea lice numbers were very high in 2010 and 2011 and, while they were lower in 2012, the annual pattern of increasing numbers in late spring and summer continue to represent a serious direct threat to wild sea trout in addition to as-yet poorly studied secondary mortality factors on infected wild fish such as increased vulnerability to predators. The high likelihood of population-level impacts on wild sea trout (and, to a lesser extent, wild salmon and char) means the disease criterion score is 0 out of 10.

Norwegian salmon farming is considered self-sufficient in terms of the supply of broodstock and ova (eggs) and, although there are recent records of minor movements of ova, international shipments are considered to be zero for the purposes of this assessment. Movements within Norway risk the spread of the salmon parasite *Gyrodactylus salaris*, but the parasite remains undetected in 2011 monitoring, and the risk of an unintentionally introduced species is low. The penalty score is 0 out of -10.

Finally, farms may apply to kill problem seals, but statistics on these and other predator mortalities are not reported in Norway. Although the mortality rate may be considered unlikely to impact the population status of affected species, this is unknown and the penalty score is a precautionary penalty of -6 out of -10.

Overall, while Norwegian salmon farming has relatively good data transparency and scientific research shows significant improvements to several aspects of the production system and its management, the scores in this assessment reflect the ongoing high concerns with respect to the impacts of escapes on wild Atlantic salmon and parasitic sea lice on wild brown trout as articulated by Norway's Veterinary Institute, the IMR, the Directorate of Fisheries, the Norwegian Seafood Federation, and Norway's Auditor General. The low but increasing use of antibiotics listed as critically important to human health by the World Health Organization is also a high concern in Norway. The final score is 3.6 out of 10, and the three red criteria (chemical use, escapes and disease) result in an overall red "Avoid" final ranking.

Table of Contents

Introduction

Scope of the analysis and ensuing recommendation

Species
Atlantic salmon (*Salmo salar)*

Geographic coverage
Norway

Production Methods
While juvenile salmon are raised in freshwater hatcheries, the bulk of the salmon growth and potential impacts occur during the seawater growout phase in coastal open net pens. The latter forms the basis of the assessment. Thus, net pen farmed Atlantic salmon in Norway is the scope of this assessment.

Species Overview

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

Production statistics
Norway produces approximately 1.25 million mt of farmed salmon each year (1.24 million mt in 2012 (FHL 2013) produced from approximately 1000 grow-out sites and 230 hatcheries and fingerling operations— these site figures include marine production of trout, which are not differentiated in the Directorate of Fisheries' statistics (Fiskeridirektoratet 2014[2]).

In Norway, production per license has increased from 26 mt in 1980 to 1,130 mt in 2010, indicating a substantial intensification in the industry (Asche et al., 2013)

Import and export sources and statistics
Export of Norwegian farmed salmon to the U.S. varies according to competition in international markets, and has been affected by factors such as the collapse and subsequent resurgence of Chilean farmed salmon production. For example, 53,000 mt of salmon were exported to the U.S. in 2010, while the figure in 2011 dropped to 28,000 mt (Fiskeridirektoratet 2014) due to the availability of cheaper Chilean product (Borge Gronbech, Norwegian Seafood Federation, personal communication, July 2012). This represented 3% of Norway's total exports in 2012 (Fiskeridirektoratet 2012[3]).

[2] http://www.fiskeridir.no/english/statistics/norwegian-aquaculture
[3] http://www.fiskeridir.no/english/statistics/norwegian-aquaculture

Common and market names

Atlantic salmon, Norwegian salmon. Packaging and marketing may imply wild capture, but salmon originating from Norway on the U.S. market will be farmed Atlantic salmon.

Product forms

Atlantic salmon is available in all common fish presentations— whole, fillets, steaks, smoked, caviar, pate etcetera.

Analysis

Scoring guide

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

Criterion 1: Data quality and availability

Impact, unit of sustainability and principle

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

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	Yes	10	10
Effluent	Yes	5	5
Locations/habitats	Yes	10	10
Predators and wildlife	Yes	0	0
Chemical use	Yes	5	5
Feed	Yes	5	5
Escapes, animal movements	Yes	7.5	7.5
Disease	Yes	7.5	7.5
Source of stock	Yes	10	10
Other – (e.g. GHG emissions)	No	Not relevant	n/a
Total			**60**

C1 Data Final Score	6.7	GREEN

With historic and ongoing concern over net pen production systems and their environmental impacts, the considerable scrutiny and scientific study means that data availability in Norway is generally good in comparison to many aquaculture industries globally. Limited detail and/or gaps in public data availability still remain in some key areas. While both government and company statistics are typically aggregated and, to a greater or lesser extent, reliant on industry self-reporting, salmon farming in Norway has been the subject of substantial scientific study. The Data Criterion score is 6.7 out of 10.

Justification of Ranking

Key sources of information include:

- Norwegian Directorate of Fisheries (Fiskeridirektoratet) http://www.fiskeridir.no/english/aquaculture
    - Site information, licenses, escapes
- Statistics Norway (Statistisk Sentralbyra): http://www.ssb.no/
    - Production statistics, sales, escapes, mortalities
- Institute for Marine Research (IMR) (Havforskningsinstituttet) http://www.imr.no/en
    - Published a "Risk Assessment – Environmental Impacts of Norwegian Aquaculture"
- Norwegian Veterinary Institute – Veterinaerinstituttet http://www.vetinst.no/eng/
    - Publishes an annual "Fish Health Situation in Norwegian Aquaculture" report covering diseases and parasites
    - Publishes (in collaboration with the Institute of Marine Research) the annual report on health monitoring of wild anadromous salmonids in Norway
- Norwegian Food Safety Authority— Mattilsynet— collects sea lice data, published at www.lusedata.no
- Norwegian Seafood Federation (FHL) http://fhl.no/norwegian-seafood-federation/
    - Industry body publishes an environmental report, covering selected information on feed, escapes, sea lice, effluent, chemical use, waste
- Norwegian Institute of Food, Fisheries and Aquaculture Research (NOFIMA) http://www.nofima.no/en
    - Feed resource use
- Norwegian Institute of public health – Folkehelseininstituttet http://www.fhi.no/eway/?pid=240
    - Chemical use data
- Company-specific data
    - The large salmon companies publish substantial amounts of data on their operations in annual reports, or sustainability reports.
    - One major feed company provided salmon-specific data.

Norwegian aquaculture, particularly salmon farming, continues to be the subject of active scientific research, particularly in the key impacts areas of sea lice and escapes. A special issue of the journal "Marine Biology Research" on the Hardangerfjord (Norway's largest fjord, which produces approximately 70-80,000 mt of farmed salmon each year) was published online in late

2013 and in print in early 2014; it provided a number of highly informative papers on one of the most intensive salmon farming regions of the world.

Data quality are generally good and valid in reasonable timeframes, but do vary between subject areas. For example:

- Some aspects of data are industry self-reported and aggregated (e.g., sea lice numbers, escapes, chemical use, feed use, and disease), so this information should be used with some caution.
- While some benthic monitoring data have been published by a few authors (by the IMR from 2008 to 2010 in Taranger et al., 2011), the Norwegian Directorate of Fisheries does not yet have a public database of ongoing results.
- Chemical use data are not officially published or easily publically accessible. Selected data have been published in various articles, but complete annual data are not available.
- Official sea lice and escapes data are aggregated, but there is also research that breaks down impacts at the county (and in some instances river) level.
- Feed data are generally considered proprietary by feed companies and, although basic feed information is perhaps better in Norway than any other region, it is still somewhat limited.
- Data on escapes recaptures are not collected.
- Data on predator mortalities are not collected.
- Production and site information is considered robust, but in some instances is not separated between salmon and rainbow trout.

Data Criterion- Conclusions and Final Score

While many of the reports listed above cannot be considered independent of the industry, and significant gaps remain in public reporting, the information is still informative if used cautiously. Overall, Norway gets a good score of 7.2 out of 10 for data availability and quality.

Criterion 2: Effluents

Impact, unit of sustainability and principle

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

C2 Effluent Final Score	**4.00**	**YELLOW**

The Seafood Watch Effluent Criterion considers impacts of farm wastes beyond the immediate farm area or outside a regulatory allowable zone of effect (AZE). Although salmon farms represent a substantial point source of nutrient pollution, and there is a large loss of the ecologically costly feed ingredients provided, the total discharge in Norway is considered a somewhat insignificant contributor to coastal nutrients at a national level. Recent studies in Norway, including the most densely farmed region (the Hardangerfjord), conclude that the benthic and pelagic communities beyond the immediate proximity of fish farms seem to be little affected by the effluent nutrients and deposition of organic matter from the salmon farming industry. Nevertheless, some uncertainties remain with respect to impacts on macroalgae up to 1 km distant from farms, cumulative impacts of total farm area, and potential sedimentation impacts within Norway's deep fjord basins, indicating that further study may still identify as-yet poorly understood impacts. These uncertainties demand a precautionary approach and, according to the Seafood Watch criteria, there is occasional, temporary or minor evidence of impacts beyond the farm. The final score for the Effluent Criterion is, therefore, 4 out of 10.

Justification of Ranking

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

Husa et al. (2014b) state, "Waste from fish farming in open cages will have a large impact on the bottom communities in the area close to the farm and the release of nutrient and fine particulate material may also have a local influence in the shallow water communities in the near-farm area. This local footprint of fish farming is well recognized. However, intense fish farming in an area may inflict regional impacts on marine ecosystems such as eutrophication, impact on shore communities, and major changes in the environmental conditions for bottom communities. In order to develop environmentally sustainable fin-fish farming, it is important to understand if such activities might have an impact beyond the immediate production area. The regional impact of intensive marine fish farming has been little studied, although some investigations do exist, mainly on the impact of dissolved nutrients."

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

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

While the two criteria cover different impact locations, there is inevitably some overlap between them in terms of monitoring data and scientific studies. The majority of this information will be presented in this Effluent Criterion, with the intent of minimizing (but not entirely avoiding) replication in the Habitat Criterion.

The majority of a salmon farm's effluents are soluble nutrients that are dispersed in the water column; salmonids excrete 75%–90% of their ammonia and ammonium waste across gill epithelia (Gormican, 1989) or in concentrated urea (Persson, 1988; Gowen et al., 1991). Nitrogen and phosphorus are also dissolved from waste feed and feces during and after descent to bottom sediments. Norway has approximately 500,000 to 600,000 mt of salmon in farms at any one time, and Wang et al., (2013) calculate the total annual discharge of carbon, nitrogen and phosphorous from Norwegian salmon farming to be 404,000, 50,600 and 9,400 mt respectively (using 2009 data). These values represent a loss to the environment of as much as 70%, 62% and 70% of the total carbon, nitrogen and phosphorous provided in the feeds (Wang et al., (2013).

Of the two waste streams (i.e., soluble and particulate), salmon farming impacts are considered to stem primarily from the latter, that is, the release of particulate matter (feces and uneaten food) into the water column (Wilding 2011).Both waste streams have the potential to impact areas beyond the immediate farm area.

Research in Norway suggests the total amount of waste discharged from salmon farms in that region can be considered somewhat insignificant compared to the natural transport of nutrients in the coastal currents (FHL 2011). Brooks (2007) came to a similar conclusion in British Columbia. Despite these large-scale regional assessments, the potential for local or regional impacts in individual waterbodies appears significant. For example, Strain (2005) concludes, "*Given the right combination of the intensity of farming and the carrying capacity of* *the receiving environment, finfish aquaculture can produce eutrophication impacts on scales of kilometers to tens of kilometers and can change the structure and functioning of the ecosystem in significant ways on these scales.*"

It should also be noted that the production and subsequent fate of organic waste at fish farms is more complex than is often assumed (Mayor et al., 2010). For example, the Auditor General of Norway has stated: "*Experts in different parts of the government administration disagree about the importance of the total discharges from the aquaculture industry*" (Kosmo 2012). Bureau et al., (2010) report the type and magnitude of any impacts will be highly dependent on the biological, chemical and physical characteristics of the receiving ecosystem and state, "*The release of wastes cannot be systematically equated to deleterious environmental changes as it is frequently assumed in much of the literature or popular press.*"

Particulate Wastes

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

Keeley et al., (2013) describe the major pathways of biodeposition from a typical net pen salmon farming system. Figure 1 shows that, of the total particulates leaving the net pen, some will dissolve or release nutrients before reaching the seabed; of the portion settling on the seabed in the primary area of deposition, some will be consumed directly by benthic organisms, some will accumulate and consolidate, and some will be 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.

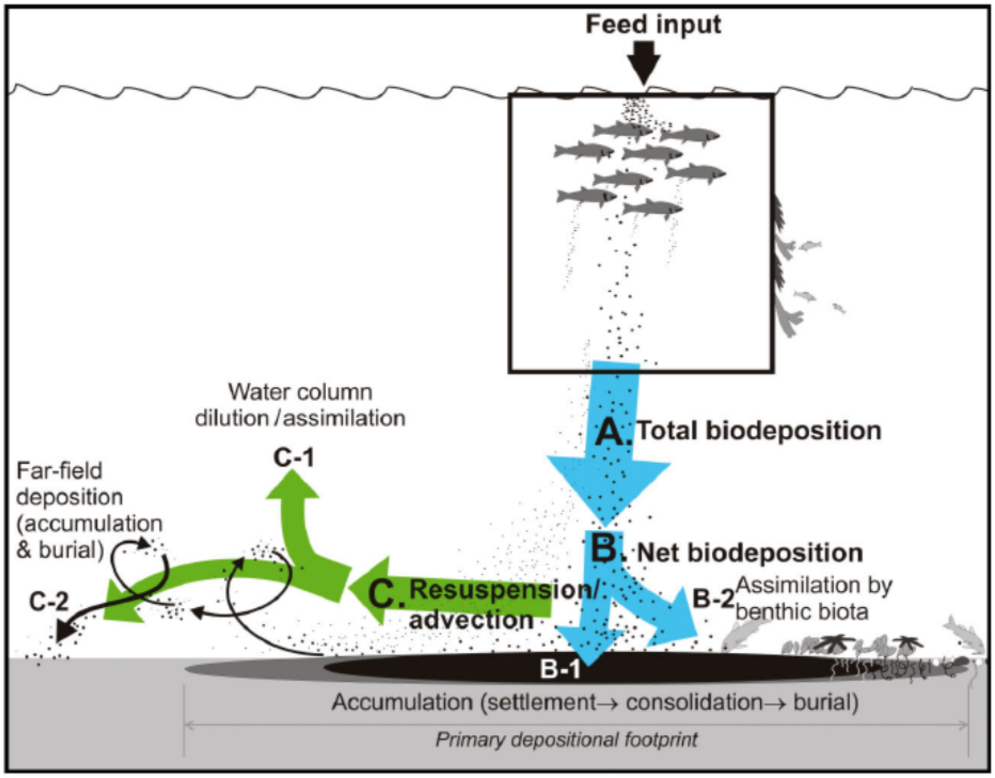

Figure 1. Summary of major pathways for salmon farm feed-derived biodeposition. A: total biodeposition = all waste particulates produced by the farm (feed and feces, ignoring dissolved organic component). B: net biodeposition includes the particulates that settle, accumulate and/or are used (assimilated) in the near-field or 'primary footprint.' C: resuspension and advection includes the fraction of A that is exported from the immediate vicinity by currents. Image copied from Keeley et al. (2013).

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

The primary depositional area below salmon net pens is typically localized and limited to the close proximity of the farm. Studies examining the spatial extent of fish farming impacts generally report that their effects on the benthic environment rapidly dissipate and decrease exponentially with increasing distance from their edge (Keeley et al., 2013; Chang et al., 2011; Mayor and Solan, 2011; Mayor et al., 2010; Brooks and Mahnken, 2003). For example, Mayor et al. (2010) suggest, that the immediate benthic impact of the fish farms examined extended to somewhere between 25 and 50 m from the cage edge, while Mayor and Solan (2011) reported that the effects of the fish farms examined (in Scotland) were only statistically discernible at less than 50 m from the cage edge. Depending on prevailing currents, detectable impacts can extend to greater distances, but on a typically limited axis (i.e., downstream). For example Brooks and Mahnken (2003) reported detectable impacts at peak production (in British Columbia) at distances of between 90 m and 205 m from the net pen perimeters and subtle changes in macrobenthic communities have been documented to distances of 205–225 m down current from salmon farms during peak production. It should be noted that impacts at these distances occur at peak production and are at the limit of detection.

Norwegian salmon farming sites are characterized by deep fjordic locations. Monitoring of areas in close proximity to fish farms in Norway occurs with mandatory "environmental monitoring of marine fish farm" (MOM) surveys (Taranger et al., 2011). This Effluent Criterion assesses the effluent impact beyond the immediate area of the salmon farms, but considering the impacts within the immediate farm area can provide a useful indication of the likely impacts beyond it. The MOM benthic inspections became mandatory in 2005, and reporting the results to the Norwegian Directorate of Fisheries became mandatory in 2009, but Taranger et al. (2011) reported that a public database for the results of the MOM inspections is lacking. As of January 2014, this still appears to be the case, but some results have been published elsewhere. Taranger et al. (2011) provided benthic monitoring results from 2008 to 2010, and FHL (2013) provided results from 2011 and 2012 (referenced to the Norwegian Directorate of Fisheries).

The monitoring results separate sites into benthic condition classes from 1 to 4 where Condition 1 ("Excellent") relates to a minor impact, and Condition 4 implies severe overloading. The results from 2008 to 2012 are shown in Figure 2.

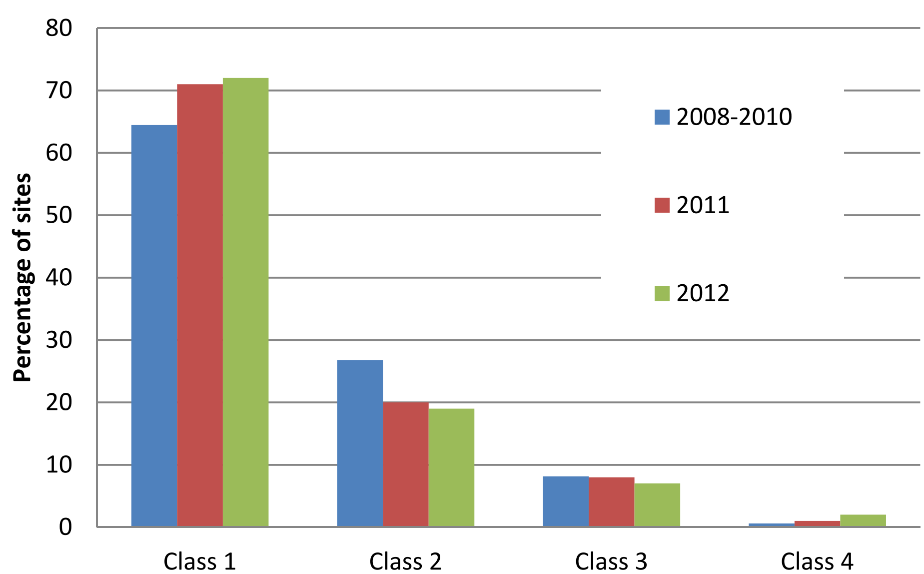

Figure 2. Norwegian salmon farm benthic monitoring results from 2008-2012 (from Taranger et al., 2011; and FHL, 2013). Condition 1 relates to a minor impact, and Condition 4 implies severe overloading.

According to these results from the edge of immediate farm area, approximately 70% of the sites surveyed were in Condition 1, approximately 20% were in Condition 2, and less than 10% in Condition 3 or 4. Benthic impacts of this nature are considered to be relatively quickly reversed with cessation of production or fallowing. The large majority of sites are in "excellent" condition (class 1) but with approximately 30% of sites being in Condition 2 or worse, the benthic impacts within the farm area are considered "moderate" overall (see the Habitat Criterion below) on a site by site basis. Therefore, after considering these impacts at the edge of the immediate farm area, the risk of benthic impacts from particulate wastes beyond the immediate farm site assessed in this Effluent Criterion would also be considered to be moderate at the site level, despite the considerable volume of particulate wastes produced by salmon farms.

When extending these site-specific results to consider potential cumulative impacts of multiple sites, studies in Norway's most densely farmed region in the Hardangerfjord provide a useful example. In this region, Husa et al. (2014a) reported that sediments (in control locations beyond salmon farms) generally supported a highly diverse infauna community dominated by species characteristic for unaffected areas in western Norwegian fjords, however, the infauna species composition in deep water basins (500–800 m depth) could be reflecting a beginning of enrichment, caused by the cumulative impact of the production and release of organic waste from several fish farms over many years (Husa et al., 2014b). Overall, oxygen levels and benthic soft bottom infauna communities were reported to be in good environmental condition, except from a high abundance of opportunistic species in the outermost deep basin, which might be slightly impacted by the high salmon production (Husa et al., 2014b).

With respect to direct sedimentation in the deep basin of the Hardangerfjord, Buhl-Mortensen et al. (2014) studied the deepwater biotopes and observed patches of silt on *Lophelia* and different sponges to a much higher degree than what had been observed during comparable studies offshore. However, they were unable to conclude whether this is a natural condition for the fjord or caused by organic input from industries (agriculture, sewage and fish farming). Husa et al. (2014b) conclude that overall, the benthic communities beyond the immediate proximity of fish farms in the Hardangerfjord seemed to be little affected by the deposition of organic matter from the salmon farming industry. However, they also note that although there is little evidence of regional impact, the cumulative effect of numerous impacted areas around the fish farms must be taken into consideration when further evaluating the total impact from fish farming on ecosystem functioning in this area (see the Habitat Criterion below).

In addition to the nutrients released in salmon wastes and uneaten feed, interactions of metals such as copper (used in antifouling paints and net treatments) and zinc (used as a mineral supplement in feeds) on organisms beyond the farm site can potentially impact net pen salmon farming. Burridge et al. (2011) note that these elements are found in close association with build-up of organic material and they likely play a role in cumulative effects associated with aquaculture activity. Metals may be present in high concentrations on sediments associated with aquaculture activity, but because of the chemical nature of the sediments, the metals may not be available to non-target organisms. According to Burridge et al. (2011), several papers have shown that effects reported are not necessarily a consequence of elevated metal concentrations.

Soluble wastes

There is no routine monitoring of soluble effluent from fish farms in Norway, but data compiled by the Norwegian IMR (Taranger et al., 2011) shows the annual total discharge of nitrogen and phosphorous from salmon farms is approximately 9,800 mt and 1,600 mt respectively (based on 2009 data), and also that the amounts discharged per square kilometer of ocean ranges from 60 kg to 460 kg for nitrogen and from 10 kg to 76 kg for phosphorous. It should be noted that these numbers are considerably different from values in Wang et al. (2012) whose calculations show approximately 36,000 mt of dissolved nitrogen were released, but there has been significant research in Norway into the actual local and regional impacts, particularly in Norway's most densely farmed area in the Hardangerfjord.

Although, Navarro et al. (2008) suggest an increase in the heterotrophic bacterial community (rather than phytoplankton) is the primary ecological response to salmon farm effluent, changes to phytoplanktonic communities or associations with harmful algal blooms have generally been the focus of the limited number of studies. In the most recent comprehensive review conducted for the WWF Salmon Aquaculture Dialogue, Buschmann et al. (2007) highlighted the lack of papers stating, *"The limited efforts made is most likely a result of the problems to detect clear environmental signals of wastes from salmon farms in the water masses and the fact that there is no general applicable scientific concept established for assessing and judging impacts of nutrients released from fish farms in water column."* A recent example highlights this challenge—Marie George and Parrish (2013) showed significant declines in dissolved organic carbon over distances of 1 km from farm sites and conversely reported lower levels of the essential fatty acid DHA in shellfish near farms. However, the different (i.e., non-significant) declines in carbon at 10 m depth, combined with some questionable regressions[4] and a lack of detection of any relationship with distance from the farm for nitrogen would urge caution in the interpretation of these results.

Several studies have reported the ability to detect soluble farm-origin nitrogen at considerable distances from salmon or other fish farms (either directly measured in the water column or after uptake in seaweeds). For example, the chemical signature of salmon farm nitrogen was detected at 200 m in seawater (Sanderson et al. 2008) and from 1 km (Sanderson 2006) up to 3-5 km (Karakassis 2005) in seaweeds. Olsen et al. (2012) show soluble wastes from salmon farms are diluted and dispersed relatively rapidly in the water column, but are detectable hundreds of meters from the farms for extended periods of time. However, these results are at the limit of detection and indications of measureable ecological effects beyond the farm (for example, enhanced growth of seaweeds) are limited to much shorter distances on scales of tens of

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

meters compared to reference sites at 150 m (e.g., Sanderson et al., 2012; Troell et al., 1997; FHL 2011).

Overall, the review by Buschmann et al. (2007) concluded only stagnant sites will exhibit increased phytoplankton biomass locally, and Sara (2007) also stated, "*Impacts on pelagic ecosystems from nutrient releases from salmon aquaculture* (in Chile) *as well as for other cultured species have generally revealed a lack of ecological response by the plankton community."* The Norwegian IMR calculated a maximum 4.8% increase in phytoplankton growth in the most heavily impacted area of Norway and concluded that this remains within the threshold for very good water quality (Taranger et al. 2011). IMR considers the risk of regional eutrophication in the pelagic zone of Norway to be low.

More recent studies and reviews in Norway's largest and most intensive salmon farming region, the Hardangerfjord where 70-80,000 mt of salmon are produced annually, show all nutrient and chlorophyll-a values were within the thresholds for high water quality set by the national authorities, and there were no indications of elevated levels in the intermediate area of the fjord, which has the greatest density of farms (Husa et al., 2014b). Modelling of the distribution of nutrients in the fjord, taking into account water exchange rates, shows that nutrient emissions from fish farms in the densest area of production will increase the natural nitrogen concentrations and phytoplankton biomass by 15% (Husa et al., 2014). Although this is higher than the 4.8% figure quoted from Taranger et al. (2011), the chlorophyll-a values measured in the Hardangerfjord in this study give no indication of any ongoing eutrophication processes (Husa et al., 2014b and references therein).

Husa et al. (2014a) studied the health of macroalgal communities in the Hardangerfjord and, while dense establishments of filamentous algae were recorded at many sites—in particular in the central part of the fjord—they concluded that while this phenomenon may be caused by local nutrient enrichment from fish farms in the area, it could also be caused by climatic variations or by the massive urchin grazing on ephemeral seaweeds (kelp) providing space for opportunistic species.

Effluent Criterion- Conclusions and Final Score

Studies in Norway's densest salmon farming region show few indications of significant impacts, but benthic impacts that occur within the immediate farm area are likely to extend beyond the AZE in some farms, and uncertain impacts on seaweeds up to 1 km from farms indicate an ongoing potential for poorly-studied impacts. The results from the well-studied Hardangerfjord, although from the most densely farmed area in Norway, are considered to be broadly equivalent to other areas in Norway where dense locations of farms could also occur at a smaller local/regional scale. Overall, the risk of local and cumulative impacts beyond the immediate farm area in Norway is relatively low, but the remaining uncertainties result in a moderate score of 4 out of 10.

Criterion 3: Habitat

Impact, unit of sustainability and principle

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

Habitat parameters	Value	Score	
F3.1 Habitat conversion and function		7.00	
F3.2a Content of habitat regulations	3.25		
F3.2b Enforcement of habitat regulations	3.25		
F3.2 Regulatory or management effectiveness score		4.2	
C3 Habitat Final Score		**6.08**	**YELLOW**
Critical?	NO		

The floating net pens have a minimal direct physical habitat impact, but the benthic habitat impacts from settling particulate wastes within their allowable zones of effect may be significant. Monitoring data show benthic conditions under the majority of Norwegian farm sites are in "good" condition, however, in densely farmed areas the cumulative impact of multiple farm footprints may also be significant. The benthic impacts are relatively quickly reversible and, overall, the combination of the lack of permanent impacts, the relatively rapid recovery and the moderately good regulatory effectiveness to avoid accumulation of impacts over multiple sites and production cycles results in a "moderate" habitat score of 6 out of 10 (calculated value is 6.08).

Justification of Ranking

The floating net pens used in salmon farming have relatively little direct habitat impacts, but the operational impacts on the benthic habitats below the farm and/or within an AZE can be profound

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

- The previous Effluent Criterion (C2) assesses impacts of both particulate and soluble wastes <u>beyond</u> the immediate farm area or a regulatory AZE

- This Habitat Criterion (C3) assesses the impacts of primarily particulate wastes directly under the farm and within a regulatory AZE.

Factor 3.1. Habitat conversion and function

As a result of uneaten food and feces, intensive fish farming activities generate a localized gradient of organic enrichment in the underlying and adjacent sediments, and strongly influence the abundance and diversity of infaunal communities. In the area under the net pens or within the regulatory AZE, the impacts may be profound, but are now relatively well understood (see Black, Hansen et al. 2008, for a review of these impacts). Primarily, changes can be anticipated in total volatile solids, redox potential, and sulfur chemistry in the sediments in the immediate vicinity of operational net pens, along with changes to the species composition, total taxa, abundance and total biomass (Brooks and Mahnken 2003).

The total aquaculture area (for salmon and trout) in Norway is approximately 420 square kilometers and is considered to be a very small proportion of Norway's coastal resource (FHL 2011). In reality, a much larger terrestrial habitat area is needed to supply the ingredients used to make the salmon's feed (NOFIMA, 2011 calculate that the salmon industry uses an area equivalent to half of Norway's cropland to provide its feed—see the feed criterion).

As previously mentioned in the Effluent Criterion, monitoring of benthic areas in close proximity to fish farms in Norway occurs with mandatory "environmental monitoring of marine fish farm" (MOM) surveys (Taranger et al., 2011). The benthic monitoring results presented in the Effluent Criterion above (Figure 2) show approximately 70% of the sites surveyed were in Condition 1 ("excellent"), approximately 20% were in Condition 2, and less than 10% in were in Condition 3 or 4 (which indicate severe overloading).

Benthic impacts of this nature are considered to be relatively quickly reversed with cessation of production or fallowing. For example, while the time taken for recovery of this area is highly variable, it is frequently as substantial as 2-3 years (Black et al., 2008). According to Brooks and Mahnken (2003), chemical and biological remediation (at sites in British Columbia) has been shown to occur naturally during fallow periods at every salmon farm studied. Chemical remediation has occurred as soon as harvests were complete at some sites, or it has taken several years at a few sites where waste was allowed to accumulate under the net pens. While full recovery may take much longer in some extreme cases, a 2-3 year period is considered to be relatively short compared to more invasive habitat impacts, indicating the impacts are relatively quickly reversible and could be recovered by fallowing and/or removing the farm. Therefore, although Husa et al. (2014b) noted the cumulative effect of numerous impacted areas around the fish farms must be taken into consideration when further evaluating the total impact from fish farming on ecosystem functioning in this area, results showing 64% of Norway's sites being in Condition 1 (i.e., a minor impact) and higher levels of impact on other sites are relatively quickly reversed with cessation of production or fallowing, overall, the habitats in Norway are considered to be maintaining functionality. The Habitat Conversion and Function score is 7 out of 10 for (Factor 3.1 in the Seafood Watch criteria).

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

The intention of this factor is to assess the ability of the management or regulatory system to control the cumulative habitat impacts of the many farms that form Norway's sizeable salmon farming industry.

The 19 counties of Norway are each responsible for management of aquaculture in their respective county, whereas the Directorate of Fisheries is also responsible for controlling each farm. The Aquaculture Act (2005)[5] administered by the Ministry of Fisheries and Coastal Affairs regulates the management, control and development of aquaculture in Norway. The act has a strong emphasis on industry profitability and growth[6], but drives the content of regulations. With regard to site locations, the issue of new licenses is restricted (new licenses have been issued in limited numbers in years 1985, 1988, 1999, 2001, 2002 and 2009), and each site has a maximum allowable biomass and a maximum stocking density of fish. There is a minimum distance between sites and fallowing requirements between production cycles. As mentioned above, mandatory surveys of benthic habitat impacts take place on selected farms.

Norway's Auditor General states, "*With respect to policy instruments, [….] there are shortcomings in the planning of marine areas. When awarding licenses to engage in fish farming, and when regulating the aquaculture facilities, the main focus is on the individual site and less on the total environmental load from several aquaculture facilities in a wider area*" (Kosmo 2012). However, he also notes, "*Environmental considerations have been given greater emphasis in recent years when considering whether the aquaculture industry's production can be increased*."

In terms of regulation enforcement relating to habitat impacts, the relevant agencies are easily identified, locations of farms are publically available and the published results of the MOM benthic surveys indicate that while not all farms are surveyed, the process is generally effective at the site level. It should be noted that there is some concern among anti-salmon farming campaigners over the true independence of various government agencies who oversee the industry (Oddelcalv 2011), and the Auditor General states, "*Breaches of the regulations are often uncovered during inspections of aquaculture facilities, and the use of sanctions varies at the regional and local levels in the Directorate of Fisheries and the Norwegian Food Safety Authority."* It is not clear, however, if this accusation relates to the habitat management effectiveness assessed in this criterion, or to other aspects of aquaculture operations.

---

[5] 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

[6] 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.

The regulations relating to habitat management in Norway score a 3.25 (out of 5), and their enforcement scores the same, producing a moderate management effectiveness score of 4.2 out of 10.

Habitat Criterion- Conclusions and Final Score

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

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

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

Chemical Use parameters	Score	
C4 Chemical Use Score	**1.00**	
C4 Chemical Use Final Score	**1.00**	**RED**
Critical?	NO	

Antibiotic use in Norway is generally considered to be low, however, the total 1.5 mt used in 2012 was a large (nearly 300%) increase on 2011, and was dominated by antibiotics (88%) considered by the World Health Organization to be critically important to human health. There are no regulations in place to limit the total antibiotic use should a disease outbreak occur. Pesticide use is substantial (6.5 mt of active ingredient in 2010, not including hydrogen peroxide) and increasing year on year. Increasingly, toxic alternatives have been introduced due to overuse and the development of resistance by parasitic sea lice to historically effective treatments. Resistance to multiple sea lice treatments is evidence of antibiotic over-use and poor management; there is also some evidence of impacts on a variety of non-target species distant to the farm, and a somewhat unknown potential for cumulative impacts from coordinated treatments at multiple farms. Overall, the Chemical Use criterion score is 1 out of 10.

Justification of Ranking

<u>Antibiotics</u>

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

According to Norway's Veterinary Institute, the usage of antimicrobial veterinary medicinal products for therapeutic use in food producing animals in Norway is low. Norway's track record of antibiotic use has frequently been used to demonstrate the declining chemical use in salmon farming; total antibiotic use dropped from approximately 50 mt per year in the late 1980s to approximately one ton per year by the mid-90s despite the considerable increase in production over the same time period (Midtlyng, Grave et al., 2011). The World Health Organization (WHO) has referred to Norwegian salmon farming as an example of declining antibiotic use and a model for all food-animal production systems. WHO (2011) stated, "*The introduction of effective vaccines and improvement of the environmental conditions [in salmon farming in Norway] have been shown to significantly reduce the need for and thus the use of antibiotics. This lesson on the importance of preventive medicine is relevant to all food-animal production.*"

Although remaining low in terms of antibiotic use per tonne of production, in 2012, the total sales of antimicrobial agents for therapeutic use in farmed fish (salmon and trout) were 1,591 kg of active substance, which represents a three-fold increase when compared to 549 kg in 2011 (Figure 3). Antibiotic use in terrestrial livestock in 2012 was 6,161 kg and human use was 51,880 kg. For further comparison, the 2012 use of antibiotics in Chile's salmon farming was nearly 210 mt (i.e., 210,000 kg) (Sernapesca 2013). Nevertheless, there are no limits in place on the frequency of use, and therefore total use of antibiotics in Norway.

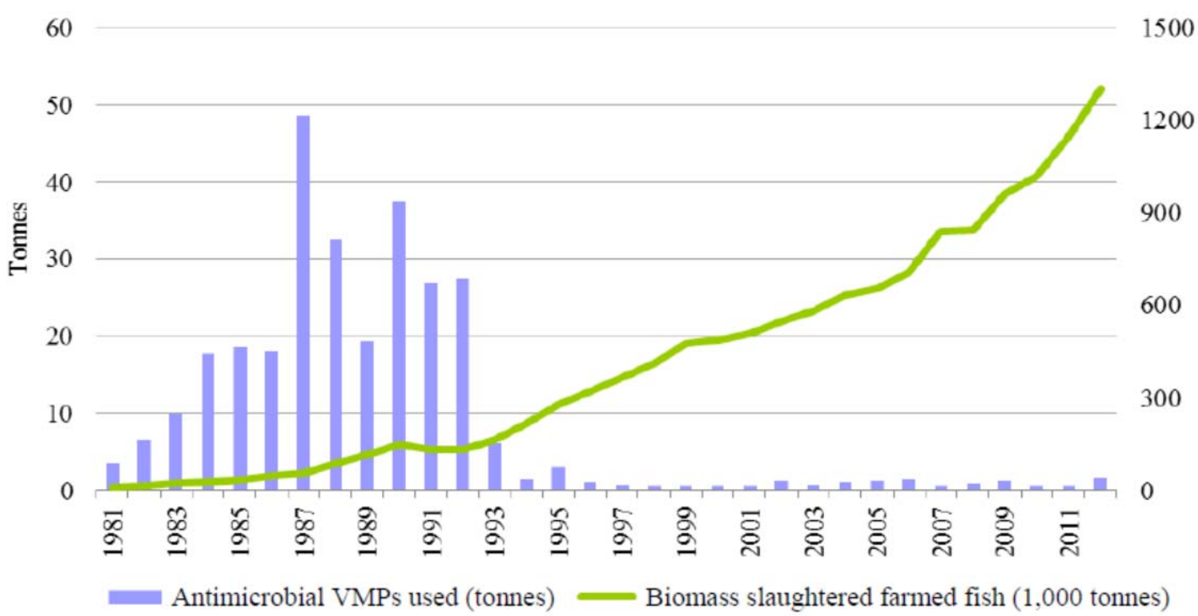

Figure 3. Antibiotic use and salmon production from 1981 to 2012 (NORM/NORM-VET 2012).

Table 1. Total sales, in kilograms of active substance, of antimicrobial veterinary medicinal products for therapeutic use in farmed fish in Norway in the period 2000-2012. (NORM/NORM-VET, 2013). Note, this is for farmed salmon and farmed trout.

Group of substances/active substance		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Tetracyclines:	Oxytetracycline	15	12	11	45	9	8	0	19	23	40	10	1	1
Amphenicols:	Florfenicol	148	109	205	154	111	202	302	139	166	303	275	336	191
Quinolones:	Flumequine	52	7	5	60	4	28	7	18	1	1	0	0	0
	Oxolinic acid	470	517	998	546	1,035	977	1,119	406	681	926	308	212	1,399
Combinations:	Spectinomycin + lincomycin (2+1)	0	0	0	0	0	0	50	66	70	43	57	0	0
Total		**685**	**645**	**1,219**	**805**	**1,159**	**1,215**	**1,478**	**648**	**941**	**1,313**	**649**	**549**	**1,591**

Data from the Norwegian Veterinary Institute in Table 1 show the dominant antibiotics used are a quinolone (oxolinic acid) and an amphenicol (florfenicol) (NORM/NORM-VET, 2013). Eighty eight percent of the antibiotics used are quinolones, which are listed by the WHO as critically important to human health, and are also included in their top-three critically important antimicrobials for human health (WHO 2009).

The use of antibiotics critically important to human health, results in a high concern in the Seafood Watch criteria, but the large decrease in the volumes used has generally been considered a success story in farm production. Additionally, the use per ton of production in Norway is relatively low, nevertheless, the 2012 figure of 1,591 kg is an increase of nearly 300% on 2011, and the highest use in the last twelve years.

Pesticides

The term “pesticide” is used below in the general context of a substance used for destroying organisms harmful to cultivated plants or animals. The term “therapeutant” or “drug,” or “medication” is also commonly used and may be specifically used in the registration of some “pesticide” compounds. The primary use for this group of compounds is the treatment of parasitic sea lice. The Norwegian Institute of Public Health collects data on pesticide use, but does not make it publically accessible.

Table 2 shows the use of a number of groups of sea lice pesticides in Norway and their volume from 2002 to 2011. It is important to note that comparing use across treatments is not valid due to the different quantities of active ingredients required per treatment, but the data show some interesting trends. Firstly, the large reduction in the use of emamectin benzoate[7] from 2008 to 2010 is accompanied by the reintroduction of three treatments, which had previously been used in the mid-1990s: azamethiphos[8], diflubenzuron[9], and teflubenzuron[10] (Torrissen et

[7] Emamectin benzoate – trade name Slice
[8] Azamethiphos - trade name Salmosan
[9] Diflubenzuron – trade name , Releeze vet, Lepsidon
[10] Teflubenzuron – trade name Ektoban, Calicide

al., 2013). This is also accompanied by dramatic increases in the use of cypermethrin[11], deltamethrin[12] and hydrogen peroxide. A large drop in teflubenzuron from 2010 to 2011 was accompanied by a large increase in emamectin use.

Table 2. Pesticide use in Norwegian salmon aquaculture for the control of parasitic sea lice in kg active product, and mt for hydrogen peroxide. Data for 2002-2010 from Norwegian Institute of Public Health reported in FHL (2011), and 2011 from Torrissen et al. (2013).

Pesticide	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Azamethiphos	-	-	-	-	-	-	66	1,884	3,346	2,437
Cypermethrin	62	59	55	45	49	30	32	88	107	48
Deltamethrin	23	16	17	16	23	29	39	62	61	54
Diflubenzuron	-	-	-	-	-	-	-	1,413	1,839	704
Emamectin benzoate	20	23	32	39	60	73	91	41	22	105
Teflunbenzuron	-	-	-	-	-	-	-	2,028	1,080	26
Total	105	98	104	100	132	132	218	5,516	6,454	3,374
Hydrogen peroxide	-	-	-	-	-	-	-	308 mt	3,071 mt	3,144 mt

Note – this table highlights the increasing use over time. It is not relevant to compare quantities used across different chemicals due to the different quantity of active ingredients required per treatment.

Based on these figures, the Norwegian Seafood Federation reported, "*While the total consumption of medications to treat salmon lice has been stable for years, even with the increased* [farmed salmon] *production, we did see an increase in consumption in 2008. This increase was substantially larger in 2009, and rose further in 2010, when 6,454 kg total active substance, spread on the various drugs, was used*" (FHL 2011). The authors (FHL) believed this to be related to elevated lice amounts in the fall of 2009, but also to reduced sensitivity to certain medications and the need for repeated treatments and higher doses in conjunction with inadequate effects (i.e., resistance). FHL (2013) reported that sales of salmon lice medicines increased again in 2012. The use of hydrogen peroxide (considered to break down rapidly in the environment) also increased substantially in 2010, but due to its limited efficacy and stressful application to the fish, the increasing use is a clear indication of the loss of effectiveness of historically preferred treatments such as emamectin benzoate. Johansen et al. (2013) found that the low use of Slice is almost certainly linked to a serious resistance situation and the dominating use of pyrethroids and azamethiphos give grounds for concern.

In recent years, the efficacy of several historically successful sea lice treatments has been on the decline and, while there are recent indications that immunostimulants provided in feeds may reduce the need for chemical intervention, salmon farming remains largely dependent on the use of pesticides that are toxic at very low concentrations (Covello et al., 2012). According to Johansen, (2013) a survey of pharmaceutical use per farming site indicates a high risk of resistance development (Johansen 2013). The survey also indicates the development of

[11] Cypermethrin – trade name Excis and Beta Max
[12] Deltamethrin – trade name Alpha Max

treatment resistance in sea lice has become problematic for salmon-farming regions around the world. Increased tolerance has been noted in sea lice for dichlorvos, azamethiphos, emamectin benzoate, deltamethrin and cypermethrin in Norway (Borno and Sviland 2010, Jones et al., 2013).

The Norwegian Veterinary Institute (referencing the Norwegian Authority for Food Safety) reported an increasing degree of reduced sensitivity (i.e., increased resistance) to anti-lice treatments in 2010, with the situation varying considerably from region to region. In Lofoten and Salten, reduced sensitivity to emamectin benzoate and pyrethroids (deltamethrin and cypermethrin) was reported in several sites; areas with multi-resistant salmon lice can now be found in multiple regions and there is generally widespread reduced sensitivity (Borno and Sviland 2010). The track record in Table 3 for emamectin benzoate (which, due to its ease of application and effectiveness, had been the most widely used treatment) is indicative of increasing use followed by overuse, development of resistance and the subsequent decline in use.

According to Jones et al. (2013), "*Typically, by the time drug resistance becomes evident in a population through documentation of multiple treatment failures, the resistant alleles are already prevalent in the population. Genes conferring resistance to a particular parasiticide likely already exist in the population and resistance emergence is inevitable because the use of the treatment selects for these resistance factors. Once resistance frequency is sufficiently high enough to detect, resistance is already rapidly spreading through the population."*

Therefore, while regulatory control of antibiotics combined with the introduction of effective vaccines and better biosecurity have enabled the salmon industry in Norway to reduce its long-term antibiotic use, although the same cannot be said for the use of sea lice pesticides, which is increasing and could be argued to be in crisis. The use of various wrasse species as a biological control for sea lice is increasing in Norway[13] and has the potential to significantly reduce chemical use. Individual farms report the ability to control lice without pesticides, however, the data in Table 3 and more recent publications quoted above clearly show that this method is not yet reducing overall chemical use in Norway.

Regarding evidence of impacts, Burridge et al. (2010) concluded, "*Data generally suggest that negative impacts from anti-louse treatments, if they occur, are minor and will be restricted in spatial and temporal scale. However, published field data are rare.*" Subsequent to that study, the Norwegian Institute for Water Research (NIVA) (on behalf of the Norwegian Climate and Pollution Agency (Klif)), investigated the increasing use of diflubenzuron and teflubenzuron in Norway in 2010. Both of these pesticides had previously been used in Norway, but a voluntary ban on their use began at the end of the 1990s due to suspected adverse environmental effects (Langford et al., 2011). There are no environmental quality standards (EQS) for these pesticides

[13] Directorate of Fisheries, statistics. http://www.fiskeridir.no/english/statistics/norwegian-aquaculture/aquaculture-statistics/atlantic-salmon-and-rainbow-trout

in Norway. Using EQS values from Scotland, Langford et al. (2011) showed levels of both diflubenzuron and teflubenzuron exceeded them, and concluded "*The dissolved levels of diflubenzuron detected in water samples collected at the farms, and up to 1 km away, are sufficiently high to pose a risk to aquatic organisms.*" They also expressed concern that crab, shrimp and blue mussels are being exposed to both diflubenzuron and teflubenzuron and noted a potential risk to shrimp could reasonably be extrapolated to any species that undergoes molting in its lifecycle.

Although emamectin benzoate use is being reduced, the quantity is still significant and a study in British Columbia raises concerns about the potential for accumulation in sediments up to 150 m from the farms, and the impacts on commercial crustacean species (in this case spot prawns) and on more sensitive non-commercial species (DFO 2012).

Antifoulants: copper is the dominant antifoulant used to reduce the growth of a variety of encrusting organisms on the nets. Copper's use varies between countries, but the majority of farms in Norway are considered to use copper-treated nets (96% of Marine Harvest's Norway nets were copper-treated in 2011 (Marine Harvest 2012). While copper is highly toxic to a variety of aquatic life and elevated levels have been found beneath salmon farms in many production regions, understanding the impact on non-target organisms is hampered by the complex chemical interactions of copper with other metals and organic matter in the substrate, in combination with the equally complex nature of degradation or resuspension and subsequent transport beyond the farm area (Burridge et al., 2010). While Louckes et al. (2012) reported the levels of copper in both sediments and sea surface microlayer at a site in Nova Scotia exceeded guidelines for protection of marine life and persisted in the sediments for 27 months, current fallowing practices and the increasing use of remote net cleaning sites indicate that these results from a site that had been continuously active for 15 years are likely to be at the extreme end of the spectrum.

Within the uncertainty of impacts of both pesticides and metals (e.g., copper and zinc) typically studied to date at the farm level, Burridge et al. (2010) add a concern about cumulative impacts of multiple treatments from multiple farms, stating, "*No studies (lab or field) have adequately addressed cumulative effects. Salmon farms do not exist in isolation*." A key strategy of sea lice management is the increasing use of coordinated area treatments, during which time the likelihood of cumulative impacts from multiple treatments on multiple farms in the same area appear to be greatly increased.

Chemical Use Criterion- Conclusions and Final Score

In conclusion, while antibiotic use in Norway is generally considered to be low, the total 1.5 mt used in 2012 was a 300% increase on 2011, and was dominated (88%) by antibiotics considered to be critically important to human health. The use of critically important antibiotics leads to an initial score of zero in the Seafood Watch criteria, but the low total use increases this score to 1 out of 10. Pesticide use is substantial and increasing and more toxic alternatives have been introduced due to overuse and resistance of existing treatments. Resistance to multiple treatments is evidence of over-use and poor management. There is some evidence of impacts on a variety of non-target species distant to the farm, and an unknown potential for cumulative impacts from coordinated treatments at multiple farms. According to the scoring criteria, confirmed cases of resistance results in a score of 2 out of 10, and negative impacts beyond the farm result in a score of zero. As the impacts are uncertain and potentially minor, the same score of 1 out of 10 is most appropriate. Therefore, overall, the Chemical Use criterion score is 1 out of 10.

Criterion 5: Feed

Impact, unit of sustainability and principle

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

Feed parameters	Value	Score	
F5.1a Fish In: Fish Out ratio (FIFO)	1.80	5.50	
F5.1b Source fishery sustainability score		-3.00	
F5.1: Wild Fish Use		4.96	
F5.2a Protein IN	315.9		
F5.2b Protein OUT	169.0		
F5.2: Net Protein Gain or Loss (%)	-47.5	5	
F5.3: Feed Footprint (hectares)	11.2	6	
C5 Feed Final Score		**5.23**	**YELLOW**
Critical?	NO		

Note – the protein IN/OUT values in this table relates to the NOFIMA/FHL data. Other final values are averaged with the feed company data - see below.

Fishmeal and oil inclusion in salmon feeds continues to be replaced by increasing levels of alternative crop protein or oil ingredients. Data from the Norwegian Seafood Federation and provided by a large salmon feed producer show that, from first principles (i.e., ignoring other uses of associated fishmeal), 1.8 mt of wild fish would need to be caught to produce one tonne of farmed salmon. There is a net edible protein loss of 47.5%, but the high inclusion level of crop ingredients (compared to marine or terrestrial animal ingredients) results in a moderate total feed footprint of 11.2 hectares per tonne of production. While salmon is (arguably) relatively more efficient than other livestock species, overall, the ongoing net nutritional losses result in a moderate final feed score of 5.23 out of 10.

Justification of Ranking

The Norwegian aquaculture industry used 1.7 million mt of feed in 2012 (FHL 2013), and salmon farming used a large majority (for example, 1,236,000 mt in 2010 according to NOFIMA (2011)). The goal of the Ministry of Fisheries and Coastal Affairs with respect to feed is: *"The* *aquaculture industry's needs for raw materials for feed will be met without over-exploitation of wild marine resources.*" While salmon can be considered the most efficient of intensively raised domesticated livestock (FHL 2013), this narrow goal appears to oversimplify the complex impacts of using an increasingly diverse array of marine and terrestrial feed ingredients.

The Seafood Watch criteria assess three factors—wild fish use (including the sustainability of the source), net protein gain or loss, and the feed "footprint" or global area required to supply the ingredients. For a full explanation of the calculations, see the Seafood Watch Aquaculture Criteria document[14].

Specific data on feed formulation and feed use is typically challenging to obtain. In Norway, general feed data are provided by the Norwegian Seafood Federation and NOFIMA (a Norwegian institute working on research and development for the aquaculture, fisheries and food industry in Norway), along with a large Norwegian feed company that provided salmon-specific feed information.

Factor 5.1. Wild Fish Use

Factor 5.1a Fish-in to fish-out ratio (FIFO)

In common with many aquaculture sectors, salmon feed formulators continue to replace fishmeal and fish oil from wild fish with alternative ingredients such as crop and/or land animal byproducts. According to the Norwegian Seafood Federation (FHL 2013) 67% of the feed in Norway in 2012 was comprised of vegetable material, including soya, sunflowers, rape seed and wheat.

According to NOFIMA, the FIFO ratio for fish oil and fish meal in Norwegian fish farming decreased from 7.2 and 4.4 respectively in 1990 to 2.3 and 1.4 respectively in 2010. When correcting for use of byproducts from capture fisheries, the 2010 values were 1.8 and 1.1 for fish oil and fish meal (NOFIMA 2011).

Independent calculations have also been made for this assessment. Two sources of data are available, firstly the Norwegian Seafood Federation Environmental Report (FHL, 2013), and secondly, a response to a questionnaire sent to a large feed company (that wished to remain anonymous). It is recognized that none of this data is verified, but due to the realities of feed production, most academic peer reviewed publications will also rely on similar survey-based data.

[14] http://www.montereybayaquarium.org/cr/cr_seafoodwatch/sfw_aboutsfw.aspx

Table 3. Feed data.

Parameter	FHL data	Feed company data
Fishmeal inclusion level	21%	21.1 %
Percentage of fishmeal from by-products[15]	31 %	23.9 %
Fishmeal yield (from wild fish)	Not specified (22% used)	Not specified (22% used)
Fish oil inclusion level	12 %	13 %
Percentage of fish oil from byproducts	24 %	22.8 %
Fish oil yield (from wild fish)	Not specified (5% used[16])	10.6%
Economic Feed Conversion ratio (eFCR)	1.2	1.3
Calculated values		
Fish In : Fish Out ratio for fishmeal	0.84	0.93
Fish In : Fish Out ratio for fish oil	2.37	1.23
Seafood Watch FIFO score (0-10)	4.08	6.92

The economic feed conversion ratio is an important aspect of these calculations. The values provided are broadly consistent with the estimates and predictions of Tacon et al. (2011) of 1.3 in both 2010 and 2015.

While the fishmeal FIFO values are all similar between the two data sources (FHL = 0.84 and Feed Company = 0.93), the final FIFO value is driven by the higher fish oil FIFO values in which there is considerable variation (FHL = 2.37 and Feed Company = 1.23). The fish oil inclusion levels are similar (12% and 13%), as are the inclusion levels of byproducts (24% and 22.8%), but the main driver of the variation is the higher fish oil yield value (i.e., the amount of fish oil obtained from processing wild caught fish) in the feed companies more specific data.

While the data provided by the feed company is considered accurate, it cannot be assumed to relate to all Norwegian production, due to the variation in the species composition of fishmeal used between feed companies (for example, a higher use of blue whiting or Norway pout that have a low oil content would reduce the yield value and increase the resulting FIFO value).

An average of the two fish oil FIFO values is 1.8 and this agrees with the value from NOFIMA (2011). Therefore this has been selected as the final FIFO value for this assessment. This means that from first principles, 1.8 pounds of wild fish would need to be caught to grow one pound of farmed salmon. This generates a score of 5.5 out of 10 in the Seafood Watch criteria, and reflects ongoing reduction of fishmeal and fish oil use and feeding efficiency per unit of farmed salmon production. This result is slightly ahead of predictions in the key reference paper

[15] While it can be argued that byproducts of wild caught fish processed for human consumption (heads, guts, skin, fins etc.) have the same ecological cost of production as the fish fillets that we value as food, the current socially logical use of these non-edible ingredients to grow more food (farmed fish) means that they do not currently contribute to the FIFO scores.

[16] 5% value is specified in the Seafood Watch criteria

(although now, perhaps, somewhat dated) by Tacon and Metian (2008) who, at that time, forecasted the FIFO ratio for salmon farming would reduce from 7.5 in 1995 to 3.0 in 2010, and to 2.0 in 2015.

Factor 5.1b – Source fishery sustainability

According to FHL (2013), the major species used for fishmeal and oil in Norwegian aquaculture are anchovy, capelin and sprat; these species have FishSource[17] scores >6 and many scores >8. According to FHL, the majority of these fisheries are certified to the International Fishmeal and Fish Oil Association's (IFFO) Responsible Sourcing scheme. Therefore, on the whole, the fisheries used are generally considered well-managed. Consequently, the sustainability score allocated is -3 (where zero indicates fully sustainable fisheries and -10 is associated with demonstrably unsustainable fisheries).

Final Wild Fish Use score

The final wild fish use calculation applies the sustainability score as a penalty factor on the FIFO score such that using less wild fish from more sustainable fisheries leads to a better final score. As the FIFO value is moderate, and the fisheries are relatively well-managed, the penalty is small (0.54) and receives a final score of 4.96 out of 10 (see the criteria document for further information on these calculations). Norwegian salmon farming is, therefore, considered to represent a moderate use of wild fish.

Factor 5.2. Net Protein Gain or Loss

According to NOFIMA, the 1,236,000 mt of feed used in 2010 contained 460,853 mt of protein, which yielded 121,807 mt of edible protein in the form of farmed salmon (NOFIMA 2011). While this represents a net loss of nearly 75% of the protein provided in the feed, the Seafood Watch criteria includes a more nuanced set of calculations that account for the use of the non-edible proteins in the feed, the conversion of crop proteins to higher quality animal proteins, the edible yield of the harvested fish, and also the subsequent use of protein from the non-edible portion of the harvested fish to produce other forms of food.

Table 4 includes calculations from NOFIMA/FHL data and the specific feed company data. For example, according to FHL (2013), 21% of the feed is fishmeal and 31% of the fishmeal comes from byproducts. Assuming a protein content of 65% for fishmeal[18] and a total feed protein content of 37.3% (NOFIMA, 2011), this means 11.3% of the total protein comes from byproducts and the remaining 88.7% comes from potentially edible marine and crop sources. According to the FAO (Tacon, Hasan et al., 2011), the crop ingredients primarily used in Norwegian salmon farming are soybean meal, wheat, wheat gluten and sunflower seed meal. This is similar to soya, sunflowers, rape seed and wheat listed by FHL (2013). These are all considered to be edible by humans, therefore, the great majority of protein— nearly 90%— used in Norwegian salmon feeds is potentially edible by humans. Figures calculated in the same way from the feed company data are also shown for comparison.

[17] www.fishsource.com

[18] Based on Peruvian anchovy from the International Fishmeal and Fish oil Organization http://www.iffo.net/downloads/Nutrient%20Analysis/Tables%20for%20UK%201981%20NA.pdf

Table 4. Protein data.

Parameter	NOFIMA/FHL data	Feed company data
Protein content of feed	37.3%	35.5%
Percentage of total protein from non-edible sources (byproducts etc.)	11.3%	9.2%
Percentage of protein from edible sources	88.7%	90.8%
Percentage of protein form crop sources	63.4%	69.0%
Feed Conversion ratio	1.2	1.3
Protein INPUT per tonne of farmed salmon	315.9 kg	328.0 kg
Protein content of whole harvested salmon[19]	16.9 %	16.9 %
Percentage of farmed salmon by-products utilized	90 %	100 %
Utilized **protein OUTPUT** per tonne of farmed salmon	162.2kg	169 kg
Net protein loss	46.5 %	48.5 %
Seafood Watch score (0-10)	5	5

The edible yield of farmed salmon is considered to be 60%, with 90% of the non-edible by-products from the processing of the harvested farmed salmon being utilized for other food production purposes (FHL 2013), therefore, 90% of the harvested protein (both edible and non-edible) is included in the protein output (compared to 100% in the feed companies data). The two calculated values for net protein loss are very close (46.5% and 48.5%), and the average gives a 47.5% net loss of edible protein during the production of farmed salmon (much of the loss is excreted as ammonia, as discussed in the Effluent Criterion), and results in a moderate score of 5 out of 10.

Factor 5.3. Feed Footprint

By considering the grouped inclusion levels of marine, terrestrial crop and terrestrial land animal feed ingredients, this factor provides an approximate guide to the ocean and land area used per tonne of farmed salmon. NOFIMA (2011) estimates the total agricultural area used for production of Atlantic salmon in 2010 was 5440 km2, which is equivalent to half of the total cropland area in Norway. Data provided by the feed company show 34.1% of the feed ingredients are marine origin, and 61.1% are from terrestrial crops (the remaining 4.8 is considered to include vitamin and mineral premixes and processing aids). The FHL fishmeal and oil data total 33% marine and, assuming the same 4.8% allocation, 62.2% are assumed be from crop sources. Land animal proteins ingredients are not reported to be used in current Norwegian salmon production.

[19] Nofima (2011), quoting unpublished marine harvest data

Table 5. Footprint data.

Parameter	NOFIMA/FHL data	Feed company data
Marine ingredients inclusion	33 %	34.1 %
Crop ingredients inclusion	62.2 %	61.1 %
Land animal ingredients inclusion	0 %	0 %
Ocean area (hectares) used per tonne of farmed salmon	10.3 ha	11.53
Land area (hectares)	0.28 ha	0.3 ha
Total area (hectares)	10.58 ha	11.8
Footprint score (0-10)	6	6

The area values calculated by the Seafood Watch criteria are very similar to the 0.33 ha of land area and 11.5 ha of ocean per ton calculated by NOFIMA (2011). An average of the two resulting total areas equals 11.2 ha and equates to a footprint score of 6 out of 10 in the Seafood Watch criteria. This is considered the final score for this factor.

Feed Criterion - Conclusions and Final Score

From first principles, 1.8 mt of wild fish would need to be caught to produce one ton of farmed salmon. Thus, there is a net edible protein loss of 47.5%, but the high inclusion level of crop ingredients (compared to marine or terrestrial animal ingredients) results in a moderate total feed footprint of 11.2 hectares per tonne of production. The final feed score combines the three factors with an increased weighting on the FIFO score. All three scores are very similar (4.96, 5 and 6), and the final feed score is 5.23 (out of 10).

Criterion 6: Escapes

Impact, unit of sustainability and principle

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

Escape parameters	Value	Score	
F6.1 Escape Risk		2.00	
F6.1a Recapture and mortality (%)	13%		
F6.1b Invasiveness		1.5	
C6 Escape Final Score		**2.00**	**RED**
Critical?	NO		

The design and construction of net pens has improved and total reported escape numbers have decreased. Low escape numbers were reported in both 2012 and 2013, but a risk of escape from catastrophic losses or more chronic “leakage” remain, along with uncertainty about unreported losses. Norway has over 200 rivers supporting native Atlantic salmon populations. Many of those populations have displayed moderate to high frequencies of domesticated farmed escapees on the spawning grounds for two decades or more, and interbreeding of escapees and wild salmon has led to highly significant genetic impacts in a number of Norwegian wild salmon populations and remains a high concern. The escape criterion score is 2 out of 10.

Justification of Ranking

On a global basis, hundreds of thousands of domesticated farmed Atlantic salmon escape into the wild each year, and in Norway, many native Atlantic salmon populations have experienced large numbers of escapees on the spawning grounds for the past 15–30 years (Glover et al., 2012). Norway alone has a farmed salmon population of 366 million fish[20], and in Norway’s densest salmon farming region, the Hardangerfjord, farmed salmon outnumber wild salmon by 5,000 times (Skaala et al., 2014). In several rivers, the recorded number of escaped farmed salmon has been high, even exceeding the number of wild salmon in some years. Escaped farmed salmon from Norway have also been found in the Arctic Ocean, suggesting that farmed Atlantic salmon that have escaped early during the post-smolt period may grow, migrate, and

[20] Statistics Norway, Aquaculture, 2011, Final Figures. www.sb.no

disperse throughout the ocean like their wild counterparts, and survive to adulthood (Jensen et al., 2013).

An investigation into the management of aquaculture made by the Office of Norway's Auditor General (Kosmo 2012) shows that because of persistently high figures for escaped fish, several rivers and watercourses have a high proportion of farmed fish among wild fish. In some areas, this has already affected the genetic distinctiveness of wild salmon, thus, the goal of reducing impacts that threaten the genetic diversity of salmon to a non-harmful level by 2010 has not been achieved. These aspects are elaborated in the context of the Seafood Watch criteria below

Factor 6.1a. Escape risk

Statistics Norway (Statistisk Sentralbyra) collect reported escapes statistics based on industry-reported figures. Reported escapes since the mid-1990s up to 2013 are shown in Figure 4.

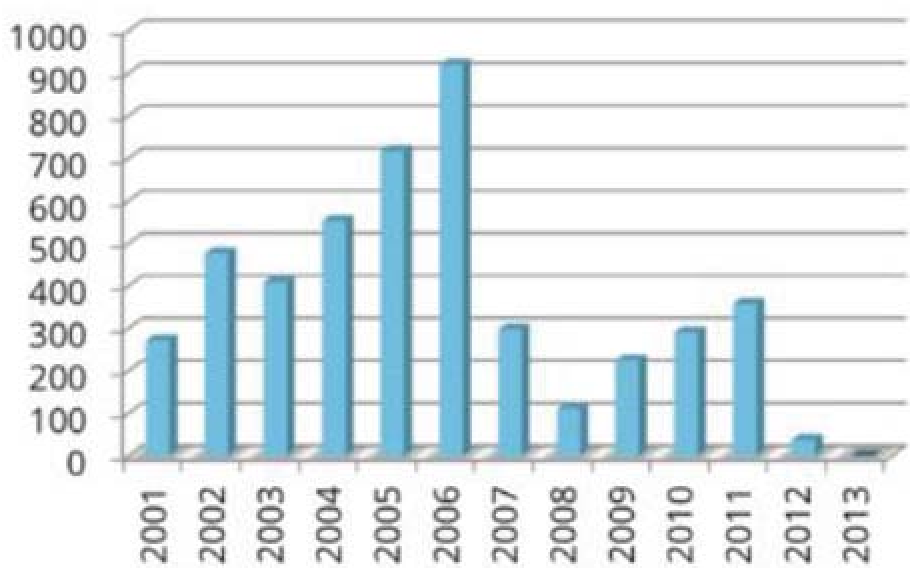

Figure 4. Reported farmed salmon escapes in Norway (in thousands) between 2001 and 2013 – data source Statistics Norway, graph copied from FHL (2013).

According to Jensen et al. (2010), correlative evidence suggests the large drop in total escapes after 2006 is associated with the implementation of Norwegian technical standard (NS 9415) for sea-cage farms (introduced in 2004), despite the substantial increase in the total number of salmon held in sea-cages during this period. Figure 4 shows reported escape numbers continued to be substantial in 2010 and 2011 and the Norwegian Seafood Federation (FHL) stated, "*It is therefore regrettable that in the first part of 2011, there have been several escapes, and that preliminary reports indicate an increased proportion of escaped salmon [….] in several rivers in Central Norway*" (FHL 2011).

Reported escape numbers in 2012 and 2013 are much lower, but the escape of 175,000 salmon in a single event in February 2011[21], and the possible escape of up to 55,000 fish in January 2014[22] clearly demonstrate the ongoing potential for large scale escape events. While the 2012 and 2013 figures are encouraging, and according to Piccolo and Orlikowska (2012), "*The frequency and magnitude of escape events might be expected to decrease as industry practices improve,"* the same authors also caution, *"Due to the nature of salmon farming, however, large accidental escapes are likely to continue to occur sporadically*."

In addition to large or catastrophic reported escape events, the "trickle" or "drip" losses are also potentially significant, and are generally considered to go unreported (Taranga et al., 2011). Skilbrei and Wennevik (2006) note small-scale unreported escape events may make up a large portion of the total escaped farmed fish. In addition, the lack of a scientific, nationally coordinated monitoring program for escaped farmed fish, with predictable funding, is a serious problem for management of fish farming and of wild salmon (Skaala et al., 2014a).

With further regard to the accuracy of these figures, FHL (2011) also states there are "*many varying figures in different contexts over the amount of fish that escape from Norwegian fish farms. Common to many of them is that they are based on guesswork and more or less plausible estimates.*" In addition, Norway's IMR states, "*There are reasons to believe that the numbers of escaped farmed fish are higher than indicated by these* [industry reported] *figures and that there are more escapes of salmon in the smolt phase, which are not included in these statistics*" (Taranga et al., 2011).

Norway's Ministry of Fisheries and Coastal Affairs has established the Aquaculture Escape Commission aimed at keeping escapes to an absolute minimum and, while Norway can be credited with leading the way on the design of sea cages and in developing international standards for their construction, FHL (2011) also states, "*In 2010, human errors seems to have caused a higher percentage of escapes.*" According to Thomassen and Leira (2012), "*There is still much room for improvement in relation to verified structural design procedures and computerized tools for structural analysis. To a large extent, they can be regarded as not being in accordance with the state-of-the-art of structural analysis and design for more traditional types of marine structures*."

It is clear that Norway is attempting to address these problems and FHL issued the following five objectives in April 2011[23]:

1. As from 2012, salmon shall be tagged/marked so that escaped farm salmon that are caught can be traced back to the owner.
2. It shall be mandatory to use an underwater camera, ROV or diver to inspect the nets in hazardous operations.

---

[21] www.intrafish.com 27 September 2011 "Salmar escape: a tiny affair"
[22] Reported at www.intrafish.com Jan 29 2014 "Salmon escape from Nova Sea Farm"
[23] Reported at www.intrafish.com April 12 2011 "Norway launches campaign to fight escapes, lice"

3. Contingency preparedness for recapture of escaped salmon shall be extended.
4. A producer must pay NOK 500 (€64.17/$91.93) per escaped salmon that is caught in rivers, plus analysis costs.
5. NOK 30 million (€3.9 million/$5.5 million) is allocated to a fund that will finance the task of retrieving escaped farm salmon from rivers.

As of January 1, 2012 the maximum allowance of number of fish-per-net is 200,000, and stricter regulations regarding technical standard for floating fish farms, the so-called NYTEK ("new technology") were introduced.

The information provided above demonstrates the basic open net pen farming methods used in Norway (and all major production regions) continues to represent a high risk system for escapes. The ongoing potential for the escape of hundreds of thousands of fish along with potentially substantial unreported trickle losses would dictate a basic score of zero in the Seafood Watch criteria. However, best management practices are in place and escape numbers overall appear to be reducing on a per-ton-of-production basis. The initial escape risk score is, therefore, improved to 2 (out of 10), but recognizes the substantial potential for ongoing improvement with further demonstrable gains in containment and confidence in reported escape numbers.

Recaptures and mortality

Evidence of escapee recaptures or direct mortality at the escape site improves the Seafood Watch escape score on a linear basis.

While academic studies (such as those by Skilbrei et al., 2010; Chittenden et al., 2011) show that up to 80% of 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, actual recapture efforts and success rates by the farms themselves at the escape sites are poorly reported. 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 and Jorgensen 2010; Olsen and Skilbrei 2010) and, according to Chittenden et al. (2011), recapture efforts need to be immediate and widespread to mitigate farm-escape events. This is not yet considered to be the case in Norway, and statistics on recaptures are not publically reported. As noted above, the lack of a scientific, nationally coordinated monitoring program for escaped farmed fish, with predictable funding, is a serious problem for management of fish farming as well as of wild salmon (Skaala et al., 2014a).

According to Skilbrei and Jorgensen (2010), a fishery that targets escapees within 500 m of the fish farm, as required by regulation, will not be effective. FHL report that, while concerted efforts can achieve an estimated recapture rate of over a third, the registered recapture of

escapees remains well under 10% (Trude Nordli, FHL, personal communication, 2012). Efforts to improve identification of farm escapees continue.[24]
Although the meta-analysis of Glover et al. (2012) indicates high mortality of escaped farmed salmon, the 2006 references on which this assumption is based now form part of a broader literature showing the highly variable survival of escapees is linked to the size and age at escape, the location, the time of year, and the presence of significant numbers of predators (Skilbrei and Jorgensen (2010), Hansen and Youngsson (2010), Whorisky (2006) and Olsen and Skilbrei (2010)). In general, Skilbrei and Jorgensen (2010) note that little is known about the general performance and causes of mortality of fish after they escape. As noted above, escapees recaptured in the Arctic Ocean suggest that farmed Atlantic salmon that have escaped early during the post-smolt period may grow, migrate, and disperse throughout the ocean like their wild counterparts, and survive to adulthood (Jensen et al., 2013).

While it is clear that, in most escape events, significant direct mortalities are likely to occur at the escape site or immediately afterwards, there is little numerical data in the literature on which to base a confident mortality percentage. The same can be said for the recapture efforts.

Results from Skilbrei et al. (2010) show that, on average, over their five simulated escape events, 15.2% of fish “disappeared” or were unaccounted for (i.e., they stopped sending signals to the receivers), and 8.2% were recaptured within 10 days of the escape event, however, of those fish that “disappeared” some may have been captured but not reported, some may have moved out the area undetected, and some may have entered the river (where there were no receivers).

With little data beyond targeted scientific studies with which to specify practical recapture rates or mortality rates at the escape site, there is no evidence with which to set a specific score for this aspect of the criteria. In addition, recapture efforts, which reportedly need to be immediate and widespread, are apparently neither. The data presented below (Factor 6.1b) from Taranger et al. (2011) also clearly demonstrate that too many escaped fish are still entering Norwegian rivers and, therefore, there is little to suggest that recaptures or direct mortalities significantly reduce the overall escape problem in Norway, as highlighted by the Office of Norway’s Auditor General in Kosmo (Kosmo 2012) (quoted above).

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

---

[24] “New fingerprint system tracks, escaped farmed salmon”; Intrafish, March 3, 2014. www.intrafish.no

Factor 6.1b. Impact (invasiveness)
Wild Atlantic salmon are characterized by highly significant population genetic structuring. This reflects evolutionary relationships among populations, including the potential for adaptive differences. After several generations of domestication, farmed salmon have become genetically differentiated from their wild counterparts (Fraser et al., 2010) and show several different physical and behavioral traits (Karlsson, Moen et al., 2011)[25]. Consequently, the large-scale invasion of Atlantic salmon populations by domesticated farmed escapees represents one of the most striking examples of human-mediated increased straying rates for any organism. This has raised global concerns for the fitness of native populations (Glover et al., 2013). The same authors note genetic changes in native Atlantic salmon populations have been observed in populations in Ireland, North America, and Norway as a result of introgression of farmed escapees.

Norway has over 200 rivers supporting native Atlantic salmon populations. Many of those populations have displayed moderate to high frequencies of domesticated farmed escapees on the spawning grounds for two decades or more (Glover et al., 2013). In several rivers, the recorded number of escaped farmed salmon has been high, even exceeding the number of wild salmon in some years (Skaala et al., 2014c).

Some areas with high densities of salmon farms, such as the Counties of Hordaland, Sogn og Fjordane, Møre og Romsdal and parts of Rogaland in particular, appear to be seriously affected (Skaala et al., 2014c). The same authors reported a recent survey of 481 Atlantic salmon populations in Norway, which suggested escaped farmed salmon, salmon lice and hydroelectric power are the three major factors that impact production[26]; while 340 populations are believed to be negatively affected by escaped farmed salmon, 187 by salmon lice, and with hydroelectric power production affecting 110 populations.

Data compiled by Norway's IMR (Taranger et al., 2011) show that over half the fish returning to some Norwegian regions, in some years, may be farm escapees (the highest percentage in 2009 was 55.6%). Zhang and Glover (2013) show that escaped farmed salmon caught in Trondheim Fjord originated from multiple farms and suggested many of the fish captured in the late period probably represent the start of the general yearly migration of farmed salmon that have escaped from a variety of farms along the Norwegian coastline to fresh water [rivers].

The goal of the Ministry of Fisheries and Coastal Affairs in relation to genetic interaction is: "*Aquaculture will not contribute to permanent changes in the genetic characteristics of wild fish stocks.*" However, Norway's Auditor General stated, "*A goal of reducing impacts that threaten the genetic diversity of salmon to a non-harmful level by 2010 has not been achieved due to persistently high figures for escaped fish,"* and that *"several rivers and watercourses have a high proportion of farmed fish among wild fish that in some areas has already affected the genetic*

[25] If further information is required, both papers (Fraser 2010, and Karlsson, 2011) list and discuss the differentiated characteristics
[26] Further survey details are available at www.lakseregisteret.no

distinctiveness of wild salmon" (Kosmo 2012). In addition, according to Besnier, Glover et al. (2011), "*The ability to detect genetic introgression is reduced when multiple farmed strains escape* (as is always the case) *and analysis is thus likely to underestimate the true level of genetic introgression."*
Glover et al. (2012) drew two conclusions:

1. The majority of the historical population genetic structure [of wild salmon] throughout Norway still appears to be retained, suggesting a low to modest overall success of farmed escapees in the wild.
2. Genetic introgression of farmed escapees in native salmon populations has been strongly population-dependent, and it appears to be linked with the density of the native population.

However, these authors also noted several of the populations studied displayed close to significant temporal genetic changes, and also that it is possible their estimated level of within-population temporal genetic changes is lower than the true level of genetic introgression by farmed escapees.

Overall, the evidence of genetic impacts in multiple regions of Norway, combined with the large scale replacement of wild fish with farmed fish in some rivers, dictates the lowest score (zero out of five) for Part A of this factor in the Seafood Watch criteria. The concerns of Norway's IMR and the Auditor General support this low score, as does the continuing domestication and genetic differentiation of farmed versus wild fish and ongoing genetic impact. It can be hoped that a continuation of the low escape numbers in 2012 and 2013 will reduce this impact in the long run, but it is too early to have any confidence that these low escape years represent a changing regime.

In addition to the genetic impacts, escaping farmed salmon can have a number of 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; and Olsen and Skilbrei 2010). While many studies continue in Norway, in earlier proceedings, Hansen and Windsor (2006) noted escapees can have a direct impact on wild populations in the following ways:

- Competition for food
- Competition for space
- Direct displacement of wild fish
- Competition for breeding partners
- Predation by farmed fish of wild fish
- Increased size at age (and life stage e.g., parr/smolt) can influence social encounters

As a result, the score for the ecosystem aspects (part C of Factor 6.1b) is 1.5 (out of 5) and, combined with the genetic impact score (0), leads to an invasiveness score of 1.5 out of 10 (see scoring annex for further details).

Escapes Criterion - Conclusions and Final Score

Overall, although the considerable reduction in escape numbers is to be commended, the continued risk of large and small scale escape events and the substantial numbers of wild fish present among wild populations, combined with the demonstrated negative genetic and ecological impacts on wild salmon populations results in an overall escape score of 2 out of 10.

Criterion 7: Disease, Pathogen and Parasite interactions

Impact, unit of sustainability and principle

- *Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same waterbody*
- *Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites*
- *Principle: aquaculture operations pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.*

Pathogen and parasite parameters	Score	
C7 Pathogen and parasite interaction	1.00	
C7 Disease; pathogen and parasite Final Score	**0.00**	**RED**
Critical?	**NO**	

Farmed salmon outnumber wild salmon by a factor of up to 700; therefore, the disease status of the farm stock has the potential to significantly impact that of the relatively small wild salmon populations as well as other wild salmonid species (e.g., sea (brown) trout or Arctic char). Although viral and bacterial disease cause the greatest production problems in Norway, sea lice parasites are the greatest concern for wild Atlantic salmon. While it could be argued that Norway is making considerable efforts to reduce impacts of pathogens and parasites on wild salmonids, these are not fully effective for wild salmon, and the impacts on wild sea trout remain a major concern. On the basis of the multiple official conclusions from within Norway itself, in addition to the potential for additional secondary impacts such as increased predation risk in all regions, the score for the disease criterion is zero (out of ten) as amplification of parasites on salmon farms leads to significant population declines in wild sea trout in Norway.

Justification of Ranking

Norway has the world's largest stocks of wild Atlantic salmon yet the standing stock of farmed Atlantic salmon on the Norwegian coast outnumbers them by factors of 250–700 (Johansen et al., 2011). Therefore, the disease status of the farm stock has the potential to significantly impact that of the relatively small wild salmon populations as well as other wild salmonid species (e.g., brown trout or Arctic char).

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

With respect to potential impacts on wild salmonids (in addition to practical production problems), there are two main areas of concern; these are firstly, bacterial and viral pathogens, and secondly, parasites of which sea lice are the focus. Johanssen et al., (2011) conclude that, with the possible exception of salmon lice, there are few reliable data sets on the distribution of fish pathogens in wild populations, and the knowledge of interactions with wild reservoirs is thus limited. While both groups will be mentioned in the assessment below, the well-documented impacts of parasitic sea lice will be the focus of the discussion.

For a review of salmon disease interactions, see Hammel et al. (2009).

Bacterial and Viral Pathogens

On a national scale, viral infections remain the most significant diseases in Norwegian aquaculture (Olsen 2012). According to Rimstad et al. (2014), owing to the high-density monoculture of hosts, the numerous possible routes of transmission and suboptimal protection by available vaccination for several viral diseases, viruses may thrive in modern salmonid aquaculture. While farm vaccines have reduced the impact of several key salmon pathogens, Johansen (2013) reports disease continues to represent one of the most important challenges to the aquaculture industry and viral diseases continue to dominate the national situation. Norway's IMR reports four viral pathogens have dominated the disease picture in Norwegian fish farming in recent years: infectious pancreatic necrosis (IPN), pancreas disease (PD), heart and skeletal muscle inflammation (HSMI), and cardiomyopathy syndrome (CMS). It appears that fallowing, separating generations, zoning and other hygienic measures have not brought these diseases, or their spread, under control and the lack of effective vaccines renders control of these diseases difficult (Taranger et al., 2011). Table 6 below shows the track record of site infections with these viruses.

Table 6. Total number of sites 1998–2012 diagnosed with infectious salmon anemia (ISA), pancreas disease (PD), heart and skeletal muscle inflammation (HSMI) and infectious pancreatic necrosis (IPN). Table copied from Johansen (2013).

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
ISA	14	23	21	12	8	16	11	4	7	17	10	7	1	2
PD	10	11	15	14	22	43	45	58	98	108	75	88	89	137
HSMB						54	83	94	162	144	139	131	162	142
IPN				174	178	172	208	207	165	158	223	198	154	119
CMS						88	71	80	68	66	62	49	74	89

A non-pathogenic strain of infectious salmon anemia virus (ISA), referred to as ISA-HPRO, has been identified in Norway (Godoy et al., 2013) and is considered a precursor of more virulent strains, but although it is now considered prevalent (Lynstad et al., 2013), and outbreaks of pathogenic ISA cause mortalities in salmon farms, there has not been a report of mortality in wild fish populations anywhere in the world due to ISA (NOAA 2012).

Piscine reovirus (PRV) has recently been described as "*a newly discovered fish reovirus of anadromous and marine fish, ubiquitous among fish in Norwegian salmon farms*" (Kibenge et al., 2013). A number of studies have now linked PRV with the clinical disease HSMI, (Palacios et al., 2010; Finstad et al., 2012; Kibenge et al., 2013). And although history of published scientific literature on the virus is limited to a few years, Finstad et al. (2012) concluded PRV is almost ubiquitously present in Atlantic salmon marine farms.

Although these viral pathogens cause significant production problems in Norwegian salmon farms, there is limited evidence of impacts on wild salmonids in Norway. For example, Norway's IMR, 2011) suggests that transmission of pathogens from farmed to wild fish may occur, but they caution "*we do not know with certainty if outbreaks of disease in today's fish farms represent a source of infection/disease in wild fish,*" and indicate a generally low (occasionally moderate) risk of a negative impact on wild salmon from a range of diseases typically affecting salmon farms. Madhun et al. (2014) consider the role of escaped farmed salmon in spreading infectious agents from aquaculture to wild salmonid populations to be largely unknown, however, they also reported that recaptured escapees in the Hardangerfjord were infected with salmon alphavirus (SAV) and piscine reovirus (PRV), demonstrating that "double-virus-infected escaped salmon ascend a river close to the likely source farms, reinforcing the potential for spread of viruses to wild salmonids."

Biering et al. (2013) conducted sampling of wild fish in Norway and concluded that viral infectious agents that are highly prevalent within the Norwegian aquaculture industry, in particular IPNV and SAV, are found only in low prevalence in wild brood fish; however, they go on to state, "*The obvious question, as raised by McVicar in 1997 (McVicar 1997), is whether this is due to a low infection pressure or if wild fish infected by a virulent agent rapidly die and thus avoid to be sampled. Sequencing of viral agents found in wild fish may show if they are similar to virus found in farmed fish or if they are specific for wild populations, and thus contribute to answer this question."* With respect to PRV, Garseth et al. (2012) stated there are no indications that wild salmonids will develop HSMI as a consequence of PRV infection, but Biering et al. (2013) cautioned that as the virus is newly identified, it would be premature to make conclusions about the effects on wild fish at the present time.

Parasites – sea lice

For this Seafood Watch assessment, the impacts of parasitic sea lice on wild salmon and sea trout (anadromous brown trout, *Salm trutta)*in Norway are much more clearly defined (compared to bacterial and viral pathogens) and are considered to be a clear driver for the final score as discussed and concluded below. The Norwegian Veterinary Institute states (Olsen, 2012), "*Salmon louse infestation represents one of the most significant challenges to Norwegian aquaculture and one which must be resolved. While this is currently and primarily a problem for wild salmonids* (salmon and sea trout)*, with the continuing increases in incidence of treatment failure in aquaculture, it has the capability of escalating to become a serious threat to farmed fish*." For a review of sea lice dynamics, see Revie et al. (2009).

The scientific study of sea lice and the farm/wild fish interactions is voluminous, ongoing, and continually contentious. For example, the review by Torrissen et al. (2013), in a special issue of the Journal of Fish Diseases in March 2013, reflects the innate complexity and variability of the issues and concludes, "*Salmon lice originating from farms negatively impact wild stocks of salmonids, although the extent of the impact is a matter of debate.*"

The correction made by Jackson et al. (2013) on the meta-analysis by Krkosek et al. (2013) further highlights the ongoing controversy (at least with respect to impacts on wild salmon rather than sea trout) in the Northeast Atlantic. The meta-analysis by Jackson et al. (2013) concluded that while sea lice-induced mortality on outwardly migrating salmon smolts can be significant, it is a minor and irregular component of marine mortality in the stocks studied and is unlikely to be a significant factor influencing conservation status of salmon stocks. Conversely, Krkosek et al. (2013) commented on the analysis by Jackson et al., concluding that sea lice can have a large impact on salmon populations with a one-third loss of overall adult recruitment. This result is supported by the meta-analysis by Krkosek et al. of similar data from the NE Atlantic, which reported an estimated 39% loss of adult salmon recruitment as a result of sea lice infections during the smolt phase (Krkosek et al., 2013).

The review of Torrisson et al. (2013) concludes that the studies convincingly demonstrate the increased host density associated with salmon farming and that it promotes transmission and population growth of the salmon louse. Although the review indicates that non-aquaculture factors also contribute to the overall variation in seawater survival of the wild salmon population in the North Atlantic, the numerous studies from Ireland and Norway, in which salmon smolts were released either with or without a "protective" sea lice pesticide treatment (also assessed by Jackson et al.,2013 and Krkosek et al., 2013), indicated an odds ratio of 1.1:1-1.2:1 for sea lice treated Atlantic salmon smolt to survive sea migration compared to untreated smolts. This was considered to have a moderate population regulatory effect. Skaala et al. (2014c) reported a recent survey of 481 Atlantic salmon populations in Norway, which suggested escaped farmed salmon, salmon lice and hydroelectric power are the three major factors that impact production[27]; 187 populations were considered to be negatively affected by salmon lice.

Compared to wild Atlantic salmon, the impacts on wild sea trout are much clearer; sea trout are particularly vulnerable to sea lice as, unlike juvenile salmon that move relatively quickly offshore, sea trout stay in coastal waters and are, therefore, at risk of infection for longer periods over summer and autumn. Norway's IMR (Taranger et al., 2011) has demonstrated a much higher concern for sea trout, indicated by the number of regions in Norway where sea lice are considered to have a high likelihood of a population regulating effect on wild sea trout (Table 7 below). Taranger et al. (2013) also reported sea trout returning prematurely to rivers as a result of heavy lice infections

[27] Further survey details are available at www.lakseregisteret.no

Table 7. Risk assessment for sea lice considering the likelihood of a population-regulating effect on wild salmonids based on 2010 data (low = green, moderate = yellow, high = red). Numeric values represent the percentage of fish with more than 0.1 lice per gram of fish. Source Taranger et al., 2011.

Norwegian county	May/June (impacts on salmon)	July/August (impacts on sea trout)
Finmark	2	0
Troms	-	-
Nordland	0	18
Nord-Trondelag	15	36
Sor-Trondelag	2	29
More og Romsdal	0	4
Sogn og Fjordane	0	19
Hordaland	0	36
Rogaland	Premature	Premature
Agder	0	0

More recent studies in the densely farmed Hardangerfjord in Norway show compelling evidence for salmon lice-induced mortality of sea trout populations (Skaala et al., 2014b). While Asplin et al. (2014) suggest the abundance of salmon lice in the Hardangerfjord is potentially large enough to be a threat to the wild fish stocks, Skaala et al. (2014a) conclude that salmon lice are an important contributor to the high mortality of anadromous brown trout (sea trout) populations in the Hardangerfjord. Although management authorities and salmon farmers have introduced a number of measures to reduce the infection pressure of salmon lice on wild fish, infection levels continue to be high and appear to be closely associated with the localization and biomass of farmed salmon (Skaala et al., 2014c).

In Norway, 29 fjords and 52 rivers have been designated for protection in order to prevent the infection of important populations of wild salmonids with salmon lice of farm origin, but these only have an effect where fish farms are kept at a minimum calculated distance of at least 30 km distant; smaller protected fjords were less effective (Serra-Llinares et al., 2014).

At the industry level in Norway, the National Action Plan for prevention and control of salmon lice was published in February 2011, formalizing many activities already established from 2009 onwards. Since 2010, IMR has taken over coordination responsibility for the national salmon lice monitoring on wild salmonids. FHL (2011) noted that these prevention and control efforts resulted in very low lice levels in spring 2010 (the important period for migrating wild salmon and the focus of sea lice reduction efforts), however, they also reported that initial figures for spring 2011 indicated a high infection risk, and expressed concern regarding impacts on sea trout in summer and autumn in both years. Importantly, however, increasing levels of sea lice later in the summer and autumn are of higher concern for wild sea trout.

Figure 5 shows the annual variation in lice levels from 2002 to 2013 (data from www.lusedata.no) and shows that, while lice levels are relatively low during the out-migration period of wild salmon in spring (i.e., weeks 16 to 24), the lice load is much higher during the important period for wild sea trout later in the summer.

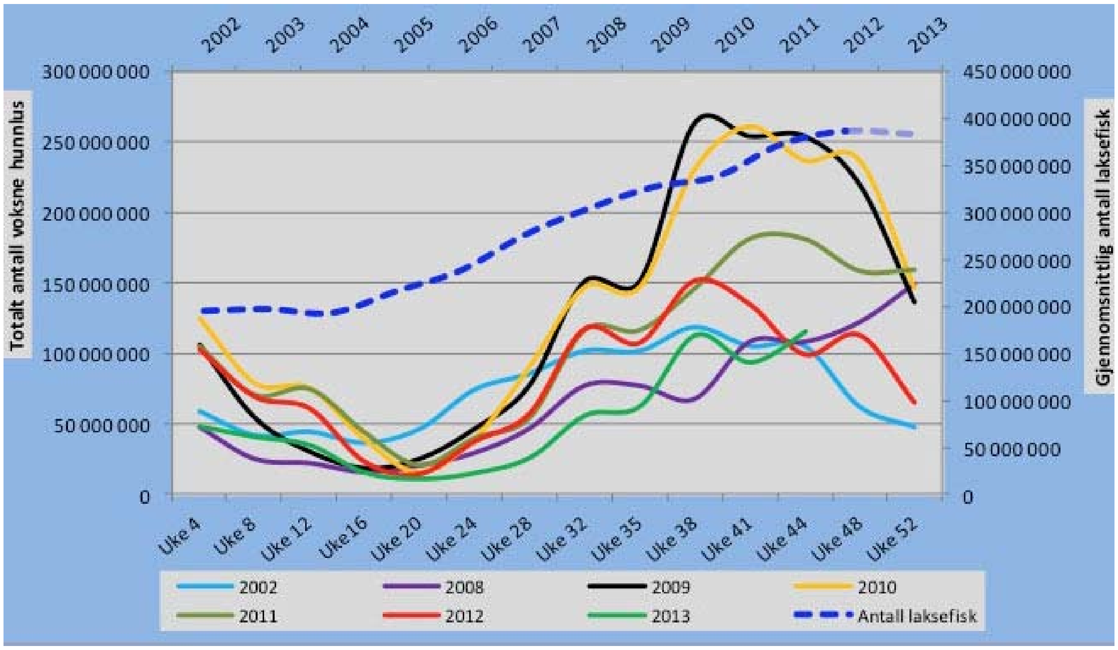

Figure 5. Annual variations in lice levels from 2002 to 2012. “Uke” on the x-axis is Week; the main x-axis is “Total number of adult female lice,” secondary y-axis (and dashed blue line) is “average number of salmonids.” Source www.lusedata.no.

In common with the majority of studies, IMR’s risk assessments (i.e., Table 6) are based on direct physiological impacts and mortality risks associated with varying lice infection levels. However, Krkosek et al. (2011) indicated that, for Pacific salmon, increased predation is an important component of salmon–louse dynamics (i.e., infected wild fish have different behavior, higher susceptibility and reduced ability to avoid predation); they conclude that the mortality of wild juvenile salmon due to sea lice infestation is probably higher than previously thought. It is considered likely that this is also the case for Atlantic salmon and sea trout in Norway.

In 2011, IMR concluded, “*The sustainability of the Norwegian aquaculture industry between Rogaland and Troms is being challenged by infection pressure of sea lice on wild salmonids (and the possible genetic impact of escaped salmon).*” IMR also concluded, “*There is a high likelihood that salmon lice have a population regulating effect in Rogaland, particularly on sea trout*.” This situation does not appear to have improved in 2012.

In 2012, the Office of the Auditor General’s investigation into the management of aquaculture in Norway concluded, “*There are extensive losses of farmed fish, particularly as a result of disease. The disease situation has not improved since 2000, and the extensive losses also mean large financial losses for the industry. The prevalence of lice remains at a high level along large* *parts of the coast and this has a negative impact on wild fish, sea trout in particular*" (Kosmo 2012)

Table 7, above, shows that the primary concerns regarding significant population level impacts are on sea trout. This species is not considered endangered[28] (for which significant population impacts would lead to a critical score in the Seafood Watch criteria).

Disease Criterion - Conclusions and Final Score

While it could be argued that Norway is making considerable efforts to reduce impacts of pathogens and parasites on wild salmonids, these are not fully effective for wild salmon and the impacts on wild sea trout remain a major concern. On the basis of the multiple official conclusions noted above from within Norway itself, in addition to the potential for additional secondary impacts, such as increased predation risk in all regions, the score for the disease criterion is zero (out of ten) as amplification of parasites on salmon farms leads to significant population declines in wild sea trout in Norway.

[28] According to the IUCN http://www.iucnredlist.org/details/full/19861/0

Criterion 8: Source of Stock – Independence from wild Fisheries

Impact, unit of sustainability and principle

- *Impact: the removal of fish from wild populations for on-growing to harvest size in farms*
- *Sustainability unit: wild fish populations*
- *Principle: aquaculture operations use eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture.*

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

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

Criterion 9X: Wildlife and Predator Mortalities

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

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

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score	**-6.00**	**YELLOW**
Critical?	NO	

Data on predator mortalities are not publically available in Norway, therefore, the impacts are unknown and the final score for this exceptional factor is a precautionary -6 (out of -10).

Justification of Ranking

Cormorants, herons, otters and mink are considered to be the most active predators along with problems with seals at the individual level, but no data are made publically available about any mortality numbers (Trude Nordli, FHL, personal communication, 2012). An exemption to Norway's seal hunting prohibition states, "*Seals which cause damage to fishing gear or fish farms in the sea may be killed. The killing may be performed by the owner, operator or other person who supervises instrument or sites*." It is necessary for the farm to apply for permission to enact this, but statistics are not reported (Trude Nordli, FHL, personal communication, 2012) and the extent of predator mortalities is not known.

Wildlife Mortality Criterion- Conclusions and Final Score

While the affected predator populations in Norway may not be considered to be threatened (Trude Nordli, FHL, personal communication, 2012), the lack of data on mortality numbers means that the impacts are unknown and the final score for this exceptional factor is a precautionary -6 (out of -10).

Criterion 10X: Escape of Unintentionally Introduced Species

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

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

Escape of unintentionally introduced species parameters	Score	
C10Xa International or trans-waterbody live animal shipments (%)	10.00	
C10Xb Biosecurity of source/destination	10.00	
C10X Escape of unintentionally introduced species final score	**0.00**	**GREEN**

Norwegian salmon farming is considered self-sufficient in terms of the supply of broodstock and ova (eggs) and, therefore, although there are recent records of minor movements of ova, international shipments are considered to be zero for the purposes of this assessment. Movements within Norway risk the spread of the salmon parasite *Gyrodactylus salaris*, but the parasite remains undetected in recent monitoring and the risk of an unintentionally introduced species is low. The penalty score is 0 out of -10.

Justification of Ranking

Factor 10Xa International or trans-waterbody live animal shipments
As the dominant salmon production regions have become more self-sufficient in terms of broodstock and ova (egg) production, the international shipment of live salmon has been reduced. Scotland exported 600,000 eggs to Norway in 2010 (Marine Scotland Science 2012), but this is estimated to represent considerably less than 1% of production and, therefore, as Norway is primarily self-sufficient the international shipments are considered to be zero, for the purposes of this assessment. It could be argued that the movement of fish between hatchery, nursery and grow out sites constitutes trans-waterbody movements, particularly with reference to the principle (and significant) threat of the salmon parasite *Gyrodactyllus salaris*. However, as recent monitoring shows zero occurrences on farmed salmon (see factor 6.2Xb below), the movements between these sites are not considered in this assessment.

Factor 10Xb Biosecurity of source/destination
Gyrodactylus is considered to be the main threat from animal movements within Norway, however monitoring by the Norwegian Veterinary Institute of 3106 salmon and trout from 93 farms in 2011 show zero detection of the parasite (Svilland et al., 2012)

Criterion 10X - Conclusions and Final Score

Overall, there are considered to be minimal shipments of significant risk and there is no penalty score (i.e., zero) for the risk of escape of unintentionally introduced species.

Overall Recommendation

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

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

Criterion	Score (0-10)	Rank	Critical?
C1 Data	6.7	GREEN	
C2 Effluent	4.0	YELLOW	NO
C3 Habitat	6.0	YELLOW	NO
C4 Chemicals	1.0	RED	NO
C5 Feed	5.2	YELLOW	NO
C6 Escapes	2.0	RED	NO
C7 Disease	0.0	RED	NO
C8 Source	10.00	GREEN	
C9X Wildlife mortalities	-6.00	YELLOW	NO
C10X Introduced species escape	0.00	GREEN	
Total	**29.0**		
Final score	**3.6**		

OVERALL RANKING

Final Score	3.6
Initial rank	YELLOW
Red criteria	3
Interim rank	RED
Critical Criteria?	NO
Final Rank	**AVOID/RED**

Acknowledgements

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

While some reviewers requested to remain anonymous, I am grateful to the following (listed alphabetically by surname) for either data, references, comment or discussion:

Lars Anderson, Petter Arnesson, Geir Borno, Borge Gronbech, Trudii Nordli, Ingrid Olesen, Ingrid Skarstein, Cecille Sviland, Aina Valland.

References

Asche, F. and K. H. Roll 2013. "Determinants Of Inefficiency In Norwegian Salmon Aquaculture." Aquaculture Economics & Management 17(3): 300-321.

Aschea, F., K. Roll, et al. 2013. "Salmon Aquaculture: Larger Companies And Increased Production." Aquaculture Economics & Management 17(3): 322-339.

Asplin, L., I. A. Johnsen, et al. 2014. "Dispersion of salmon lice in the Hardangerfjord." Marine Biology Research 10(3): 216-225

Besnier, F., K. Glover, et al. 2011. "Investigating genetic change in wild populations: modelling gene flow from farm escapees." Aquaculture Environment Interactions 2: 75-86.

Biering, E., Madhun, A., Isachsen, I., Omdal, L.,Einen, A., Garseth, A.,Bjorn, P.,Nilsen, R.,Karlsbakk, E. 2013. Annual report on health monitoring of wild anadromous salmonids in Norway. Institue of Marine Research, Annual Report 2012, No 6-2013.

Black, K., P. K. Hansen, et al. 2008. Working Group Report on Benthic Impacts and Farm Siting, Salmon Aquaculture Dialogue, WWF.

Borno, G. and C. Sviland 2010. "The health situation in Norwegian aquaculture 2010 " Norwegian Veterinary Institute.

Brooks, K. and C. Mahnken 2003. "Interactions of Atlantic salmon in the Pacific Northwest environment III Accumulation of zinc and copper." Fisheries Res 62: 295-305.

Buhl-Mortensen, P. and L. Buhl-Mortensen 2014). "Diverse and vulnerable deep-water biotopes in the Hardangerfjord." Marine Biology Research 10(3): 253-267.

Bureau, D. P. and K. Hua. 2010. "Towards effective nutritional management of waste outputs in aquaculture, with particular reference to salmonid aquaculture operations." Aquaculture Research 41(5): 777-792.

Burridge, L., J. S. Weis, et al. 2010. "Chemical use in salmon aquaculture: A review of current practices and possible environmental effects." Aquaculture 306: 7-23.

Cabello, F. C., H. P. Godfrey, et al. 2013. "Antimicrobial use in aquaculture re-examined: its relevance to antimicrobial resistance and to animal and human health." Environ Microbiol 15(7): 1917-1942.

Chang, B. D., F. H. Page, et al. 2011. "Characterization of the spatial pattern of benthic sulfide concentrations at six salmon farms in southwestern New Brunswick, Bay of Fundy " Can. Tech. Rep. Fish. Aquat. Sci. 2915.

Chittenden, C., A. H. Rikardsen, et al. 2011. "An effective method for the recapture of escaped farmed salmon." Aquaculture Environment Interactions 1(3): 215-224.

Covello, J. M., S. E. Friend, et al. 2012. "Effects of Orally Administered Immunostimulants on Inflammatory Gene Expression and Sea Lice (Lepeophtheirus salmonis) burdens on Atlantic salmon (Salmo salar)." Aquaculture(0).

DFO 2012. "Assessment of the Fate of Emamectin Benzoate, the Active Ingredient in SLICE®, near Aquaculture Facilities in British Columbia and its Effect on Spot Prawns (*Pandalus platyceros*)." DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/082.

FHL 2011. "Environmental Report 2010." Norwegian Seafood Federation.

Finstad, O., K. Falk, et al. 2012. "Immunohistochemical detection of piscine reovirus (PRV) in hearts of Atlantic salmon coincide with the course of heart and skeletal muscle inflammation (HSMI)." Veterinary Research 43: 27.

Fraser, D. J., A. L. S. Houde, et al. 2010. "Consequences of farmed-wild hybridization across divergent wild populations and multiple traits in salmon." Ecological Applications 20(4): 935-953.

Garseth, A., E. Biering, et al. 2013. "Associations between piscine reovirus infection and life history traits in wild-caught Atlantic salmon Salmo salar L. in Norway." Preventive Veterinary Medicine 112(1–2): 138-146

Godoy MG, Kibenge MJT, Suarez R, Lazo E, Heisinger A, Aguinaga J, Bravo D, Mendoza J, Llegues KO, Avendano-Herrera R, Vera C, Mardones F, Kibenge FSB. 2013. Infectious salmon anaemia virus (ISAV) in Chilean Atlantic salmon (Salmo salar) aquaculture: emergence of low pathogenic ISAV-HPR0 and re-emergence of virulent ISAV-HPRΔ: HPR3 and HPR14. Virology Journal, 10:334.

Glover, K., C. Pertoldi, et al. 2013. "Atlantic salmon populations invaded by farmed escapees: quantifying genetic introgression with a Bayesian approach and SNPs." BMC Genetics 14: 74.

Glover, K., M. Quintela, et al. 2012. "Three Decades of Farmed Escapees in the Wild: A Spatio-Temporal Analysis of Atlantic Salmon Population Genetic Structure throughout Norway." Plos One 7(8): e43129.

Hammell, L., C. Stephen, et al. 2009. Salmon Aquaculture Dialogue Working Group Report on Salmon Disease, Salmon Aquaculture Dialogue, WWF.

Hansen, L. P. and M. L. Windsor 2006. "Interactions between Aquaculture and Wild Stocks of Atlantic Salmon and other Diadromous Fish Species: Science and Management, Challenges and Solutions: An introduction by the Conveners." ICES J. Mar. Sci. 63(7): 1159-1161.

Hansen, L. P. and A. F. Youngson 2010. "Dispersal of large farmed Atlantic salmon, Salmo salar, from simulated escapes at fish farms in Norway and Scotland." Fisheries Management and Ecology 17(1): 28-32.

Husa, V., H. Steen, et al. 2014a. "Historical changes in macroalgal communities in Hardangerfjord (Norway)." Marine Biology Research 10(3): 226-240.

Husa, V., T. Kutti, et al. 2014b. "Regional impact from fin-fish farming in an intensive production area (Hardangerfjord, Norway)." Marine Biology Research 10(3): 241-252.

Jensen, O., T. Dempster, et al. 2010. "Escapes of fishes from Norwegian sea-cage aquaculture: causes, consequences and prevention." Aquaculture Environment Interactions 1: 71-83.

Jensen, A., S. Karlsson, et al. 2013. "Escaped farmed Atlantic salmon grow, migrate and disperse throughout the Arctic Ocean like wild salmon." Aquaculture Environment Interactions 3(3): 223-229.

Johansen, L. H., I. Jensen, et al. 2011. "Disease interaction and pathogens exchange between wild and farmed fish populations with special reference to Norway." Aquaculture 315(3â€“4): 167-186.

Johansen, R., (ed). 2012. Fish Health Report 2012. Oslo: Norwegian Veterinary Institute; 2013.

Jones, P. G., K. L. Hammell, et al. 2013. "Detection of emamectin benzoate tolerance emergence in different life stages of sea lice, Lepeophtheirus salmonis, on farmed Atlantic salmon, Salmo salar L." Journal of Fish Diseases 36(3): 209-220.

Karakassis, I., P. Pitta, et al. 2005. "Contribution of fish farming to the nutrient loading of the Mediterranean." Scientia Marina 69: 313-321.

Karlsson, S., T. Moen, et al. 2011. "Generic genetic differences between farmed and wild Atlantic salmon identified from a 7K SNP-chip." Molecular Ecology Resources, 11: 247-253.

Kibenge, M., T. Iwamato, et al. 2013. "Whole-genome analysis of piscine reovirus (PRV) shows PRV represents a new genus in family Reoviridae and its genome segment S1 sequences group it into two separate sub-genotypes." Virology 10: 230.

Kosmo, J. 2012). Significant environmental challenges in the aquaculture industry. The Office of the Auditor General. Document 3:9 (2011-2012).

Krkosek, M., C. W. Revie, et al. 2013. "Comment on Jackson et al. 'Impact of Lepeophtheirus salmonis infestations on migrating Atlantic salmon, Salmo salar L., smolts at eight locations in Ireland with an analysis of lice-induced marine mortality'." Journal of Fish Diseases: Published online 14 Aug 2013.

Krkosek, M., C. W. Revie, et al. 2013. "Impact of parasites on salmon recruitment in the Northeast Atlantic Ocean." Proceedings of the Royal Society B: Biological Sciences 280(1750).

Lander, T. R., S. M. C. Robinson, et al. 2013. "Characterization of the suspended organic particles released from salmon farms and their potential as a food supply for the suspension feeder, Mytilus edulis in integrated multi-trophic aquaculture (IMTA) systems." Aquaculture 406–407(0): 160-171.

Langford, K. H., S. Øxnevad, et al. 2011. "Environmental screening of veterinary medicines used in aquaculture - diflubenzuron and teflubenzuron." NIVA-rapport 6133-2011

Laxminarayan, R., A. Duse, et al. 2013. "Antibiotic resistance - the need for global solutions." The Lancet Infectious Diseases 13(12): 1057-1098.Loucks, R. H., R. E. Smith, et al. 2012. "Copper in the sediment and sea surface microlayer near a fallowed, open-net fish farm." Marine pollution bulletin 64(9): 1970-1973.

Lyngstad T, Kristoffersen A, et al. 2012. "Low virulent infectious salmon anaemia virus (ISAV-HPR0) is prevalent and geographically structured in Norwegian salmon farming." Diseases of aquatic organisms 101(3): 197-206.

Madhun, A. S., E. Karlsbakk, et al. 2014. "Potential disease interaction reinforced: double-virus-infected escaped farmed Atlantic salmon, Salmo salar L., recaptured in a nearby river." Journal of Fish Diseases: In Press

Marine Harvest 2012. "Annual Report 2011." www.marineharvest.com.

Marine Scotland Science 2012). "Scottish Fish Farm Production Survey." The Scottish Government.

Miranda, C. 2012. Antimicrobial Resistance in the Environment, First Edition. Edited by Patricia L. Keen and Mark H.M.M. Montforts . John Wiley & Sons, Inc.

Mayor, D. J. and M. Solan 2011. "Complex interactions mediate the effects of fish farming on benthic chemistry within a region of Scotland." Environmental research 111(5): 635-642.

Mayor, D. J., A. F. Zuur, et al. 2010. "Factors Affecting Benthic Impacts at Scottish Fish Farms." Environmental science & technology 44(6): 2079-2084.

Middlemas, S. J., R. J. Fryer, et al. 2013. "Relationship between sea lice levels on sea trout and fish farm activity in western Scotland." Fisheries Management and Ecology 20(1): 68-74.

Midtlyng, P. J., K. Grave, et al. 2011. "What has been done to minimize the use of antibacterial and antiparasitic drugs in Norwegian aquaculture?" Aquaculture Research 42: 28-34.

Murray, A. 2013. "Implications of leaky boundaries for compartmentalised control of pathogens: A modelling case study for bacterial kidney disease in Scottish salmon aquaculture." Ecological Modelling 250(0): 177-182.

Nofima. 2011. " Resource utilisation and eco-efficiency of Norwegian salmon farming in 2010 http://www.nofima.no/filearchive/rapport-53-2011_5.pdf.

NOAA 2012. Informational Bulletin on the Status of Infectious Salmon Anemia Virus in the Pacific Northwest. Federal Aquatic Animal Health Task Force. February 14, 2012.

Noakes, D. 2011. "Impacts of salmon farms on Fraser River sockeye salmon: results of the Noakes investigation." Cohen Commission Tech. Rept. 5C. 113p. Vancouver, BC www.cohencommission.ca.

Norwegian salmon farming in 2010." Report 53/2011,Published December 2011.

NORM/NORM-VET 2012. Usage of Antimicrobial Agents and Occurrence of Antimicrobial Resistance in Norway. Tromsø / Oslo 2013. ISSN:1502-2307 (print) / 1890-9965 (electronic).

Oddelcalv, K. E. 2011. "Report on the Environmental Impact of farming of North Atlantic Salmon in Norway." www.lakskrigen.no.

Olsen, A. and O. Skilbrei 2010. "Feeding preference of recaptured Atlantic salmon Salmo salar following simulated escape from fish pens during autumn." Aquaculture Environment Interactions 1: 167-174.

Olsen, A. E. 2012). "Fish Health Report 2011." Norwegian Veterinary Institute *ISSN 1893-1480 elektronisk utgave*.

Palacios, G., M. Lovoll, et al. 2010. "Heart and Skeletal Muscle Inflammation of Farmed Salmon Is Associated with Infection with a Novel Reovirus." Plos One 5(7): e11487.

Piccolo, J. and E. Orlikowska 2012. "A bilogical risk assessment for an Atlantic salmon (Salmo salar) invasion in Alaskan waters." Aquatic Invasions 7(2): 259-270.

Revie, C., L. Dill, et al. 2009. "Salmon Aquaculture Dialogue Working Group Report on Sea Lice " commissioned by the Salmon Aquaculture Dialogue available at http://wwf.worldwildlife.org/site/PageNavigator/SalmonSOIForm

Rimstad, E. 2011. "Examples of emerging virus diseases in salmonid aquaculture." Aquaculture Research 42: 86-89.

Sægrov, H., K. Hindar, et al. 1997. "Escaped farmed Atlantic salmon replace the original salmon stock in the River Vosso, western Norway." ICES Journal of Marine Science 54: 1166-1172.

Sanderson, C. 2006. Reducing the environmental impacts of sea-cage fish farming through cultivation of seaweed.

Sanderson, J. C., C. J. Cromey, et al. 2008. "Distribution of nutrients for seaweed cultivation around salmon cages at farm sites in north-west Scotland." Aquaculture 278(1-4): 60-68.

Sanderson, J. C., M. J. Dring, et al. 2012. "Culture, yield and bioremediation potential of Palmaria palmata (Linnaeus) Weber & Mohr and Saccharina latissima (Linnaeus) C.E. Lane, C. Mayes, Druehl & G.W. Saunders adjacent to fish farm cages in northwest Scotland." Aquaculture 354-355(0): 128-135.

Sernapesca 2013. "Informe sobre uso de antimicrobianos en la salmonicultura nacional 2012." Subdirección de Acuicultura Unidad de Salud Animal Valparaíso, febrero 2013.

Skaala, O., Kevin A. Glover, et al. 2012. "Performance of farmed, hybrid, and wild Atlantic salmon (Salmo salar) families in a natural river environment." Canadian Journal of Fisheries and Aquatic Sciences 69(12): 1994-2006.

Skaala, O., K. Sjotun, et al. 2014a. "Interactions between salmon farming and the ecosystem: Lessons from the Hardangerfjord, western Norway." Marine Biology Research 10(3): 199-202.

Skaala, O., S. Kalas, et al. 2014b. "Evidence of salmon lice-induced mortality of anadromous brown trout (Salmo trutta) in the Hardangerfjord, Norway." Marine Biology Research 10(3): 279-288.

Skaala, O., G. H. Johnsen, et al. 2014c. "A conservation plan for Atlantic salmon (Salmo salar) and anadromous brown trout (Salmo trutta) in a region with intensive industrial use of aquatic habitats, the Hardangerfjord, western Norway." Marine Biology Research 10(3): 308-322.

Skilbrei, O., J. Holst, et al. 2010. "Horizontal movements of simulated escaped farmed Atlantic salmon (*Salmo salar)* in a western Norwegian fjord." ICES J Marine Sci 67: 1206-1215.

Skilbrei, O. and T. Jorgensen 2010. "Reacpture of cultured salmon following a large scale escape event." Aquaculture Environment Interactions 1: 107-115.

Skilbrei, O. and V. Wennevik 2006. "The use of catch statistics to monitor the abundance of escaped farmed Atlantic salmon and rainbow trout in the sea." ICES Journal of Marine Science 63: 1190-1200.

Svilland, C., H. Hansen, et al. 2012. "The surveillance and control programme for *Gyrodactylus salaris* in Atlantic salmon and rainbow trout in Norway 2011." Norwegian Veterinary Institute

Tacon, A., M. R. Hasan, et al. 2011. "Demand and supply of feed ingredients for farmed fish and crustaceansTrends and prospects." FAO Fisheries and Aquaculture Technical Paper 564.

Tacon, A. G. J. and M. Metian 2008. "Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects." Aquaculture 285(1-4): 146-158.

Taranga, G., K. Boxaspen, et al. 2011. "Risk Assessment - environmental impacts of Norwegian aquaculture." Institue for Marine Research, Norway,.

Thomassen, P. E. and B. J. Leira 2012. "Assessment of Fatigue Damage of Floating Fish Cages Due to Wave Induced Response." Journal of Offshore Mechanics and Arctic Engineering 134(1): 011304.

Torrissen, O., S. Jones, et al. 2013. "Salmon lice – impact on wild salmonids and salmon aquaculture." Journal of Fish Diseases 36(3): 171-194.

Troell, M., C. Halling, et al. 1997. "Integrated marine cultivation of Gracilaria chilensis (Gracilariales, Rhodophyta) and salmon cages for reduced environmental impact and increased economic out put." Aquaculture 156: 45-61.

Venayagamoorthy, S., H. Ku, et al. 2011. "Numerical modeling of aquaculture dissolved waste transport in a coastal embayment." Environmental Fluid Mechanics 11(4): 329-352.

Wang, X., L. Olsen, et al. 2013. "Discharge of nutrient wastes from salmon farms: environmental effects, and potential for integrated multi-trophic aquaculture." Aquaculture Environment Interactions 2(3): 267-283.

WHO (2009). "Critically important antimicrobials for human medicine. 2nd revision - 2009." World Health Organization.

Whoriskey, F., P. Brooking, et al. 2006. "Movements and survival of sonically tagged farmed Atlantic salmon released in Cobscook Bay, Maine, USA." ICES Journal of Marine Science 63: 1218-1223.

Wilding, T. A. 2011. "A characterization and sensitivity analysis of the benthic biotopes around Scottish salmon farms with a focus on the sea pen Pennatula phosphorea L." Aquaculture Research 42: 35-40.

Zhang, Z., K. A. Glover, et al. 2013. "Genetic analysis of Atlantic salmon captured in a netting station reveals multiple escapement events from commercial fish farms." Fisheries Management and Ecology 20(1): 42-51.

About Seafood Watch®

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

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

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

Disclaimer

Seafood Watch® strives to ensure all our Seafood Reports and the recommendations contained therein are accurate and reflect the most up-to-date evidence available at time of publication. All our reports are peer reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science or aquaculture. Scientific review, however, does not constitute an endorsement of the Seafood Watch program or its recommendations on the part of the reviewing scientists. Seafood Watch is solely responsible for the conclusions reached in this report. We always welcome additional or updated data that can be used for the next revision. Seafood Watch and Seafood Reports are made possible through a grant from the David and Lucile Packard Foundation.

Guiding Principles

Seafood Watch™ defines sustainable seafood as originating from sources, whether fished[29] or farmed, that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

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

Seafood Watch will:

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

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

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

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

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

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

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

Data points and all scoring calculations

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

Criterion 1: Data quality and availability

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	*Yes*	10	10
Effluent	Yes	5	5
Locations/habitats	Yes	10	10
Predators and wildlife	Yes	0	0
Chemical use	Yes	5	5
Feed	Yes	5	5
Escapes, animal movements	Yes	7.5	7.5
Disease	Yes	7.5	7.5
Source of stock	Yes	10	10
Other – (e.g. GHG emissions)	No	Not relevant	n/a
Total			**60**

C1 Data Final Score	6.7	GREEN

Criterion 2: Effluents

Effluent Rapid Assessment

C2 Effluent Final Score	**4.00**	**YELLOW**

Criterion 3: Habitat

3.1. Habitat conversion and function

F3.1 Score	**7**

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

Factor 3.2a - Regulatory or management effectiveness

Question	Scoring	Score
1 - Is the farm location, siting and/or licensing process based on ecological principles, including an EIAs requirement for new sites?	Mostly	0.75
2 - Is the industry's total size and concentration based on its cumulative impacts and the maintenance of ecosystem function?	Moderately	0.5
3 – Is the industry's ongoing and future expansion appropriate locations, and thereby preventing the future loss of ecosystem services?	Mostly	0.75
4 - Are high-value habitats being avoided for aquaculture siting? (i.e. avoidance of areas critical to vulnerable wild populations; effective zoning, or compliance with international agreements such as the Ramsar treaty)	Mostly	0.75
5 - Do control measures include requirements for the restoration of important or critical habitats or ecosystem services?	Yes	0.5
		3.25

Factor 3.2b - Siting regulatory or management enforcement

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

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

C3 Habitat Final Score	**6.08**	**YELLOW**
	Critical?	NO

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	Score	
C4 Chemical Use Score	**1.00**	
C4 Chemical Use Final Score	**1.00**	**RED**
Critical?	NO	

Criterion 5: Feed

5.1. Wild Fish Use

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

Fishmeal inclusion level (%)	Average NOFIMA/Feed company FIFO result used
Fishmeal from byproducts (%)	See text in tables in Criterion 5
% FM	
Fish oil inclusion level (%)	
Fish oil from byproducts (%)	
% FO	
Fishmeal yield (%)	
Fish oil yield (%)	
eFCR	
FIFO fishmeal	
FIFO fish oil	
Greater of the 2 FIFO scores	1.80
FIFO Score	**5.50**

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

SSWF	-3
SSWF Factor	-0.54

F5.1 Wild Fish Use Score	**4.96**

5.2. Net protein Gain or Loss

Protein INPUTS	
Protein content of feed	37.3
eFCR	1.2
Feed protein from NON-EDIBLE sources (%)	11.3
Feed protein from EDIBLE CROP sources (%)	63.4
Protein OUTPUTS	
Protein content of whole harvested fish (%)	16.9
Edible yield of harvested fish (%)	60
Non-edible by-products from harvested fish used for other food production	90
Protein IN	315.9
Protein OUT	162.2

Net protein gain or loss (%)		-48.6
	Critical?	NO
F5.2 Net protein Score	**5.00**	

5.3. Feed Footprint

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

Inclusion level of aquatic feed ingredients (%)	33
eFCR	1.2
Average Primary Productivity (C) required for aquatic feed ingredients (tonne C/tonne fish)	*69.7*
Average ocean productivity for continental shelf areas (tonne C/ha)	*2.68*
Ocean area appropriated (ha/tonne fish)	10.3

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

Inclusion level of crop feed ingredients (%)	62.2
Inclusion level of land animal products (%)	0
Conversion ratio of crop ingredients to land animal products	*2.88*
eFCR	1.2
Average yield of major feed ingredient crops (t/ha)	*2.64*
Land area appropriated (ha per tonne of fish)	0.28

Value (Ocean + Land Area)	**10.58**

F5.3 Feed Footprint Score	**6.00**

C5 Feed Final Score	**5.23**	**YELLOW**
	Critical?	**NO**

Criterion 6: Escapes

6.1a. Escape Risk

Escape Risk	**2**

Recapture & Mortality Score (RMS)	
Estimated % recapture rate or direct mortality at the escape site	13

Recapture & Mortality Score	0.13
Factor 6.1a Escape Risk Score	**3**

6.1b. Invasiveness

Part A – Native species

Score	0

Part B – Non-Native species

Score	**0**

Part C – Native and Non-native species

Question	Score
Do escapees compete with wild native populations for food or habitat?	Yes
Do escapees act as additional predation pressure on wild native populations?	Yes
Do escapees compete with wild native populations for breeding partners or disturb breeding behavior of the same or other species?	Yes
Do escapees modify habitats to the detriment of other species (e.g. by feeding, foraging, settlement or other)?	No
Do escapees have some other impact on other native species or habitats?	To some extent
	1.5

F 6.1b Score	**1.5**

Final C6 Score	**2.00**	**RED**
	Critical?	**NO**

Criterion 7: Diseases

Pathogen and parasite parameters	Score	
C7 Biosecurity	0.00	
C7 Disease; pathogen and parasite Final Score	**0.00**	**RED**
Critical?	NO	

Criterion 8: Source of Stock

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

Exceptional Criterion 9X: Wildlife and predator mortalities

Wildlife and predator mortality parameters	Score	
C9X Wildlife and Predator Final Score	**-6.00**	**YELLOW**
Critical?	NO	

Exceptional Criterion 10X: Escape of unintentionally introduced species

Escape of unintentionally introduced species parameters	Score	
F10Xa International or trans-waterbody live animal shipments (%)	10.00	
F10Xb Biosecurity of source/destination	10.00	
C10 X Escape of unintentionally introduced species Final Score	**0.00**	**GREEN**