Monterey Bay Aquarium
Seafood Watch®

Atlantic Salmon

Salmo salar

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Scotland

Marine Net Pens

September 18, 2017
Seafood Watch Consulting Researcher

Final Seafood Recommendation

There are two final recommendations: the first for the mainland and Shetland and Western Islands regions of Scotland and a second for the Orkney Islands region of Scotland.

Scotland: Mainland, Shetland and Western Islands

Criterion	Score	Rank	Critical?
C1 Data	7.27	GREEN	NO
C2 Effluent	5.00	YELLOW	NO
C3 Habitat	6.27	YELLOW	NO
C4 Chemicals	1.00	RED	NO
C5 Feed	3.58	YELLOW	NO
C6 Escapes	2.00	RED	NO
C7 Disease	1.00	RED	NO
C8X Source	-0.00	GREEN	NO
C9X Wildlife mortalities	-4.00	YELLOW	NO
C10X Introduced species escape	-3.60	YELLOW	
Total	**18.52**		
Final score (0-10)	**2.65**		

OVERALL RANKING

Final Score	2.65
Initial rank	RED
Red criteria	3
Interim rank	RED
Critical Criteria?	NO

FINAL RANK
RED

Scoring note – scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of -10 reflects a very significant impact. Two or more Red criteria result in a Red final result.

Scoring Summary – Scotland: Mainland, Shetland and Western Islands

Salmon farmed in net pens in the Mainland and Shetland and Western Islands regions of Scotland has a final score of 2.65 out of 10 and has three Red-ranked criteria (Chemical Use, Escapes and Disease), and therefore the final recommendation of "Avoid."

Scotland: Orkney Islands

Criterion	Score	Rank	Critical?
C1 Data	7.27	GREEN	NO
C2 Effluent	5.00	YELLOW	NO
C3 Habitat	6.27	YELLOW	NO
C4 Chemicals	8.00	GREEN	NO
C5 Feed	3.58	YELLOW	NO
C6 Escapes	2.00	RED	NO
C7 Disease	6.00	YELLOW	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife mortalities	-4.00	YELLOW	NO
C10X Introduced species escape	-3.60	YELLOW	
Total	**30.52**		
Final score (0-10)	**4.36**		

OVERALL RANKING

Final Score	4.36
Initial rank	YELLOW
Red criteria	1
Interim rank	YELLOW
Critical Criteria?	NO

FINAL RANK
YELLOW

Scoring note – scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of -10 reflects a very significant impact. Two or more Red criteria result in a Red final result.

Scoring Summary – Scotland: Orkney Islands

Salmon farmed in net pens in the Orkney Islands of Scotland has a final score of 4.36 out of 10 and one Red-ranked criterion (Escapes), and therefore the final recommendation is "Good Alternative."

Executive Summary

Scotland's annual farmed salmon production was 171,722[1] metric tons (MT) in 2015 and predicted to rise to 177,857 MT in 2016, almost all of which (98.7%) comes from only 6 companies operating 87 freshwater sites and 254 active sea sites. Production is concentrated on the west and northwest mainland coasts, the Western Islands (also known as Eilean Siar or Outer Hebrides) and the northern island groups of Orkney and Shetland. The marine ongrowing sites all use the ubiquitous floating net pen farming system. There is a trend towards bigger farm sizes with nearly 82% of production now coming from sites producing more than 1,000 MT. The industry body is the Scottish Salmon Producer's Organisation (SSPO) and all SSPO members participate in the *Code of Good Practice for Scottish Finfish Aquaculture*.

This Seafood Watch assessment involves 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.[2] Given the clarity of data now available in Scotland (described below) it is possible to differentiate characteristics between regions in Scotland. As such, the low prevalence of sea lice in the Orkney Islands region and resulting low chemical use (Criterion 4), lower risk of impacts to wild sea trout (Criterion 7) and no use of wild wrasse as cleaner fish (Criterion 8X) are highlighted and considered sufficient to merit a separate overall score and final recommendation for this region. The annual production in Orkney of approximately 10,000 MT is substantially lower than other regions in Scotland, but the low prevalence of lice is considered due primarily to high tidal flushing between Orkney's separate small islands (as opposed to lower flushing rates around the larger island landmasses or the more enclosed sea lochs in other regions).

There is a large amount of data readily available on salmon farming in Scotland, particularly through "*Scotland's Aquaculture*" database, established as a collaboration between the Crown Estate, Food Standards Scotland, the Scottish Environmental Protection Agency (SEPA), and the Scottish Government. In addition, the annual "Scottish Fish Farm Production Survey" provides detailed information on a wide variety of production characteristics at the industry (i.e., aggregated) level. Some company information is available in annual reports, and two companies (Marine Harvest and Grieg Seafood) report data through the Global Salmon Initiative (GSI). Information on antibiotic use is only available by request under Freedom of Information regulations. Much of the data are initially self-reported by the farms (including benthic monitoring, sea lice numbers, seal mortalities, and escapes). Impacts to wild salmon and sea trout in Scotland resulting from escapes and particularly from sea lice continue to be poorly understood. In addition, the impacts of the collection of wild wrasse for use as cleaner fish is uncertain. Overall, the data availability is good, and resources such as *Scotland's Aquaculture* are to be commended. The final score for Criterion 1 – Data is 7.3 out of 10.

[1] Figures are whole fish equivalent weights (WFE), calculated from the weight of gutted fish.
[2] The full Seafood Watch Aquaculture Standard is available at:
http://www.seafoodwatch.org/seafood-recommendations/our-standards

Scottish salmon farms discharge approximately 11,000 MT of nitrogen, 1,500 MT of phosphorous, and 36,500 MT of organic carbon each year. Due to increasing feeding efficiencies, these values have remained stable over the last five years despite a considerable increase in production, and although scientific research indicates impacts beyond the immediate farm area are unlikely, the potential for cumulative impacts exists in densely farmed areas. Within the farm boundary or AZE, the nature of the floating net pens means that the farm construction itself has minimal direct habitat impact; however, the operational impacts of particulate wastes on the benthic habitats below the farm can be locally severe. Benthic monitoring results show most sites (77.5%) are compliant with Scottish Environmental Protection Agency requirements, and 22.5% have unsatisfactory seabed conditions, but these impacts are typically rapidly reversible, and on average, farms greatly exceed the fallowing guidelines set out in the Scottish *Code of Good Practice*.

The Scottish regulatory system for aquaculture's nutrient wastes is based on site-specific maximum biomass limits set according to predicted benthic impacts within an Allowable Zone of Effect (AZE). These site-level impacts are linked to the broader cumulative impacts based on the enrichment sensitivity classifications of 114 water bodies in Scotland under the government's *Locational Guidelines for the Authorisation of Marine Fish Farms in Scottish Waters*. While this regulatory system is well-developed, it continues to evolve as the industry increases production, and is in the process of transferring to a new model of impact prediction based on a Depositional Zone Regulation. There are currently concerns regarding the efficacy of enforcement with the industry self-reporting the impacts by which it is managed. SEPA has limited resources for audits and enforcement, and (as noted above) 22.5% of salmon sites currently have (self-reported) unsatisfactory benthic monitoring results. Considering the potential for impacts beyond the immediate farm area, the score for Criterion 2- Effluent is 6 out of 10, and regarding impacts within the immediate area, the score for Criterion 3 – Habitat is 6.27 out of 10.

The total quantity of antibiotics used in Scotland has decreased considerably over the last 10 years and they were used on only 8 sites in 2016. Both types of antibiotics used in recent years (oxytetracycline and florfenicol) are listed by the World Health Organization as "highly important" for human medicine, but the data indicate that, across the industry, they are used much less than once per production cycle with an overall relative use of 0.52g/ton. The greater concern for impacts of chemical use in Scottish salmon farming is pesticide use to treat parasitic sea lice. The pattern of pesticide use is complex and variable by treatment type and region, but on average, there were four sea lice treatments per active site in 2016, excepting the Orkney Islands region, which has a very low number of sea lice treatments (less than once per production cycle) and a very low relative use, apparently due to different sea lice infection dynamics in the area. Nationwide, the bath treatment azamethiphos has increased rapidly from 2013 to 2016, and the use of hydrogen peroxide as an alternative bath treatment increased by 3,700% between 2011 and 2015 with a total use of 19,500 MT in 2015, but then decreased to 11,874 in 2016 (although this is not considered to have a significant environmental impact, and is also used to treat conditions other than sea lice). The primary impacts are considered to be on the seabed due to the settlement of in-feed treatments in uneaten feed and feces, and monitoring for residues shows the use of emamectin benzoate (used in 354 treatments in 2015) is sufficient to exceed environmental quality standards at 100 m from the net pens on almost a quarter of treated sites in Scotland. Concerns with seabed residues of emamectin benzoate have led to a review of site discharge licenses for this pesticide.

Overall, there is an increasing trend in use of pesticides with a potential for rapid fluctuations between treatments of differing toxicity. There are multiple treatments on average at each site, resistance is well established, and the use of one in-feed treatment is sufficient to exceed environmental quality standards at many sites. The final score for the mainland of Scotland and the Shetland and Western Islands for Criterion 4 – Chemical Use is 1 out of 10. But, given the stark differences in the Orkney Islands region, this is scored separately, and the final score for Orkney is 8 out of 10.

Fishmeal and fish oil inclusion in Scottish salmon feeds continue to be replaced by increasing levels of alternative crop protein or oil ingredients. Data provided by one of three major feed companies supplying Scottish farms show the economic feed conversion ratio (eFCR) is 1.25, and from first principles, 2.24 tons of wild fish must be caught to provide the fish oil required to produce one ton of farmed salmon. A variety of global fisheries provide these marine ingredients with a range of sustainability scores (a majority are IFFO RS-certified, some are MSC-certified, others have low FishSource scores) and result in an overall Wild Fish Use score of 2.16 out of 10. There is a net edible protein loss of 30.5% and a total feed footprint of 16.15 hectares per ton of production. Overall, the final score for Criterion 5 – Feed is 3.58 out of 10.

Reported escapes of more than 10,000 fish occur annually in Scotland due to a variety of reasons, and very large-scale events such as the loss of 154,549 in 2014 continue to occur sporadically. These events represent a very small proportion of farm sites in Scotland, but additional undetected or unreported trickle losses may also cumulatively be substantial. Escaped fish are of varying sizes (up to >5 kg pre-harvest adults) and are present among wild salmon populations in rivers. Studies on genetic introgression are limited in Scotland (compared to Norway) but show evidence of farmed genetic material already present within wild Scottish salmon population. Although the situation regarding the genetic profile of salmon in Scotland is complex (for example, hatchery-reared salmon of Norwegian origin have previously been released into Scottish rivers under agreements with fishery managers in the 1970s and early 1980s), there is sufficient cause for concern regarding the fitness of native salmon populations from comprehensive studies in Norway and from agreement among international experts that a precautionary approach is required in Scotland. As such, the final score for Criterion 6 – Escapes is 2 out of 10.

The open nature of net pen salmon farms means the fish are vulnerable to infection by pathogens and parasites from the surrounding environment, and 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 and other wild resident species. The number of farmed salmon in Scotland exceeds their wild counterparts by approximately 700:1. The annual mortality on salmon farms in Scotland has increased from 7,859 MT in 2010 to an estimated 19,800 MT in 2016 (in the same period, production increased 15%), while the mortality as a percentage of production has more than doubled from 5% in 2010 to over 12% in 2016. Despite the likelihood that bacterial and viral diseases are significant factors in these mortalities, there is little evidence of impacts from their transmission to wild fish, and the focus of the Disease Criterion is on parasitic sea lice, whose numbers have been shown to be elevated in the environment around salmon farms and to impact wild salmon and sea trout at the individual level. Sea lice numbers on farms are increasing despite the frequent use of pesticide treatments, with a large proportion of farming regions exceeding *Code of Good Practice* guidelines established for the protection of wild fish. Importantly, there is sufficient clarity in the data to highlight the Orkney Islands as a region not suffering from the same lice infection pressure as other regions in Scotland.

The Scottish Government accepts that salmon farms are a source of lice in the environment and that the increased lice levels observed on wild salmon and sea trout (i.e., anadromous brown trout) near farms can affect or kill individual fish, but there is limited research on population-level impacts in Scotland, particularly for sea trout; therefore, this aspect is currently inconclusive. Examples from similar situations in Norway, where research has been more comprehensive, shows a high level of concern particularly for population-level impacts to discreet populations of sea trout in areas with high levels of sea lice. Both Atlantic salmon and brown trout are listed in the UK as Biodiversity Action Plan priority species, and identified as being the most threatened and in need of conservation action under the plan. Without sufficient study on the impacts in Scotland, the Risk-Based Assessment has been used and the apparent high potential for population-level impacts to discreet wild sea trout populations, while the industry continues to struggle to control sea lice in Scotland, results in a final score for Criterion 7 – Disease of 1 out of 10 for the regions of mainland Scotland and the Shetland and Western Islands. Though not entirely comprehensive, the available data for the Orkney Islands region show that on-farm lice levels are consistently below the recommendations and treatment thresholds (and near-zero), and any discharge of lice pressure from farms is considered to be very low. The score for Criterion 7 – Disease for the Orkney Islands is 6 out of 10.

As is common throughout the global salmon aquaculture industry, Scottish salmon farming is based on hatchery-raised broodstocks selectively bred over many generations, and is considered independent of wild salmon fisheries for broodstock, eggs, or juveniles. The final deductive score for Criterion 8X – Source of Stock is –0 out of –10. Scottish salmon farms currently use large but unspecified numbers of wild caught cleaner fish as part of their sea lice control strategies, but this is currently beyond the scope of the Seafood Watch Aquaculture Standard; further information is provided in Appendix 2 for reference, but this aspect does not contribute to the score. The final score for Criterion 8X – Source of Stock is a deduction of –0 out of –10.

The industry in Scotland has been increasingly reliant on egg imports with nearly 60 million eggs (approximately 86% of its total production) imported in 2015 in addition to much smaller yet significant amounts of live parr and smolts. The majority of these shipments come from Norway where the potential impacts of introducing *Gyrodactylus* and/or other pathogens or parasites into Scotland could be severe, but the sources of shipments typically have high biosecurity in addition to required health certificates for all imports into Scotland. The final score for Criterion 10X is a moderate deduction of –3.6 out of 10.

Overall, the final numerical score for Scotland is 2.656 out of 10 with red criteria scores for Criterion 4 – Chemical Use, Criterion 6 – Escapes and Criterion 7 – Disease. These scores reflect ongoing high levels of concern regarding these potential impacts. Given the high level of data specificity now available in Scotland, it is now possible to distinguish regional differences. Due to differences in sea lice dynamics, the Orkney Islands region has lower chemical use, a lower potential for sea lice transfer to wild sea trout, and a lower need for wild wrasse for cleaner fish. Accordingly, this assessment recognizes these characteristics as sufficient to give a different overall recommendation. The final numerical score for the Orkney Islands is 4.36 out of 10, and there is one red criterion score for Criterion 6 – Escapes. The final recommendation for the Orkney Islands region is therefore yellow “Good Alternative.”

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Species Overview

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

Production system
Nearly all farmed salmon in Scotland (and all within the scope of this assessment) are produced in floating net pens in coastal inshore environments, typical to the industry worldwide. The hatchery phase and production of smolts is conducted primarily in tanks or raceways on land (60% of smolts), but 40% of smolts are produced in net pens in freshwater lochs (Munro and Wallace 2016). As the primary environmental impacts are considered to occur at the sea site, this assessment focuses on the marine growout phase of production.

Production statistics.
According to the annual "Scottish Fish Farm Production Survey" (Munro and Wallace 2016), 171,722 metric tons (MT) of salmon (whole fish equivalent weight[3]) were produced in 2015. Of this total, 171,543 MT were produced in net pens, with 179 MT produced in tank-based systems. The 2015 production is a slight decrease from 179,022 in 2014, but the prediction for 2016 was 177,857 MT and is part of a long-term trend of increasing production (Figure 1). There

[3] Note there is some potential for inaccuracy from these figures that are calculated from gutted weights using standard conversion factors.

were 87 freshwater sites producing eggs, fry, and smolts in 2015 (49 land-based in tanks and raceways, and 38 using net pens) and 254 active[4] net pen marine sites.

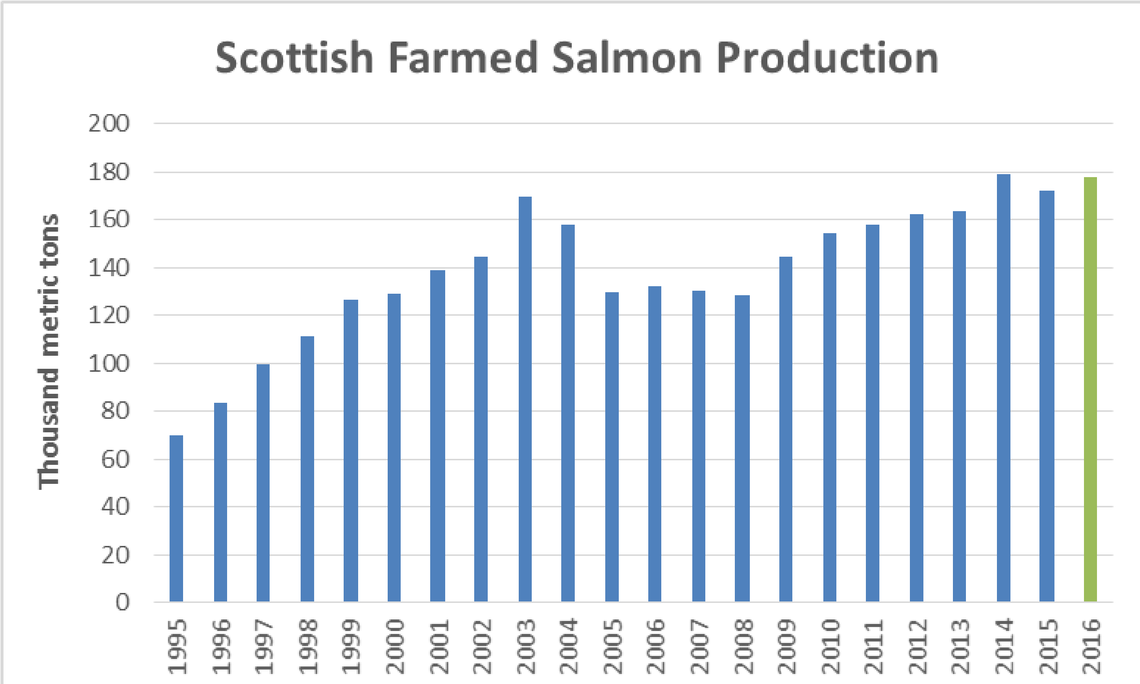

Figure 1: Annual Scottish farmed salmon production from 1995 to 2016. Value for 2016 is predicted based on smolt inputs in 2015. Data from Munro and Wallace (2016).

Salmon farming is concentrated on the west and northwest coasts, the Western Islands (also known as the Outer Hebrides and referred to in this report as Eilean Siar), and the northern island groups of Orkney and Shetland; see Figures 2 and 3 below.

[4] Active sites are those with fish in the water.

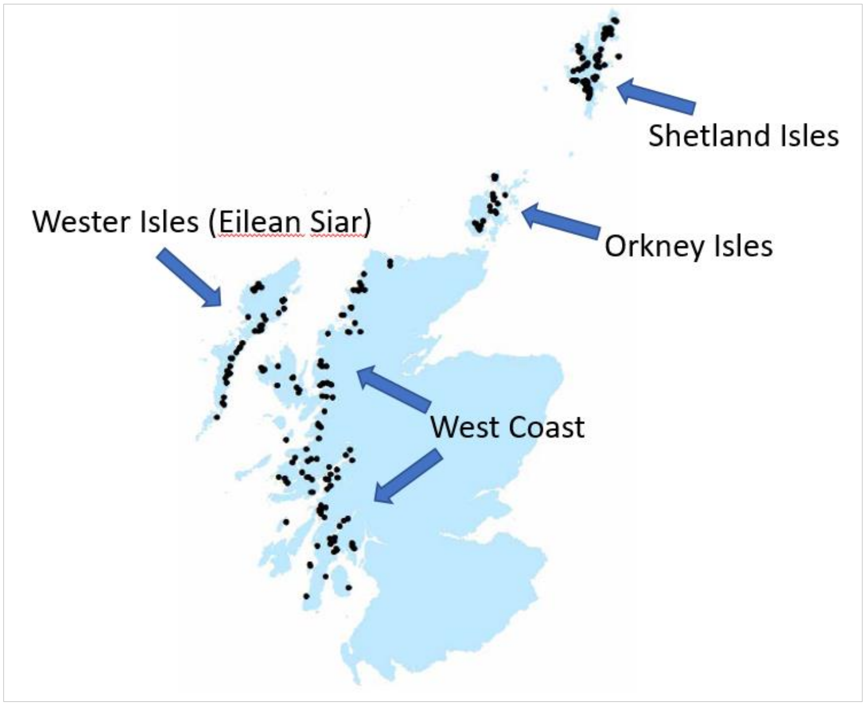

Figure 2: Active Scottish marine salmon production sites in 2015 (map from Munro and Wallace (2016); annotations added for this report).

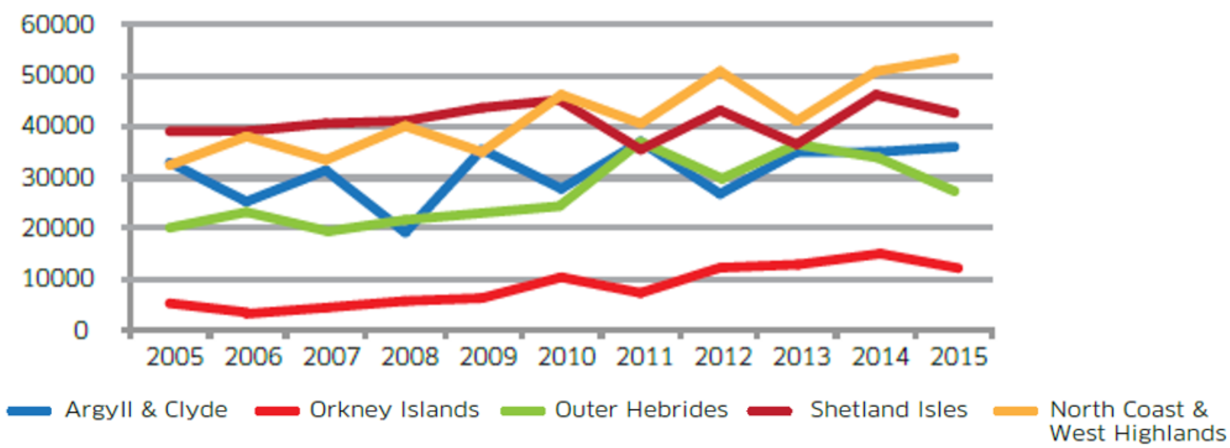

Figure 3: Regional production of farmed salmon in Scotland. Graph copied from Munro and Wallace (2016).

As noted in relevant sections of the assessment below, the Orkney Islands are highlighted as having distinctly different sea lice parasite dynamics than the other production regions of Scotland. This is considered due to Orkney's geographic nature as a group of small islands and channels that experience high tidal flows and flushing between them, as opposed to the larger island masses or more enclosed lochs and voes of other regions (pers. comm., SSPO January 2017).

Import and export sources and statistics

According to the Scottish Salmon Producers Organisation (SSPO 2016), the United States is a major market for Scottish salmon, and the top importing country; volumes fluctuate depending on global salmon market dynamics, but 30,039 MT of farmed salmon were exported from Scotland to the U.S. in 2015.

Common and market names

Atlantic salmon, Scottish salmon. Packaging and marketing may imply wild capture, but salmon originating from Scotland on the U.S. market is farmed Atlantic salmon unless clearly stated otherwise.

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

Product forms

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

Analysis

Scoring guide

- With the exception of criteria (8X, 9X and 10X), all scores result in a zero to ten final score for the criterion and the overall final rating. A zero score indicates poor performance, while a score of ten indicates high performance. In contrast, the three exceptional criteria result in negative scores from zero to minus ten, and in these cases zero indicates no negative impact.
- The full Seafood Watch Aquaculture Standard that the following scores relate to are available on the Seafood Watch website. http://www.seafoodwatch.org/seafood-recommendations/our-standards

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.

Criterion 1 Summary

All Regions

Data Category	Data Quality	Score (0-10)
Industry or production statistics	10	10
Management	10	10
Effluent	5	5
Habitat	7.5	7.5
Chemical use	7.5	7.5
Feed	5	5
Escapes	5	5
Disease	5	5
Source of stock	10	10
Predators and wildlife	7.5	7.5
Introduced species	7.5	7.5
Other – (e.g. GHG emissions)	Not Applicable	n/a
Total		**80.0**

C1 Data Final Score (0-10)	**7.3**	**GREEN**

Brief Summary

A large amount of data are readily available on salmon farming in Scotland, particularly through "*Scotland's Aquaculture*" database, established as a collaboration between the Crown Estate, Food Standards Scotland, the Scottish Environmental Protection Agency (SEPA), and the Scottish Government. In addition, the annual "Scottish Fish Farm Production Survey" provides detailed information on a wide variety of production characteristics at the industry (i.e., aggregated) level. Some company information is available in annual reports, and two companies (Marine Harvest and Grieg Seafood) report data through the Global Salmon Initiative (GSI). Information on antibiotic use is only available by request under Freedom of Information regulations. Much of the data are initially self-reported by the farms (including benthic monitoring, sea lice numbers, seal mortalities, and escapes). Impacts to wild salmon and sea trout in Scotland resulting from escapes and particularly from sea lice continue to be poorly understood. In addition, the impacts of the collection of wild wrasse for use as cleaner fish is uncertain. Overall, the data availability is good, and resources such as *Scotland's Aquaculture* are to be commended. The final score for Criterion 1 – Data is 7.3 out of 10.

Justification of Ranking

The key source of information is *Scotland's Aquaculture* website,[5] a collaboration between the Crown Estate, Food Standards Scotland, the Scottish Environmental Protection Agency, and the Scottish Government. It is an impressive central hub for a large amount of detailed data on all of Scotland's aquaculture production. An example screenshot of the data availability categories is shown in Figure 4.

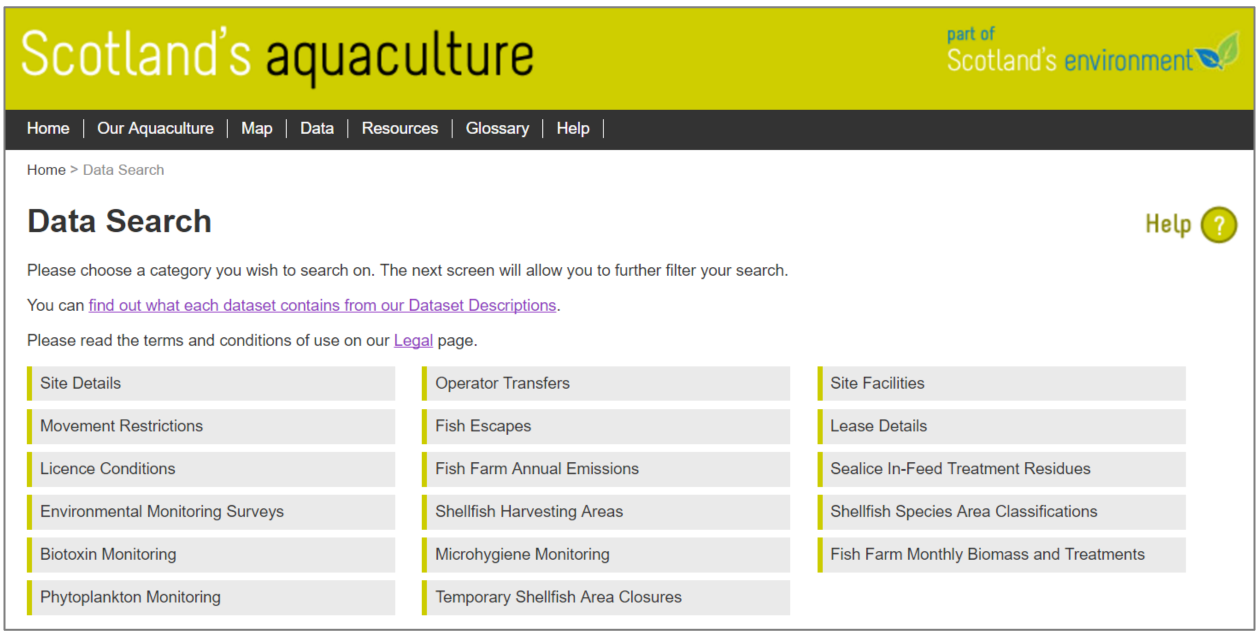

Figure 4: Screenshot of *Scotland's Aquaculture* website.

This website is referred to in relevant sections below, along with a variety of other sources of information and data.

Industry and Production Statistics

The primary source of this information is the annual "Scottish Fish Farm Production Survey," produced by the Scottish Government through Marine Scotland Science. The latest version available at the time of writing was published in 2016, and provides data for 2015 (Munro and Wallace 2016). It includes detailed information on production volumes, production numbers (ova, smolts, harvested fish), aggregated company information, site numbers (freshwater and marine), site sizes (biomass), and site locations (map).

[5] http://aquaculture.scotland.gov.uk/

Scotland's Aquaculture website includes information on every site regarding location (latitude and longitude) and license reference number, maximum biomass, and monthly current biomass (in addition to other information outlined in further sections below). The information is also included in an interactive map. The data score for Industry and Production Statistics is 10 out of 10.

Management and Regulations

The Scottish Government website includes a large amount of information on the regulatory process for establishing aquaculture facilities in Scotland. A recent "Independent Review of Scottish Aquaculture Consenting" (Nimmo et al. 2016) provides a comprehensive review of the current process and includes options for improvement in subsequent revisions. The *Locational Guidelines for Marine Fish Farms in Scottish Waters,* updated in 2016, provides information on site-specific and area-dependent consenting for maximum biomass (MSS 2016). Regarding the regulatory requirements of established sites, the Scottish Environmental Protection Agency (SEPA) has a large amount of information on required environmental monitoring, particularly within the "Fish Farm Manual."[6] Also, the Scottish *Code of Good Practice for Scottish Finfish Aquaculture* is available in full online.[7] The data score for Management and Regulations is 10 out of 10.

Effluent and Habitat

Scotland's Aquaculture website includes data on annual emissions of nitrogen, phosphorous, total organic carbon, zinc (from feed) and copper (from feed and net pen antifoulants) for every site; the website is updated quarterly. The benthic monitoring method and results are also available for every site for more than ten years, although these data are largely self-reported by the farm companies. The SSPO's Fish Health Management report includes quarterly fallowing information for sites in each region, and annual fallowing figures are available in the "Scottish Fish Farm Production Survey." There are no requirements for monitoring water column impacts in Scotland, and benthic monitoring does not include areas beyond the Allowable Zone of Effect, therefore these data are not available and some uncertainty continues regarding potential cumulative impact from multiple farms in shared waterbodies. The score for Effluent is 5 out of 10, and for Habitat is 7.5 out of 10.

Chemical Use

Aggregated antibiotic data for UK fish farming (all species) is available from the Veterinary Medicines Directorate (UK-VARSS 2015), but salmon-specific data are only available on request from SEPA under Freedom of Information regulations. *Scotland's Aquaculture* website has data on every sea lice treatment at every site since 2002 (updated quarterly) in grams of active ingredient. This does not include hydrogen peroxide, which is also available on request from SEPA. Data on sediment residue testing are available for all sites using in-feed sea lice treatments. As noted in the previous section, data on copper releases (although not differentiated between net antifoulants and feed) are available for every site on *Scotland's*

[6] http://www.sepa.org.uk/regulations/water/aquaculture/fish-farm-manual/

[7] http://thecodeofgoodpractice.co.uk/

Aquaculture website. The Scottish Salmon Producer's Organisation (SSPO) publishes a quarterly Fish Health Management report (since January 2013), which includes monthly average sea lice treatment numbers by region.[8] A substantial body of literature is available on the fate and potential impacts of antibiotics and sea lice treatments, but some gaps remain, and the data score for Chemical Use is 7.5 out of 10.

Feed

Scotland's Aquaculture website has the monthly feed inputs per site from 2002. With production figures, this can be used to calculate the economic Feed Conversion Ratio (eFCR). Detailed information on feeds, feed ingredients, and feed formulations are typically considered proprietary information by feed manufacturers, but requests for aggregated feed performance data were made to all three major feed companies in Scotland (Biomar, Skretting, and EWOS). Only one company provided information, therefore it is not named in this report to maintain commercial confidentiality. Two farming companies provide a Forage Fish Dependency Ratio (FFDR) value on the GSI website. The Feed data score is 5 out 10 reflecting the good understanding provided by one feed company and the general feed input data, but also the limited certainty regarding how accurately it reflects the entire industry.

Escapes

Industry-reported escape numbers are available from *Scotland's Aquaculture* database with the site name, location, company, initial number estimated, a final number, the size of the fish, and the number recaptured. The annual "Scottish Fish Farm Production Survey" also provides aggregated annual totals from the same data. Key Norwegian authors provide some broadly applicable studies on potential trickle losses, recapture, and mortality (e.g., Skilbrei et al. 2015). The number of farmed fish reported among wild catches is available from the Scottish salmon fisheries statistics.[9] Studies on the impacts of escaped farmed salmon in Scotland are limited (compared to Norway) and generally dated (excepting Verspoor et al. 2016). Overall, the data score for Escapes is 5 out of 10 due to the limited understanding of the fate and impact of escaped farmed salmon in Scotland.

Disease

The SSPO Fish Health Management reports include monthly average sea lice numbers, treatment numbers and site fallowing information for 30 regions across Scotland. These data are aggregated by region, and therefore hide site variability. The Scottish Government website has basic information on notifiable diseases and a "Summary of the Science" on sea lice impacts to wild salmon and sea trout. *Scotland's Aquaculture* database has information on site-specific mortalities; but, in general, there is no specific information on disease outbreaks in Scotland. Information on impacts is also limited in Scotland, with few recent academic studies (Peacock et al. 2014) (Shephard et al. 2016) (Middlemas et al. 2016), resulting in a need to consider studies of similar situations in Norway, e.g., (Taranger et al. 2015) (Hjeltnes et al. 2016) (Nilson

[8] http://scottishsalmon.co.uk/publications/

[9] Scottish Government Topic Sheet NO. 68 V7 2016. www.gov.scot

et al. 2016) (Vollset et al. 2015) (Anon. 2016) (Thorstad et al. 2015). Scottish Fishery Statistics provide some information on wild salmon and sea trout numbers, but considering the limited understanding of impacts to these species in Scotland, the data score for Disease is 5 out of 10.

Source of Stock
The annual "Scottish Fish Farm Production Survey" has detailed information on the sources of salmon eggs (ova) used in Scotland and the wild/domesticated nature of their broodstock. Information on the use of wild wrasse as cleaner fish to control parasitic sea lice is included in Appendix 2 for reference, but does not affect the scoring of this data criterion; therefore, the data score for Source of Stock is 10 out of 10.

Predator and Wildlife Mortalities
The Scottish government provides information on lethal seal control in terms of license numbers and (industry self-reported) mortality records.[10] These are aggregated with fisheries licenses, but detailed figures allow an estimate of the proportions killed on salmon farms. The figures include population size estimates for the relevant species and indicators of population impacts (Potential Biological Removal values). With some potential for unreported mortalities, the data score for Predator and Wildlife Mortalities is 7.5 out of 10.

Escape of Secondary Species
The annual "Scottish Fish Farm Production Survey" provides aggregated figures on the use of imported eggs, parr, and smolts, and the dominant source countries each year. Information on the biosecurity of the sources of these shipments is limited, but there is evidence of health certificates for imports, and robust assumptions can be made about the production systems based on the globally similar method of salmon egg production and husbandry. The data score for Escape of Secondary Species is 7.5 out of 10.

Conclusions and Final Score
The final numerical score for Criterion 1 – Data is 7.3 out of 10.

[10] http://www.gov.scot/Topics/marine/Licensing/SealLicensing

Criterion 2: Effluent

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.*

Criterion 2 Summary

All Regions

Effluent Risk-Based Assessment

Effluent parameters	**Value**	**Score**
F2.1a Waste (nitrogen) production per of fish (kg N ton-1)	44.4	
F2.1b Waste discharged from farm (%)	80	
F2 .1 Waste discharge score (0-10)		6
F2.2a Content of regulations (0-5)	4	
F2.2b Enforcement of regulations (0-5)	3	
F2.2 Regulatory or management effectiveness score (0-10)		4.8
C2 Effluent Final Score (0-10)		4.0
Critical?	NO	**YELLOW**

Brief Summary

Scottish salmon farms discharge approximately 11,000 MT of nitrogen, 1,500 MT of phosphorous, and 35,000 MT of organic carbon each year. Due to increasing feeding efficiencies, these values have remained stable over the last five years despite a considerable increase in production, and though scientific research indicates that impacts beyond the immediate farm area are unlikely, the potential for cumulative impacts exists in densely farmed areas. The Scottish regulatory system for aquaculture's nutrient wastes is based on site-specific maximum biomass limits set according to predicted benthic impacts within an Allowable Zone of Effect (AZE). These site-level impacts are linked to the broader cumulative impacts based on the enrichment sensitivity classifications of 114 waterbodies in Scotland under the government's *Locational Guidelines for the Authorisation of Marine Fish Farms in Scottish Waters.* Although this regulatory system is well-developed, it continues to evolve as the industry continues to increase production. There are currently some concerns regarding the efficacy of enforcement, since the industry self-reports the impacts by which it is managed. SEPA has limited resources for audits and enforcement, and 22.5% of salmon sites currently have (self-reported) unsatisfactory benthic monitoring results. Combining the waste discharge and management scores results in a final score for Criterion 2 - Effluent of 5 out of 10.

Justification of Ranking

The Effluent Criterion considers impacts of farm wastes beyond the immediate farm area or outside a regulatory allowable zone of effect, and the Habitat Criterion considers impacts within the immediate farm area. Although the two criteria cover different impact locations, there is inevitably some overlap between them in terms of monitoring data and scientific studies.

Figure 5 shows that the total discharges of nitrogen, phosphorous, and organic carbon from Scottish salmon farms have remained stable over the last five years with total annual values of approximately 11,000 MT of nitrogen, 1,500 MT of phosphorous and 36,500 MT of organic carbon. This is despite a substantial increase in farmed salmon production, most likely due to increasing feeding efficiency; these wastes clearly represent a substantial loss of ecologically costly and globally sourced feed ingredients, and their discharge at farm sites represents a substantial point source of nutrients.

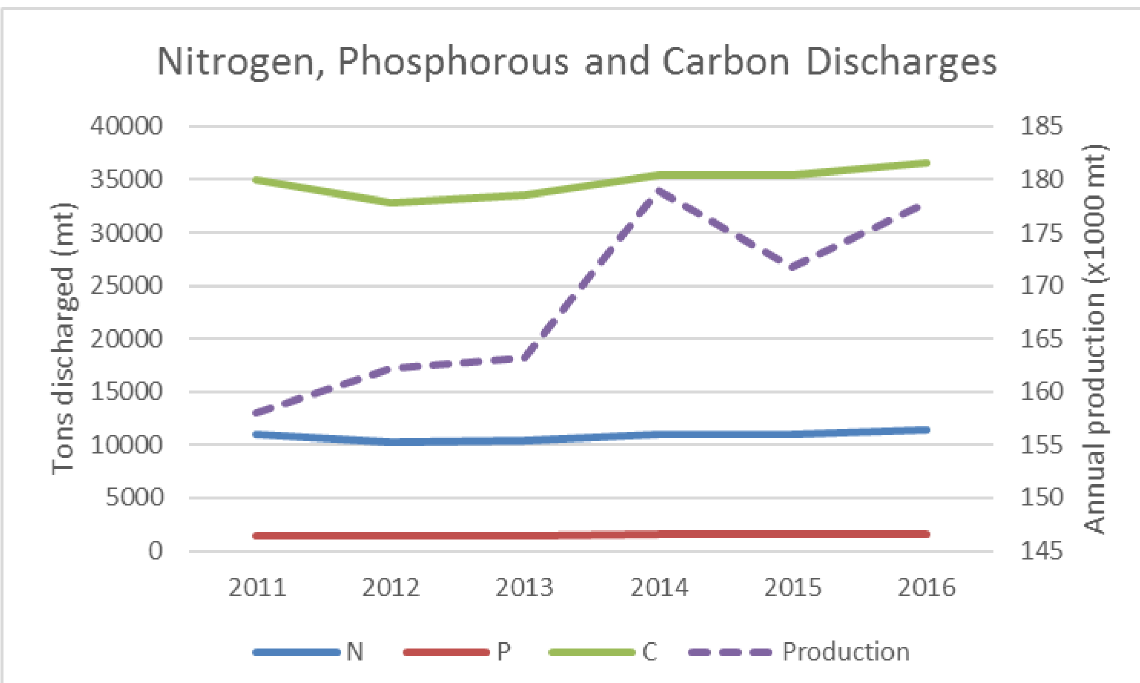

Figure 5: Annual nutrient discharge (nitrogen [N], phosphorus [P], carbon [C]) and total farmed salmon production (dotted line). Data from SEPA in *Scotland's Aquaculture* database.

There is a substantial body of literature on the fate and impact of nutrient wastes from net pen fish farms, including salmon farms, and key recent reviews such as Price et al. (2015) provide a useful summary. Price et al. (2015) conclude modern operating conditions have minimized impacts of individual farms on marine water quality; effects on dissolved oxygen and turbidity have been largely eliminated through better management, and near-field nutrient enrichment to the water column is usually not detectable beyond 100 m of the farm (when formulated feeds are used, feed waste is minimized, and farms are properly sited in deep waters with flushing currents). But, when sited nearshore, extra caution should be taken to manage farm location, size, biomass, feeding protocols, orientation with respect to prevailing currents, and water depth to minimize near- and far-field impacts. Price et al. caution that regardless of location, other environmental risks may still face this industry; for example, significant questions remain about the cumulative impacts of discharge from multiple, proximal farms, potentially leading to increased primary production and eutrophication. In the context of these concerns, Scotland does have a well-regarded regulatory system for aquaculture, which is discussed in Factor 2.2 below.

Benthic monitoring data in the immediate farm area are available from Scotland (see Factor 2.2b below), and can be used to infer likely impacts beyond it, but there is no regulatory requirement for direct monitoring of soluble nutrient levels or impacts in the water column in Scotland. Considering the general concerns about cumulative impacts outlined above from Price et al. (2015) and a lack of robust data on the far-field impacts of Scottish salmon farms, the Risk-Based Assessment option is the most appropriate.

Factor 2.1 Waste discharged per ton of fish production

Factor 2.1 assesses the amount of waste produced by the fish (Factor 2.1a) and the amount of that waste that is discharged from the farm (Factor 2.1b).

<u>Factor 2.1a – Biological waste production per ton of fish</u>

Using a feed protein content of 37%, and an economic Feed Conversion Ratio (eFCR) of 1.25 (see Feed Criterion for further information on these values), the total protein input in feed per ton of salmon harvested is 462.5 kg.

Since protein is 16% nitrogen, the total nitrogen input in feed is 74 kg N per ton of production.

The protein content of whole farmed salmon is 18.5% (Boyd, 2007), or 185 kg per ton. Considering the aforementioned nitrogen content of protein, the nitrogen output in harvested fish is 29.6 kg N per ton of production.

The net loss of nitrogen in soluble and particulate wastes is therefore 44.4 kg N per ton of production.

<u>Factor 2.1b – Production system discharge</u>

In net pen production systems, the Seafood Watch Aquaculture Standard considers 80% of discharged waste (i.e., 35.5 kg N) to have the potential to impact the ecosystem beyond the immediate farm area (in both soluble and particulate forms).

Factor 2.1a and 2.1b combine to result in a Factor 2.1 Waste Discharge Score of 6 out of 10.

Factor 2.2 Management of farm-level and cumulative impacts

Factor 2.2a assesses the content of the farm-level and regulatory management measures, and Factor 2.2b assesses the enforcement of those management measures. Combined, they indicate the effectiveness of the management system overall to control cumulative impacts from the total tonnage of production of individual sites, and of multiple sites that share one receiving water body, area, or region.

Factor 2.2a – Content of effluent management measures

The Scottish Government website includes a large amount of information on the aquaculture consenting process, and the final report of the Independent Review of Scottish Aquaculture Consenting (Nimmo et al. 2016) describes all current measures. According to Mayor et al. (2010), the regulatory framework that underpins the salmon farming industry in Scotland is internationally regarded as a benchmark standard; according to Scott (2010), the regulations in place are probably the most stringent in the world. Nevertheless, Appendix E of SEPA's fish farm manual[11] (currently being updated) shows there is no requirement for monitoring soluble nutrients in the water column at sites with less than 1,000 MT maximum permitted biomass, and only a recommendation for larger sites.

For the specific impacts assessed here, the website of the Scottish Environmental Protection Agency (SEPA) contains a large amount of information on the environmental monitoring and licensing process of fish farms.[12] Summarizing briefly at the farm level, all operators must be granted a license under the Water Environment (Controlled Activities) (Scotland) Regulations 2011 (CAR). The licensing system uses models to determine a maximum site biomass and a site-specific Allowable Zone of Effect (AZE) based on the predicted sediment faunal response to increases in carbon deposition (specified as the Infaunal Trophic Index at the edge of the AZE).

This is managed at the waterbody level using the *Locational Guidelines for Marine Fish Farms in Scottish Waters,* updated in 2016 (MSS 2016), which predict an equilibrium concentration enhancement (ECE) for soluble nitrogen in the water column and the benthic area with carbon deposition greater than 0.70 kg C m^{-2} y^{-1} for 114 waterbodies in Scotland. These values are combined to define and categorize the environmental sensitivity of Scottish sea lochs to aquaculture development, and are used in the licensing and biomass limits for the waterbody as a whole, and for individual farm sites within it. Categories 1 to 3 are defined by the combined sensitivity to nutrient enhancement and benthic impact, and used to generate a maximum biomass of farmed fish in each waterbody. In Scotland, an Allowable Zone of Effect (AZE) is typically about 25 m from the farm (although its shape can be modified according to the dominant hydrographic characteristics—primarily depth and current).

[11] Water Column Monitoring: https://www.sepa.org.uk/regulations/water/aquaculture/fish-farm-manual/

[12] www.sepa.org.uk http://www.sepa.org.uk/regulations/water/aquaculture/

The current licensing system is now under review,[13] and SEPA is consulting on a proposed new system based on a Depositional Zone Regulation (DZR).[14] The details and timeline of this are uncertain, but an area-based cumulative management system is currently considered to be operating at the waterbody level. Although the limits at the farm level are based on models, they are considered largely appropriate to the receiving waterbody according to the *Locational Guidelines.* Therefore, the content of the regulatory system is scored 4 out of 5 for Factor 2.2a.

<u>Factor 2.2b – Enforcement of effluent management measures</u>
Enforcement of effluent impacts is focused on "self-monitoring" benthic surveys used to demonstrate that the maximum site biomass permitted for each site is appropriate and not overloading the receiving environment. Requirements for biological or chemical assessments of benthic conditions, or visual benthic surveys (dependent on site biomass, depth, and substrate type) are set out in Appendix A and F of SEPA's fish farm manual.[15] The survey results are self-reported to SEPA by farming companies, with a limited number of audit checks conducted by SEPA.

Reported data are available on *Scotland's Aquaculture* database and shown in Figure 6. The time series from 2011 to 2016 shows some variation, but an increasing trend of satisfactory results (55% in 2016) and decreasing unsatisfactory results (22.5% in 2016), with borderline sites being more stable (also 22.5% in 2016). The total percentage of compliant sites for benthic conditions is 77.5% in 2016. These results focus on the immediate farm area, but are part of the wider waterbody management of relevance to this Effluent Criterion.

It is uncertain how many sites are audited by SEPA. Anecdotal evidence indicates that SEPA has very limited funding with which to enforce these measures and largely relies on the industry self-reported data to regulate the same industry; for example, in November 2016, a member of the Scottish Parliament (Mark Ruskell, environment spokesperson for the Scottish Greens party) challenged SEPA for relying on data from the aquaculture industry that it is trying to regulate.[16] Referring to a meeting of the Parliament's Environment Committee, SEPA admitted that their budgets have been cut, forcing them to reduce their attention on potential polluters using a risk-based approach. There is no readily-available evidence of penalties for infringements.

[13] Independent Review of Scottish Aquaculture Consenting. http://www.gov.scot/Publications/2016/07/9269/0
[14] SEPA Agency Board Meeting 29 November 2016. https://www.sepa.org.uk/media/219685/sepa-37-16-chief-executives-report.pdf
[15] Seabed Monitoring and Assessment. https://www.sepa.org.uk/media/114761/ffm_anx_f.pdf
[16] Scottish Greens Media Release 15 November 2016. https://greens.scot/news/regulators-don-t-have-teeth-budget-to-control-fish-farm-industry

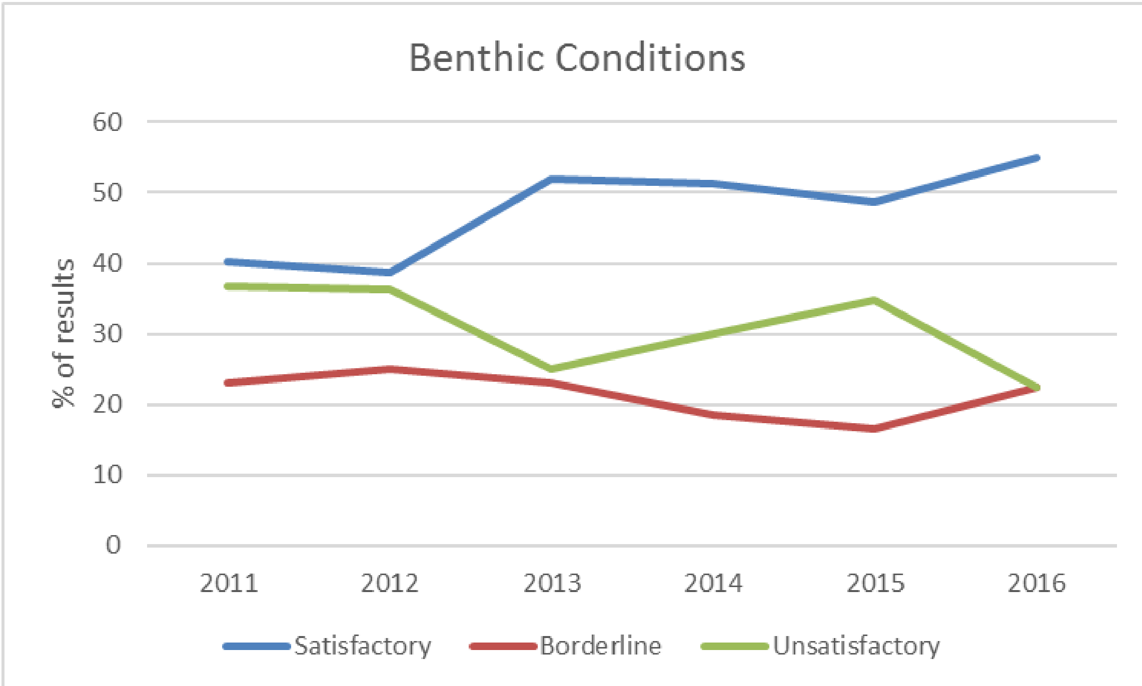

Figure 6: Benthic condition results from self-reported monitoring from 2011 to 2016. Data from SEPA in *Scotland's Aquaculture* database.

Overall, though the enforcement organizations are clearly identifiable and active as evidenced by the detailed site-specific data available from SEPA, there are minor concerns about the efficacy of enforcement due to the self-reported nature of the results, the potentially limited "risk-based" approach of auditing, and the results showing 22.5% of sites in unsatisfactory condition. The score for Factor 2.2b Enforcement of effluent management measures is 3 out of 5.

The final score for Factor 2.2 combines the scores for the regulatory content (Factor 2.2a) with the effectiveness of the enforcement (Factor 2.2b). In Scotland, there are comprehensive siting and waterbody management regulations through the *Locational Guidelines,* but also some limited confidence in current enforcement measures. As such, the score for Factor 2.2 is 4.8 out of 10.

Conclusions and Final Score

Without direct monitoring of the water column or other impacts beyond the immediate farm area, the Risk-Based Assessment was used, which takes into account the effectiveness of the regulatory management system. There is an estimated discharge of 35.5 kg of nitrogen per ton of salmon production in Scotland, and although the regulatory system at both the site level and cumulatively at the waterbody level is well developed, there remain some concerns regarding the efficacy of enforcement. The final score for the Criterion 2 - Effluent is 5 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.*

Criterion 3 Summary

All Regions

Habitat parameters	Value	Score
F3.1 Habitat conversion and function		7
F3.2a Content of habitat regulations	4	
F3.2b Enforcement of habitat regulations	3	
F3.2 Regulatory or management effectiveness score		4.8
C3 Habitat Final Score (0-10)		**6.27**
Critical?	NO	**YELLOW**

Brief Summary

The floating net pens ubiquitous for salmon farming and employed in Scotland have a minimal direct physical habitat impact and Scotland has a comprehensive and well-respected regulatory system that considers farm- and waterbody-level impacts; yet, there are concerns regarding the effectiveness of enforcement with limited evidence of independent audits and self-reported benthic results showing 22.5% of sites with unsatisfactory seabed conditions. Typically, these impacts are rapidly reversible, and on average, farms exceed the fallowing guidelines set out in the Scottish *Code of Good Practice*. Overall, there is "moderate" concern regarding benthic impacts and the final score for Criterion 3 – Habitat is 6.27 out of 10.

Justification of Ranking

Although the floating net pens used in salmon farming have relatively little direct habitat impacts, the operational impacts on the benthic habitats below the farm and/or within an Allowable Zone of Effect (AZE) can be profound. There has been an ongoing trend toward bigger sea sites in Scotland, with 82% of 2015 production coming from sites with over 1,000 MT capacity, compared to 65% in 2005 (Munro and Wallace 2016).

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). Although the Effluent Criterion assesses impacts beyond the immediate farm area, the Habitat Criterion considers impacts within it.

Factor 3.1. Habitat conversion and function

Intensive farming activities generate a localized gradient of organic enrichment in the underlying and adjacent sediments as a result of uneaten food and feces. These farming activities can strongly influence the abundance and diversity of infaunal communities; in the area under the net pens or within the regulatory AZE, the impacts are now relatively well understood (Black et al. 2008) (Keeley et al. 2013, 2015). The effects vary according to the depositional or erosional nature of the site; significant decreases in both the abundance and diversity of macrofauna are sometimes seen under farms located in depositional areas characterized by slow currents and fine-grained sediments, while net pens located in erosional environments with fast currents and sediments dominated by rock, cobble, gravel, and shell hash can dramatically increase macrobenthic production (Keeley et al. 2013).

Hambrey et al. (2008) reported one-quarter of Scottish salmon production takes place within or near areas identified as important for Biodiversity Action Plan (BAP) habitats or species, and around 10% of production takes place within or near Natura 2000 sites (Special Areas of Conservation (SACs), and Special Protected Areas [SPAs]). Wilding (2011) and Wilding et al. (2012) considered the overlap to be greater, and "most" Scottish salmon farms are located over muddy sediments that are classified as the Biodiversity Action Plan (BAP) habitat "mud in deep water." Salmon farming is considered (on the basis of spatial overlap and habitat sensitivity) to pose a high risk to beds of maerl (a coralline algae) and the horse mussel *M. modiolus,* and although research showed burrowers and suspension feeders to be relatively resilient to salmon farms in muddy sea-loch habitats in Scotland, detectable impacts were noted at 100 m from the cage boundary (Wilding et al. 2012).

As noted in the Effluent Criterion, 77.5% of (self-reported) benthic assessments were "satisfactory" in 2015 (Figure 6), and 22.5% were unsatisfactory; nonetheless, these direct habitat impacts below the net pens are relatively rapidly reversible and could be recovered by fallowing and/or moving the farm (Keeley et al. 2015). The Scottish *Code of Good Practice* recommends a fallow period of four weeks at the end of each cycle, and this should be synchronized with other farms when production is coordinated within a Farm Management Area. In practice, fallow periods are typically longer. Figure 7 shows 80% of sites had >4 weeks recovery in 2015, and most commonly between 9 and 26 weeks; 19% of sites were fallow for the entire year (note the 18% of sites with zero weeks fallowing are those sites in production throughout 2015, since the growout phase of production is greater than 12 months). Nevertheless, Keeley et al. (2015) note that after fallowing, impacts begin on the resumption of production; thus, there is an ongoing, cyclical pattern of impacts.

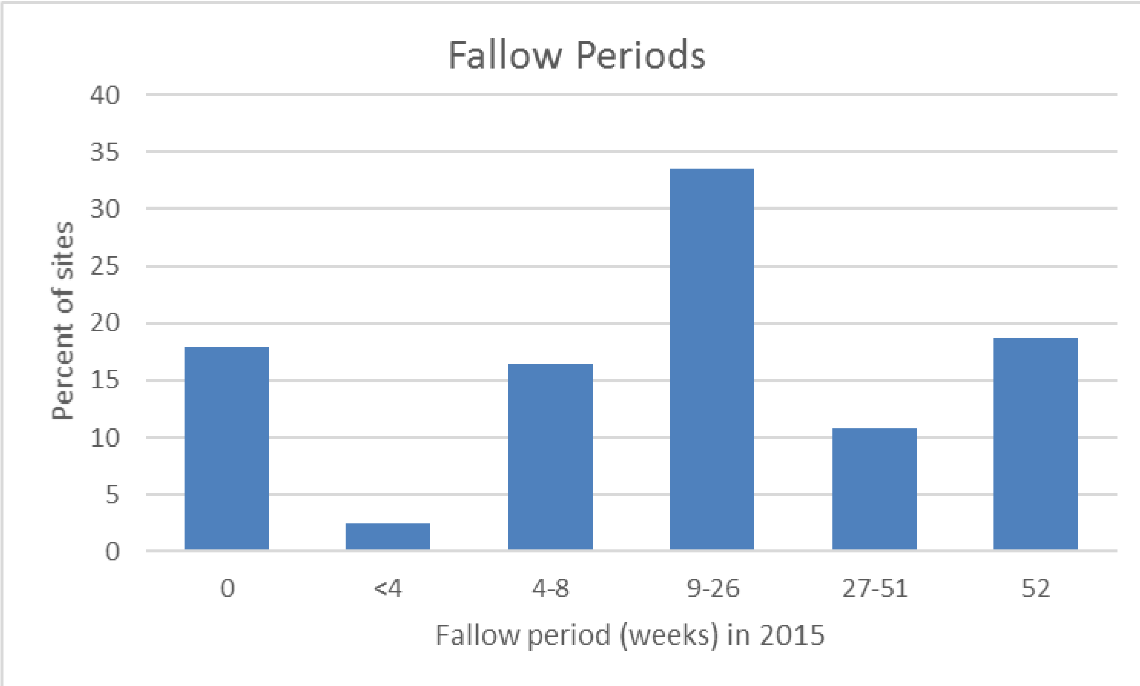

Figure 7: Fallow periods in 2015. Percentage of sites with varying number of weeks fallow. Data from Munro and Wallace (2016).

Overall, although localized benthic impacts immediately under the net pens may be severe because of their rapid reversibility (i.e., a lack of irreversible impacts) and limited spatial scale, there is considered only a "moderate" habitat impact on the provision of ecosystem services at any one farm site. The score for Factor 3.1 is 7 out of 10.

Factor 3.2. Habitat and farm siting management effectiveness

Factor 3.2a – Content of effluent management measures

Licensing and permitting of new sites is complex in Scotland. Planning consent from the Local Authority, a discharge consent for farm wastes and veterinary medicines from the SEPA under the Controlled Activity Regulations (CAR), a navigation consent from Marine Scotland, and a seabed lease from the Crown Estate must all be obtained. It may be necessary for a new development to carry out an Environmental Impact Assessment (EIA) as required by the Environmental Impact Assessment (Scotland) Regulations 1999 (as amended). Marine fish farming is listed as a Schedule 2 development, meaning if production exceeds 100 MT per year or covers an area greater than 1,000 m,[2] or if the proposed site is in a sensitive area, the project must be assessed by a planning authority to determine whether a full EIA is needed. In addition, if a proposed site is close to an area with a nature conservation designation (e.g., Special Protection Area, Special Areas of Conservation, Natura sites, and Ramsar sites), consultation with Scottish Natural Heritage and other relevant stakeholders is mandatory. Operationally, the regulatory system controlling the benthic habitat impacts has been described previously in the Effluent Criterion, and is based on site-specific biomass limits set according to modelling of the site hydrodynamics and the larger waterbody carrying capacity defined within the *Locational*

Guidelines for Marine Fish Farms in Scottish Waters. These systems are comprehensively described on the SEPA website, and are not repeated here.

As described above (Criterion 2 – Effluent), the regulations in Scotland are highly regarded internationally; nonetheless, the industry continues to expand and the licensing system is currently under review.[17] SEPA is consulting on a proposed new system based on a Depositional Zone Regulation (DZR),[18] which may facilitate expansion, and in theory restrict it to suitable sites. The timeframe for consultation and implementation is uncertain at the time of writing. The primary goal of the current site-specific biomass limits is to avoid significant impacts beyond the Allowable Zone of Effect, presumably accepting that the impacts within it will be more substantial; despite this, the area affected is limited and overall, an area-based cumulative management system is considered to be operating at the waterbody level under the *Locational Guidelines*. The content of the regulatory system is scored 4 out of 5 in Factor 3.2a, and future revisions of this assessment will consider developments of the new regulatory system and the effectiveness of the DZR.

<u>Factor 3.2b – Enforcement of habitat management measures</u>
With the similarity in regulatory enforcement between the Effluent and Habitat Criteria, the content in Factor 2.2b in the Effluent Criterion above is referred to here. Overall, though the enforcement organizations are clearly identifiable and active, as evidenced by the data available from SEPA, the limited potential for SEPA to conduct regular audits is a concern, as are the self-reported results showing a significant number (22.5%) of sites have unsatisfactory conditions in the immediate farm area assessed in this Habitat Criterion. The score for Factor 3.2b Enforcement of effluent management measures is 3 out of 5.

The final score for Factor 3.2 combines the scores for the regulatory content (Factor 3.2a) with the effectiveness of the enforcement (Factor 3.2b), and with the similarity between the Effluent and Habitat criteria for net pen production systems, the score Factor 3.2 is also 4.8 out of 10.

Conclusions and Final Score
Overall, the limited direct habitat impacts of the floating net pen production system and the reversible nature of the benthic impacts result in a score for Factor 3.1 of 7 out of 10. Although the regulatory system is well established and highly regarded, the enforcement appears to be limited and 22.5% of sites in 2015 had unsatisfactory benthic conditions in the immediate farm area. Overall, the final score for Criterion 3 – Habitat is 6.27 out of 10.

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[17] Independent Review of Scottish Aquaculture Consenting. http://www.gov.scot/Publications/2016/07/9269/0
[18] SEPA Agency Board Meeting 29 November 2016. https://www.sepa.org.uk/media/219685/sepa-37-16-chief-executives-report.pdf

Criterion 4: Chemical Use

Impact, unit of sustainability and principle

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

Criterion 4 Summary

Mainland, Shetland and Western Islands

Chemical Use parameters	Score	
C4 Chemical Use Score (0-10)	**1**	
Critical?	NO	**RED**

Orkney Islands

Chemical Use parameters	Score	
C4 Chemical Use Score (0-10)	**8**	
Critical?	NO	**GREEN**

Brief Summary

The total quantity of antibiotics used in Scotland has decreased considerably over the last ten years and they were used on only eight sites in 2016. Both types of antibiotics used in recent years (oxytetracycline and florfenicol) are listed by the World Health Organisation as "highly important" for human medicine, but the data indicate that, across the industry, they are used much less than once per production cycle with an overall relative use of 0.52g/ton. The greater concern for impacts of chemical use in Scottish salmon farming is pesticide use to treat parasitic sea lice. The pattern of pesticide use is complex and variable by treatment type and region, but on average, there were four sea lice treatments per active site in 2016, excepting the Orkney Islands region, which has a very low number of sea lice treatments (less than once per production cycle) and a very low relative use, apparently due to different sea lice infection dynamics in the area. Nationwide, the bath treatment azamethiphos has increased rapidly from 2013 to 2016. The use of hydrogen peroxide as an alternative bath treatment increased by 3,700% between 2011 and 2015 with a total use of 19,500 MT in 2015, but then decreased to 11,874 in 2016 (although this is not considered to have a significant environmental impact, and is also used to treat conditions other than sea lice). The primary impacts are considered to be on the seabed due to the settlement of in-feed treatments in uneaten feed and feces. Monitoring for residues shows the use of emamectin benzoate (used in 354 treatments in 2015) is sufficient to exceed environmental quality standards at 100 m from the net pens on almost a quarter of treated sites in Scotland. Concerns with seabed residues of emamectin benzoate have led to a review of site discharge licenses for this pesticide.

Overall, there is an increasing trend in use of pesticides with a potential for rapid fluctuations between treatments of differing toxicity. On average, there are multiple treatments at each site, resistance is well established, and the use of one in-feed treatment is sufficient to exceed environmental quality standards at a large number of sites. The final score for the mainland of Scotland and the Shetland and Western Islands for Criterion 4 – Chemical Use is 1 out of 10. But, given the stark differences in the Orkney Islands region, this is scored separately, and the final score for Orkney is 8 out of 10.

Justification of Ranking

The expansion of commercial aquaculture has necessitated the routine use of veterinary medicines to prevent and treat disease outbreaks, assure healthy stocks, and maximize production (FAO 2012). This Seafood Watch assessment focuses on antibiotics and sea lice pesticides as the dominant veterinary chemicals applied to salmon farming. Although other types of chemicals may be used in salmon aquaculture (e.g., antifoulants, anesthetics), the risk of impact to the ecosystems that receive them is widely acknowledged to be less than that for antibiotics and pesticides.

Antibiotics

Aggregated data for all farmed fish from the UK's Veterinary Medicines Directorate (UK-VARSS 2015) shows a general decline from 2.1 MT in 2011 to 0.7 MT in 2015, but with a spike to 2.4 MT in 2014; but, without further information on the relative use between species (e.g., farmed trout or other species in the UK), these figures are not considered applicable to salmon only. Instead, Figure 8 shows the quantities of antibiotics (in kg of active ingredient) used in Scottish salmon aquaculture between 2006 and 2016, obtained by a Freedom of Information request from SEPA. In 2016, there were only eight sites reporting antibiotic use in Scotland (two sites using oxytetracycline and two florfenicol) with a total weight of active ingredient of 92.6 kg. Of this total, 80.6% (by weight) was florfenicol, and 19.4% oxytetracycline (note: any comparisons between antibiotic types made according to weights of active ingredient are challenging due to the different potency and dose rate of the different treatments). The 2016 relative use, in terms of grams of antibiotic per ton of production, was 0.52 g/ton. For comparison, Chile's salmon farming industry in 2015 used 735 g/ton (data analyzed from Sernapesca [2016]).

Due to the increased use of vaccines and better biosecurity, the total annual quantities have declined since the early- and mid-2000s (Burridge, Weis et al. 2008). Spikes in use continue in response to specific disease events, but the site-level data provided by SEPA show the 2014 spike in use was due to only two oxytetracycline treatments (out of 11 treatments total industry-wide that year).

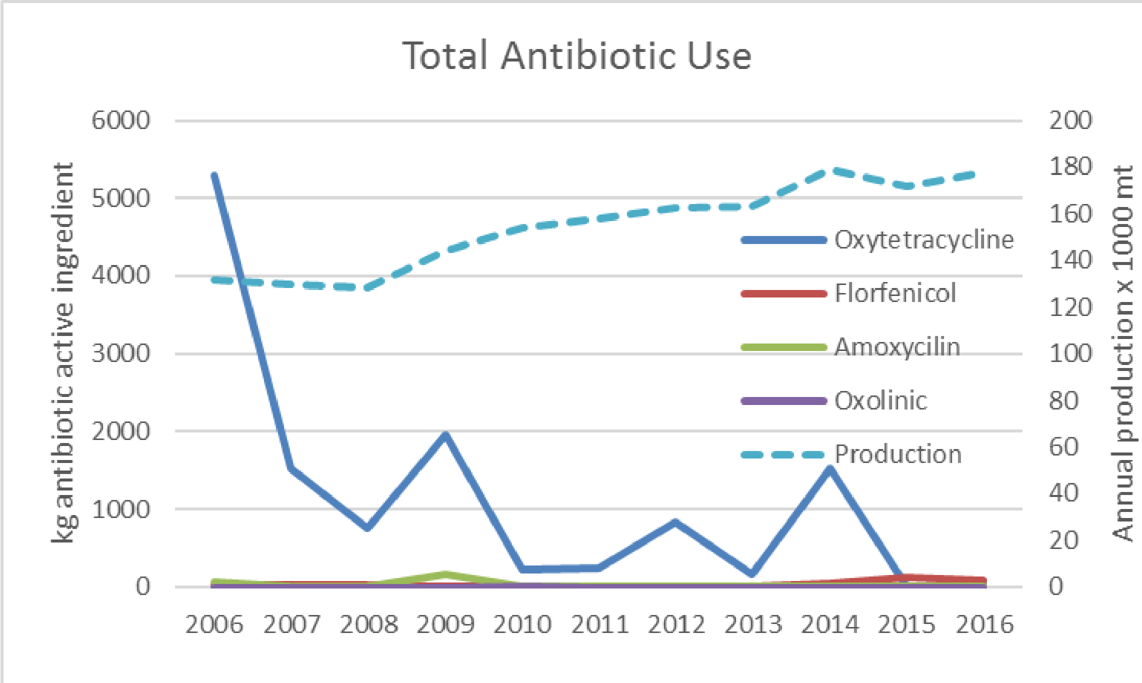

Figure 8: Antibiotic use in Scotland from 2006 to 2016 (solid lines) and total salmon production (dashed line). Antibiotic use data from SEPA (FOI request), production data from Munro and Wallace (2016).

These limited numbers of treated sites imply that relatively large amounts of antibiotics are occasionally used on those sites; for example, the two dominant sites responsible for the spike in 2014 (both in the Highlands region) used 761.5 kg and 743.4 kg of oxytetracycline respectively. Both oxytetracycline and florfenicol are listed by the World Health Organisation as "Highly Important" for human medicine (WHO 2016).

Despite this, the use of antibiotics in Scotland is clearly limited to a small number of sites each year, and the relative use is low (0.5 g/ton); thus, the broader concerns regarding chemical use (and the driver of the Chemical Use score) relate to sea lice pesticides as discussed below.

<u>Pesticide use</u>

Pesticide use as a veterinary medication in Scotland is regulated on a site-specific basis with discharge consents under the SEPA Controlled Activity Regulations. The primary target for pesticide use in salmon farming in Europe is the parasitic sea louse *Lepeophtheirus salmonis*, and to a lesser extent *Caligus elongatus*, which together with similar species in other regions are considered the most economically important ectoparasites affecting Atlantic salmon culture worldwide (Covello et al. 2012). Salmon farming remains largely dependent on the use of pesticides; Figure 9 shows the annual quantities of five different treatments used in Scottish aquaculture between 2008 and 2016. When considering different pesticides and quantities of use, it is essential to note that they vary greatly in their toxicity and dose rates; therefore, although the data in Figure 9 and in the text below are useful for comparing temporal changes in use of any one treatment, they should not be used for comparisons by weight or volume across different treatments.

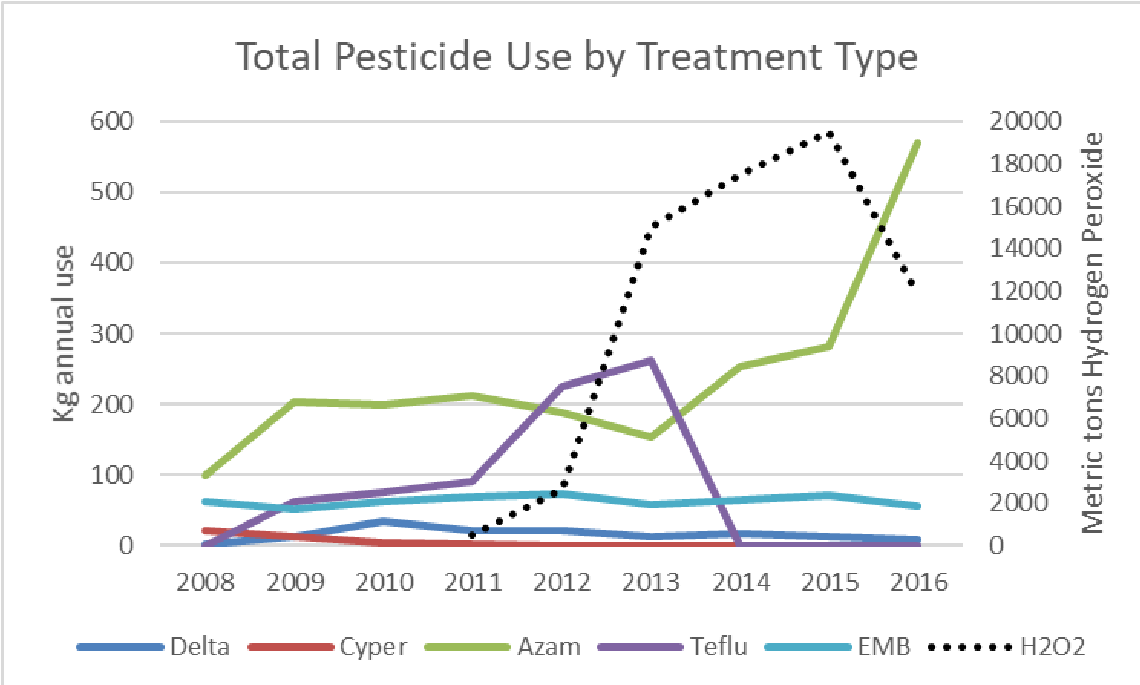

Figure 9: Pesticide use from 2008 to 2016. Quantities in kg active ingredient, except hydrogen peroxide (H_2O_2) in metric tons (dotted line and secondary y-axis). Data from SEPA in *Scotland's Aquaculture* database, and FOI request for H2O2.

Figure 9 shows changing patterns of treatment use with high and increasing use (by weight) of teflubenzuron in 2013, then dropping to zero in 2014, while azamethiphos concurrently increased rapidly, apparently as an alternative. Nonetheless, it is important to use caution with these data; teflubenzuron by weight was high in 2013, but the frequency of treatment was low (five treatments in total). Figure 10 shows the frequency of use of each treatment over recent years, and the total number of all treatments. This shows emamectin benzoate is still the most common treatment with 253 treatments in 2016, with azamethiphos the second.

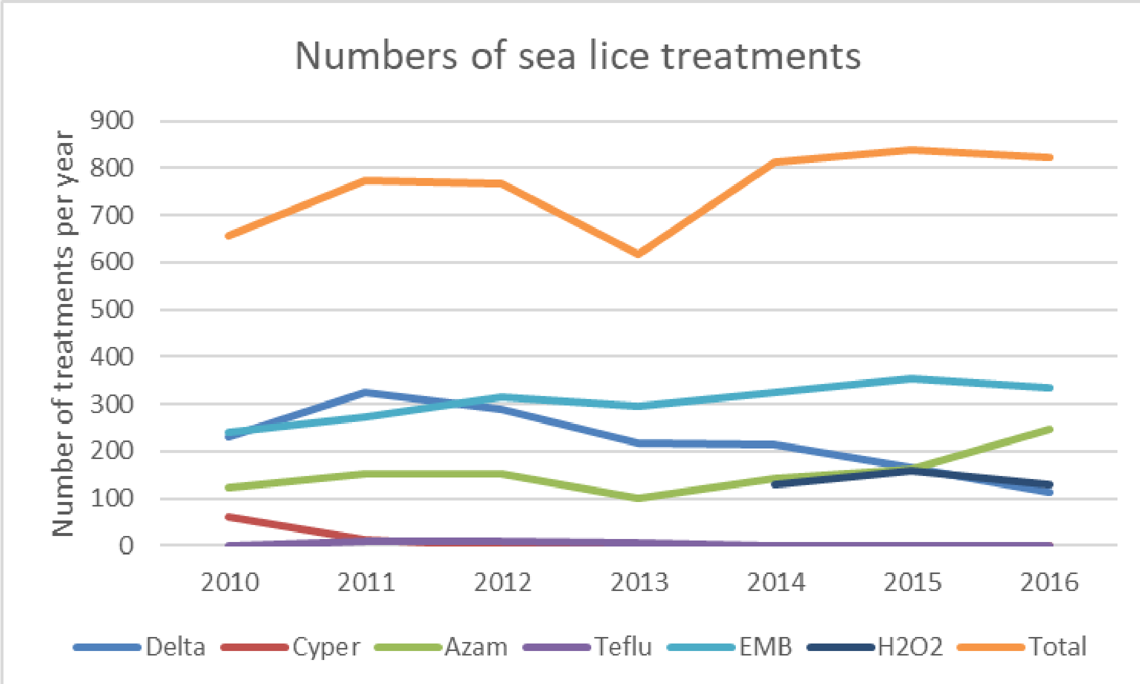

Figure 10: Number of treatments by pesticide type, and total for the years 2010 to 2016. Data from *Scotland's Aquaculture* database, and from a Freedom of Information request from SEPA for hydrogen peroxide (H_2O_2).

The use of hydrogen peroxide also increased very rapidly from 527 MT in 2011 to 19,500 MT in 2015, with a substantial decrease to 11,874 MT in 2016 (anecdotally, the large increase to 2015 is considered in this assessment to be largely due to developing resistance in other treatments, and due to reaching discharge consent limits for veterinary medicines under the SEPA Controlled Activity Regulations, but this chemical is used for other conditions too—for example, amoebic gill disease). The use of the other pesticide treatments in Figure 9 (deltamethrin, cypermethrin, and emamectin benzoate) has remained somewhat stable, and cypermethrin has not been used since 2010 (it no longer has a marketing authorization in Scotland). The total number of sea lice treatments in 2016 was 823, which, given the 207 active[19] marine sites (Munro and Wallace 2016), is an average of four treatments per site per year.

<u>Pesticides – regional use</u>

From a regional perspective, the relative use of pesticides in grams of pesticide per ton of production[20] is highly variable. Figure 11 shows the relative regional use of pesticides in grams per ton of production (see footnote 20 on calculation) and total number of treatments per region in 2016. Orkney stands out with minimal pesticide use, but the Highlands, Western Islands (Eilean Siar), and Argyl-Bute have both high relative use and a high number of treatments. North Ayreshire had only one active site in 2016, which was treated six times with

[19] Although 254 "active" sites were reported in 2015, 47 were fallow for the whole year = 207 active sites (Munro and Wallace, 2016).

[20] Regional production was calculated by converting total feed data per region (extracted farm-by-farm from *Scotland's Aquaculture* database) to salmon production based on a Scotland-wide eFCR value of 1.25.

emamectin benzoate in 2016, therefore it has low total production of salmon and a low total number of treatments, but high relative use.

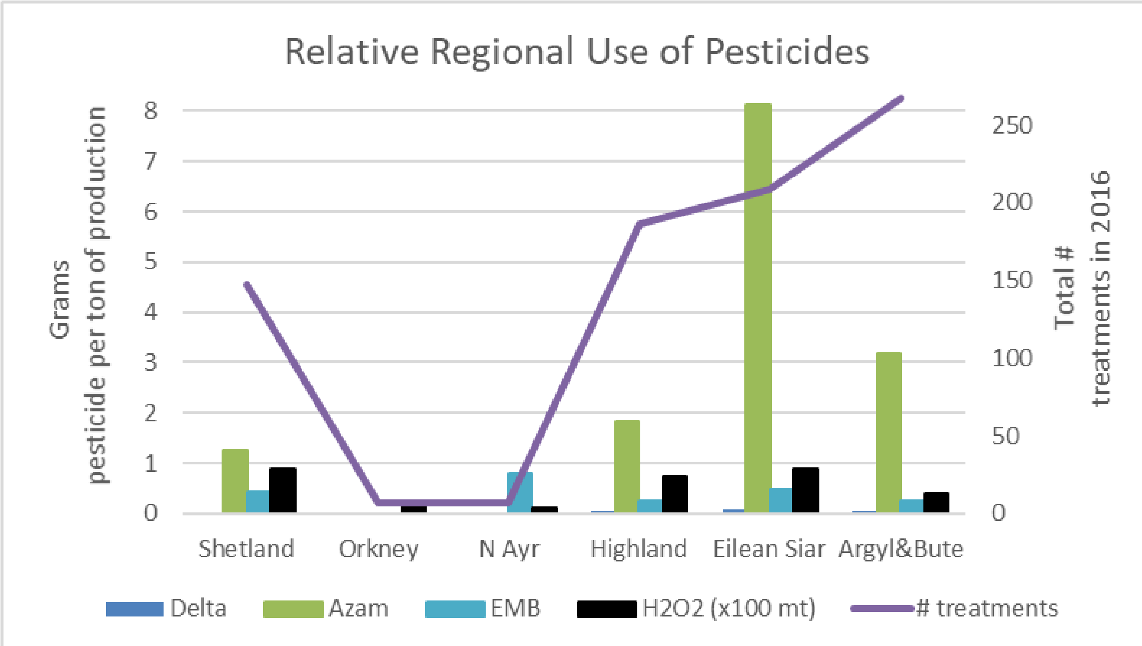

Figure 11: Relative regional use of pesticides in grams per ton of production (bars) and total number of treatments per region* (line – secondary y-axis) in 2016. Values for hydrogen peroxide (H2O2) are in hundreds of metric tons. Data from SEPA in *Scotland's Aquaculture* database and an FOI request for H2O2. *Note: this value is on a monthly basis (i.e., the number of sites in any one month that use pesticides), and may err on the low side by not counting multiple treatments at any one site in a month.

Orkney has lower production than the other four main regions (Figure 3), but at over 10,000 MT in 2015 with approximately 15 to 18 active sites at any one time (in 2015), Orkney's production is still substantial. Therefore, the very low number of treatments in 2016 (seven treatments, all hydrogen peroxide) is less than one treatment per site; the current avoidance of the more ecologically-harmful treatments presents a significantly different risk of impact and is highlighted in the scoring below.

<u>Pesticides – potential impacts</u>
Sea lice treatment pesticides are non-specific (i.e., their toxicity is not specific to the targeted sea lice) and, therefore, may affect non-target organisms—in particular crustaceans—in the vicinity of treated net pens (Burridge et al. 2010). The dominant treatment by weight or volume is hydrogen peroxide, but this is considered environmentally benign since, upon contact with water, it rapidly dissociates in the immediate farm area into elemental hydrogen and oxygen (Lillicrap et al. 2015). Azamethiphos is a bath treatment and the dominant pesticide used in Scotland by weight. Though some authors contest that such treatments may retain toxicity for a substantial period after release (Burridge et al. 2010), Macken et al. (2015) conclude that bath treatments such as azamethiphos (and deltamethrin) have a rapid release, dispersion, and dilution post treatment, and primarily impact non-target organisms in an acute manner with limited potential for chronic impacts. In their study on the epibenthic copepod *Tisbe battagliai*,

azamethiphos was acutely toxic at high concentrations (such as within the immediate net pen area), but was found to cause no developmental effects at lower concentrations (such as after rapid dispersion and dilution from the net pen). In Scotland, SEPA[21] considers azamethiphos to remain in the aqueous phase until it is broken down into non-toxic derivatives, for which a decay half-life of 8.9 days has been determined. Two Environmental Quality standards have been set for residue levels at 3 hours and 3 days post-treatment, and site permitting and consent allowances are based on modelling of dispersion.

In-feed treatments tend to be dispersed in uneaten feed and fecal particles that settle to the seabed (Burridge et al. 2010); Samuelsen et al. (2015) and references therein showed that residues in settling organic particles (feces) can be more concentrated than in the feeds. Persistence in the sediment ultimately depends on the chemical nature of the product used and the chemical properties of the sediment, and toxicity to non-target organisms of in-feed sea lice treatments tends to be of a chronic nature at low concentrations (Macken et al. 2015) (Lillicrap et al. 2015). Samuelsen et al. (2015) showed that, although pesticide residue levels in the sediments are low, particles containing residues have been found as far as 1,100 m from the treatment site. Of in-feed treatments recorded in Scotland, teflubenzuron has not been used since 2013, but emamectin benzoate is actively used in Scotland. Benthic monitoring data for teflubenzuron and emamectin residues is available from SEPA in *Scotland's Aquaculture* database.

Regarding the available data for emamectin benzoate, the Environmental Quality Standard (EQS) for emamectin is 7.63 µg/kg sediment at the net pen edge, and 0.763 µg/kg at 100 m from the pen (based on SEPA's modelling of in-feed treatments for site permits and consenting[22]). An analysis of the residue data from 2010 to 2016 (Figure 12) shows less than 5% of the samples at the pen edge exceed the limit in 2016, but 24.6% of samples at 100 m exceed it. The average period between the end of treatment and the sampling date is 153 days in 2016 (i.e., approximately 5 months). As part of a longer-term study by the Scottish Aquaculture Research Forum (SARF), a recent study (SARF098, 2016) assessing the highest reported use of emamectin in Scotland in terms of per production cycle (3 kg) and per site (10 kg in repeated treatments) showed strong evidence of a substantial decline in crustacean richness and abundance, even at reference sites 150 m away from cages. Although this peak use may not be representative of many sites in Scotland, the study has prompted a review of site licenses by the Scottish Environmental Protection Agency. Therefore, despite the apparently low total quantity used per year (56.5 kg in 2016), the use of emamectin benzoate in 253 treatments in 2016 is sufficient to exceed environmental quality standards on many sites in Scotland.

[21] Models for assessing the use of medicines in bath treatments: https://www.sepa.org.uk/media/114774/ffm_anx_g.pdf

[22] Methods for modelling in-feed anti-parasitics and benthic effects: https://www.sepa.org.uk/media/114787/ffm_anx_h.pdf

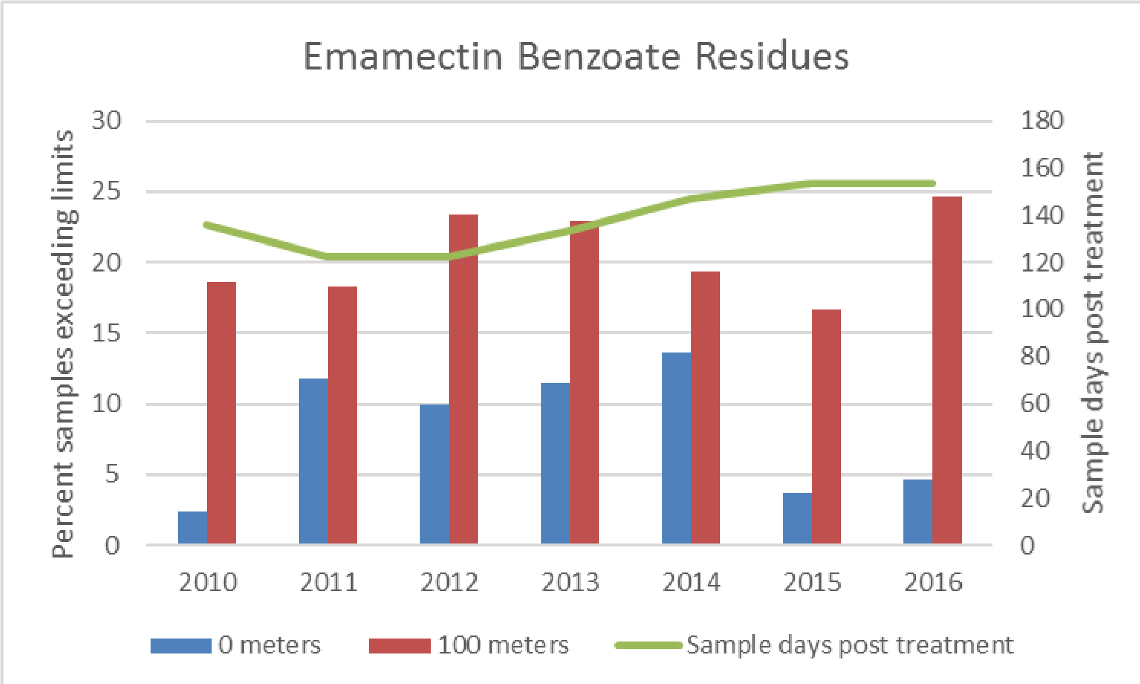

Figure 12: Percentage of samples exceeding the emamectin benzoate EQS from benthic residue testing at the cage edge and at 100m from 2010 to 2016. Green line is the average number of days between the end of treatment and the sampling date. Data from *Scotland's Aquaculture* database.

Importantly, Burridge et al. (2010) highlight the fact that: "no studies (lab or field) have adequately addressed cumulative effects and salmon farms do not exist in isolation." These authors state "While the salmon industry has made significant progress in sea lice control using coordinated area treatments, multiple treatments within a single area may result in significantly different exposure regimes for non-target organisms than a single treatment." Therefore, although there may be minimal effects from a single farm, this may not be the case where there are cumulative impacts from multiple farms in close proximity (Dill 2011).

<u>Resistance to sea lice treatments</u>

According to Jones et al. (2013), the development of treatment resistance in sea lice has become problematic for salmon-farming regions around the world. Aaen et al. (2015) provide a review of drug resistance in sea lice, and report resistance has developed or been reported for all the sea lice treatments used in Scotland; resistance to emamectin benzoate, cypermethrin, and deltamethrin is widespread, and has been reported for azamethiphos and hydrogen peroxide.

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 (Aaen et al. 2015). Genes conferring resistance to a particular parasite treatment 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 (Jones et al. 2013).

Antifoulants and other metals

Copper use as a net antifoulant in Scotland continues to be significant, but Figure 13 shows the quantity used is dropping, from a peak of over 140 MT in 2012 to less than 60 MT in 2016. Zinc discharge as a result of feed use has increased slowly from 26 MT in 2008 to 32 MT in 2016.

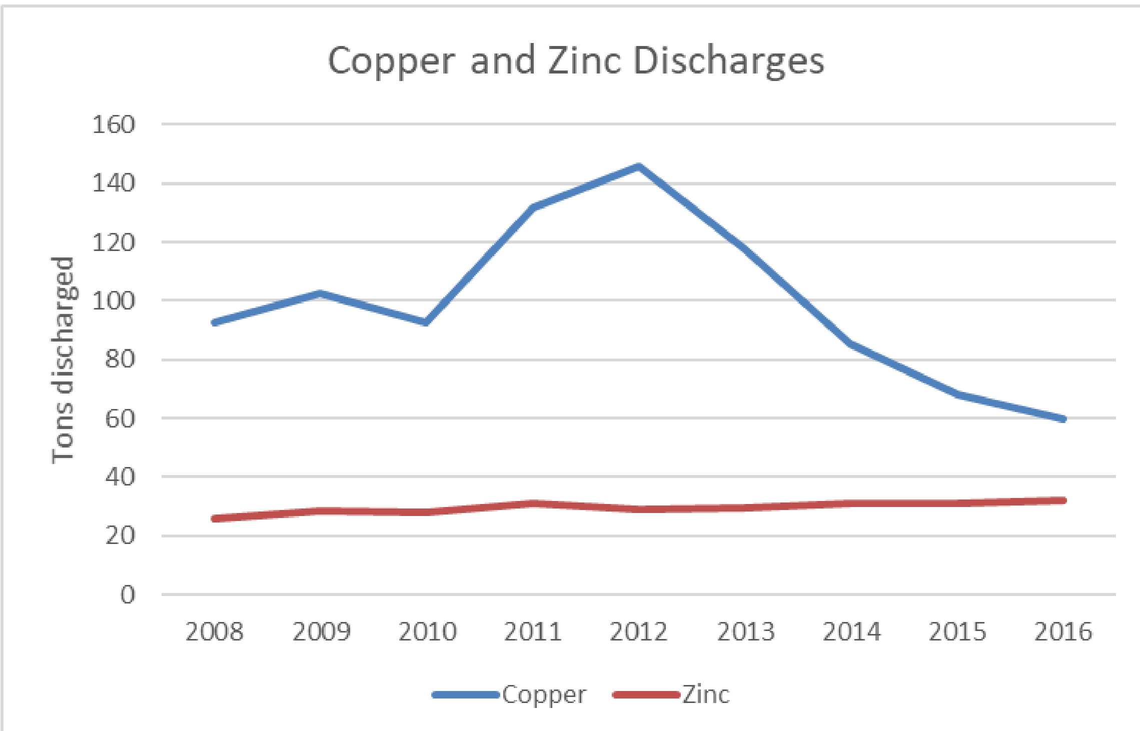

Figure 13: Annual copper and zinc discharge from salmon sites in Scotland. Data from SEPA in *Scotland's Aquaculture* database.

The amounts used and discharged to the environment (and therefore their impacts) vary according to inter-related factors of using (or not using) treated nets and the use of in-situ or on-land net washing systems. Although Loucks et al. (2012) reported that 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 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 persistence and impact spectrum. In general, impacts on non-target organisms are likely to be restricted to areas close to net pens and within the AZE; for example, Russell et al. (2011) showed sediment samples with concentrations of copper that might cause adverse effects in the environment were all within 25 m of the pens. They concluded that any impact on the environment from organic pollutants or trace metals such as copper and zinc is of a local nature. It must also be noted that, because of the chemical nature of the sediments, the metals may not be bio-available to non-target organisms, and according to Burridge et al. (2011), several papers have shown that effects reported are not necessarily a consequence of elevated metal concentrations. For example, references quoted in Hambrey and Nickell (2011) show there is good evidence that copper is unavailable to infaunal organisms in anoxic conditions; similarly, Brooks et al. (2003, 2004) concluded that both zinc and copper were unlikely to be toxic when sulphides were abundant in marine sediment. Therefore, the potential impacts of these metals is considered minor in relation to other chemicals, particularly pesticides, which are the driver for the final scores in Scotland.

Conclusions and Final Score

A small number of sites in Scotland still use large amounts of antibiotics, but overall, the total quantity has decreased considerably and is limited to a small number of sites each year (eight sites in 2016); industry-wide, therefore, antibiotics are used much less than once per production cycle. Pesticide use to treat parasitic sea lice is complex and variable by treatment type and region; the very low use in Orkney is highlighted and scored separately below. While the in-feed treatment teflubenzuron was the most-commonly used (by weight) in 2013, the frequency of use was low and has since dropped to zero. The bath treatment azamethiphos has increased rapidly and dominates by weight, but emamectin benzoate is still the most commonly used. Also, the use of hydrogen peroxide as an alternative bath treatment increased by 3,700% between 2011 and 2015, with a total use of 19,500 MT in 2015, but decreased substantially to 11,874 MT in 2016. On average, there were four sea lice treatments per site in 2016. These increasing treatments with rapid changes in chemical choice indicate the complex management (and perhaps the struggle) to control sea lice in Scotland, as does the documented development of resistance to key treatments. The primary impacts are considered to be on the seabed due to the settlement of in-feed treatments in uneaten feed and feces; monitoring for residues shows the use of emamectin benzoate (used in 354 treatments in 2015) is sufficient to exceed environmental quality standards at 100 m from the net pens on almost one-quarter of treated sites in Scotland. Concerns with seabed residues of emamectin benzoate has led to the review of site discharge licenses for this pesticide.

Overall, there is an increasing trend in the use of pesticides across Scotland with a potential for rapid fluctuations between treatments of differing toxicity. There are multiple treatments on average at each site, resistance is well established, and the use of one in-feed treatment is sufficient to exceed environmental quality standards at many sites. The final score for Criterion 4 – Chemical Use is 1 out of 10 for the mainland of Scotland and the Shetland and Western Islands. The demonstrated significant difference in necessity for sea lice treatments at farm sites in the Orkney Islands (less than once per site per production cycle) represents a similarly significant difference in the risk that such treatments pose to the receiving ecosystem. The final score for Criterion 4 – Chemical Use is 8 out of 10 for the Orkney Islands.

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.

Criterion 5 Summary

All Regions

Feed parameters	Value	Score
F5.1a Fish In: Fish Out ratio (FIFO)	2.24	4.40
F5.1b Source fishery sustainability score	–5.00	
F5.1: Wild fish use score		2.16
F5.2a Protein IN (kg/100kg fish harvested)	33.63	
F5.2b Protein OUT (kg/100kg fish harvested)	23.38	
F5.2: Net Protein Gain or Loss (%)	–30.50	6
F5.3: Feed Footprint (hectares)	16.15	4
C5 Feed Final Score (0-10)		**3.58**
Critical?	NO	**YELLOW**

Brief Summary

Fishmeal and fish oil inclusion in Scottish salmon feeds continues to be replaced by increasing levels of alternative crop protein or oil ingredients. Data provided by one of three major feed companies supplying Scottish farms show the economic feed conversion ratio (eFCR) is 1.25, and from first principles, 2.24 ton of wild fish must be caught to provide the fish oil required to produce one ton of farmed salmon. A variety of global fisheries provide these marine ingredients with a range of sustainability scores (a majority are IFFO RS-certified, some are MSC-certified, others have low FishSource scores) and result in an overall Wild Fish Use score of 2.16 out of 10. There is a net edible protein loss of 30.5% and a total feed footprint of 16.15 hectares per ton of production. Overall, the final score for Criterion 5 – Feed is 3.58 out of 10.

Justification of Ranking

The Seafood Watch Aquaculture Standard assesses three feed-related 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 full detail of the calculations, see the Seafood Watch Aquaculture Standard document.[23]

The following assessment is based on data provided anonymously by one of three major feed companies active in Scotland and represents feeds used in 2016. Requests for information from the remaining two were not answered. In addition, various parameters are available from Shepherd et al. (2017) although it is noted that the data in that study are from 2014 to 2015. According to Shepherd et al. (2017), the feed situation in Scotland is complicated by a proliferation of bespoke diets driven by external standards (e.g., organic or Label Rouge), or linked to retail requirements; however, the volumes of these feeds are relatively low, with the well-known Label Rouge production being only 4% of Scottish feeds. It is acknowledged that there is a risk that the calculated values below are not fully representative of Scottish production, but differences between companies are considered likely to be relatively minor compared to the broader regional differences and markets within which they operate; for example, Europe typically does not use land animal ingredients in feeds, while Chile and Canada do. In Scotland, the use of land animal feed ingredients is not permitted under the *Code of Good Practice* (Shepherd et al. 2017).

Factor 5.1. Wild Fish Use

Factor 5.1a – Feed Fish Efficiency Ratio (FFER)

Total fishmeal and fish oil inclusion levels are 33% and 16% respectively, but 46% of fishmeal and 44% of fish oil come from byproduct sources. The basic inclusion levels (33% and 16%) are slightly higher than the 25% and 16% for fishmeal and oil respectively reported by Shepherd et al. (2017), but the inclusion levels of byproduct sources are not specified. An annual economic feed conversion ratio (eFCR) was calculated by dividing total annual feed inputs (data from *Scotland's Aquaculture* database) by annual production[24] (Munro and Wallace 2016). Annual eFCR figures from 2012 to 2015 range between 1.23 and 1.28 with no obvious trend; therefore, an average of these four years, in addition to a value of 1.20 for 2016 provided by the feed company, was used to generate the final eFCR of 1.25. This is close to the estimated value of 1.3 for 2014 from Shepherd et al. (2017). These figures generate FFERs for fishmeal and fish oil of 0.99 and 2.24 respectively, which, for reference, are close to the 0.74 and 2.28 averages for fishmeal and fish oil from the two farming companies reporting this value through GSI. The higher calculated fish oil value (2.24) results in an FFER score of 4.40 out of 10.

Table 1: The parameters used and their calculated values to determine the use of wild fish in feeding farmed Scottish salmon.

Parameter	Data
Fishmeal inclusion level	33.0%
Percentage of fishmeal from byproducts	46%

[23] http://www.seafoodwatch.org/seafood-recommendations/our-standards

[24] It was noted previously that this figure is calculated based on conversion from gutted weight to whole fish equivalent; thus, there is some potential for a minor error. Nevertheless, it is the most reliable data point available.

Fishmeal yield (from wild fish)	22.5%[25]
Fish oil inclusion level	16%
Percentage of fish oil from byproducts	44%
Fish oil yield	5.0%[26]
Economic Feed Conversion Ratio (eFCR)	1.25
Calculated Values	
Feed Fish Efficiency Ratio (FFER) (fishmeal)	0.99
Feed Fish Efficiency Ratio (FFER) (fish oil)	2.24
Seafood Watch FFER Score (0-10)	**4.40**

Factor 5.1b – Sustainability of the source

The FFER score is adjusted by a factor determined by the sustainability of the fisheries sourced to provide marine ingredients. The default adjustment value of 0 considers that aquaculture should use sustainable feed ingredients, and an increasingly negative penalty is generated by increasingly unsustainable sources.

According to the feed company, the primary fisheries supplying the fishmeal and fish oil are somewhat global in nature (Ireland, Denmark, Iceland, South Africa, Norway, Peru, USA) with a range of species (anchoveta, blue whiting, capelin, menhaden, Norway pout, sand eel, sprat). Assessing the sustainability is therefore challenging. The feed company reports 98% of fishmeal and 10% of fish oil come from fisheries certified to the IFFO RS[27] responsible sourcing scheme, and an analysis of the available FishSource profiles show a range of scores. Some fisheries (or parts of them) are also MSC certified or in assessment, but the overlap between the feed company's broad fisheries-region classification and the specific components of fisheries certified to the MSC are not always clear. The fisheries therefore correspond to a range of sustainability scores in the Seafood Watch Aquaculture Standard, from –2 to –8, and therefore an intermediate score of –5 out of –10 is the most appropriate reflection of the range.

The adjustment to the FFER score is therefore is –2.24 giving a final score for Factor 5.1 – Wild Fish Use of 2.16 out of 10.

Factor 5.2. Net protein gain or loss

According to the feed company data provided, all protein comes from fishmeal or terrestrial crop sources (i.e., there are no land animal proteins used). The average feed protein content is 37%, and compares well with a value of 36% from Shepherd et al. (2017). Of this, 59.3% of total protein comes from fishmeal, of which almost half (i.e., 27.3% of total protein) comes from non-edible byproduct sources. The remaining 40.7% of total protein comes from terrestrial crop sources (e.g., soy, wheat, and pea proteins), considered to fall within the "edible" protein

[25] The fixed value from the Seafood Watch Aquaculture Standard is 22.5%, based on global values of the yield of fishmeal from typical forage fisheries. Yield estimated by Tacon and Metian (2008).

[26] The fixed value from the Seafood Watch Aquaculture Standard is 5%, based on global values of the yield of fish oil from typical forage fisheries. Yield estimated by Tacon and Metian (2008).

[27] http://www.iffo.net/iffo-rs

inputs. Considering the eFCR of 1.25, the edible protein input is 462.5 kg per ton of salmon produced.

Table 2: The parameters used and their calculated values to determine the protein gain or loss in the production of farmed Scottish salmon.

Parameter	Feed company data
Protein content of feed	37%
Percentage of total protein from non-edible sources (byproducts, etc.)	27.3%
Percentage of protein from edible sources	72.7%
Percentage of protein from crop sources	40.7%
Economic Feed Conversion Ratio	1.25
Protein INPUT per ton of farmed salmon	462.5 kg
Protein content of whole harvested salmon	18.5%
Percentage of farmed salmon by-products utilized	100%
Utilized **protein OUTPUT** per ton of farmed salmon	233.8 kg
Net protein loss	30.50%
Seafood Watch score (0-10)	**6**

The whole-fish protein content is 18.5% (Boyd 2007) and based on an earlier assessment made by Ramirez (2007), all by-products from harvested salmon are considered to be utilized (for fish silage and salmon meal); after the adjustment for the conversion of crop ingredients to farmed fish, the calculated protein output is 233.8 kg per ton of farmed salmon production and a net edible protein loss of 30.50%. This results in a score of 6 out of 10 for Factor 5.2 – Net Protein Gain or Loss.

Factor 5.3 Feed footprint

The data provided show that approximately 49% and 47% of total feed ingredients come from aquatic sources and terrestrial crop sources respectively. The area of aquatic and terrestrial primary productivity required to produce these ingredients is calculated to be 15.93 ha and 0.22 ha respectively. The total area of 16.15 ha equates to a score of 4 out of 10 for Factor 5.3 – Feed Footprint.

Table 3: The parameters used and their calculated values to determine the ocean and land area appropriated in the production of farmed Scottish salmon.

Parameter	Feed company data
Marine ingredients inclusion	49 %
Crop ingredients inclusion	47 %
Land animal ingredients inclusion	0 %
Ocean area (hectares) used per ton of farmed salmon	15.93 ha
Land area (hectares) used per ton of farmed salmon	0.22 ha
Total area (hectares)	16.15
Seafood Watch Score (0-10)	**4**

Conclusions and Final Score

The final score is a combination of the three factors with a double weighting for the Wild Fish Use factor. Factors 5.1 (2.16 out of 10), 5.2 (6 out of 10), and 5.3 (4 out of 10) combine to result in a final score of 3.58 out of 10 for Criterion 5 – Feed. As noted above, it is acknowledged that this value is based on data from only one of three major feed companies supplying feeds to Scotland; but, for the purposes of this assessment, the value is considered to be representative of the average producer in the region.

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.*

Criterion 6 Summary

All Regions

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

Brief Summary

Reported escapes of more than 10,000 fish occur annually in Scotland due to a variety of reasons, and very large-scale events such as the loss of 154,549 in 2014 continue to occur sporadically. These events represent a very small proportion of farm sites in Scotland, but additional undetected or unreported trickle losses may also cumulatively be substantial. Escaped fish are of varying sizes (up to >5 kg pre-harvest adults) and are present among wild salmon populations in rivers. Studies on genetic introgression are limited in Scotland (compared to Norway), but show evidence of farmed genetic material already present within wild Scottish salmon population. Although the situation regarding the genetic profile of salmon in Scotland is complex (for example, hatchery-reared salmon of Norwegian origin have previously been released into Scottish rivers under agreements with fishery managers in the 1970s and early 1980s), there is sufficient cause for concern regarding the fitness of native salmon populations from comprehensive studies in Norway and from agreement among international experts that a precautionary approach is required in Scotland. Therefore, the final score for Criterion 6 – Escapes is 2 out of 10.

Justification of Ranking

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

Factor 6.1 Escape risk

As long as aquaculture facilities are not fully contained, the escape of farmed fish into the wild is considered to be inevitable, and the net pens used in salmon farming offer the greatest opportunity for escapes as there is only a net barrier between the fish and the wild (Glover et al. 2017). With approximately 45 million smolts put to sea each year for growout in Scotland (45.5 million in 2015; Munro and Wallace [2016]), the total standing stock of farmed salmon is large, and on a global basis, hundreds of thousands of farmed Atlantic salmon escape into the wild each year (Glover et al. 2017). There is no doubt that the salmon industry in Scotland (and elsewhere) has gone to significant lengths to reduce escapes; as a result of the Scottish Government's Containment Working Group,[28] a "Technical Standard for Scottish Finfish Aquaculture"[29] was published in June 2015. In addition to the *Code of Good Practice for Scottish Finfish Aquaculture,* the purpose of the standard is to: "prevent escapes of finfish as a result of technical failure and related issues at Scottish finfish farms." It covers site surveys, mooring, pen and net design and construction, feed barges, secondary equipment, and site installations. All equipment is expected to meet the requirements by 2020, so full implementation of the Code and its requirements cannot currently be assumed. Requirements for reporting escape events under the Aquatic Animal Health regulations are detailed in Marine Scotland's *What to Do in the Event of an Escape of Fish from a Fish Farm.*[30] Any escape (or any event where there is a risk of escape) must be reported immediately, and followed up within 28 days with detailed information on losses and recaptures.

Figure 14 shows the Scottish industry's self-reported escape numbers between 2002 (when reporting escapes first became mandatory) and May 2017.

[28] http://www.gov.scot/Topics/marine/Fish-Shellfish/MGSA/Containmentwg
[29] http://www.gov.scot/Resource/0047/00479005.pdf
[30] http://www.gov.scot/Resource/0040/00403925.pdf

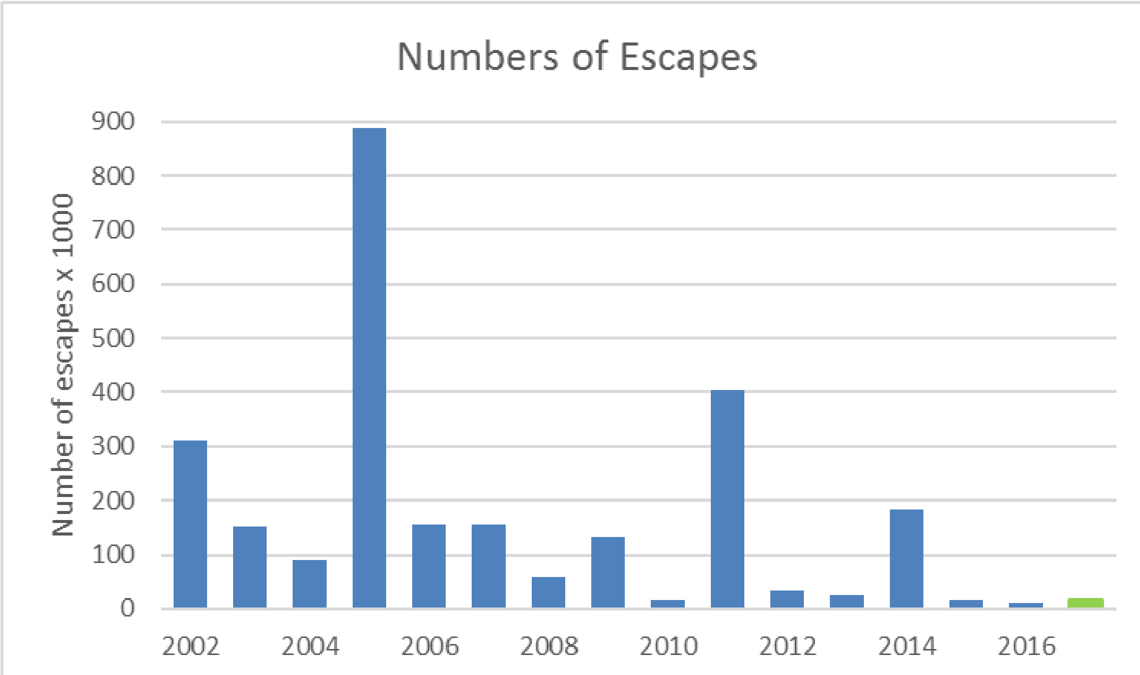

Figure 14: Scottish farmed salmon escape numbers (in thousands of fish), 2002 to May 2017. Data from Marine Scotland in *Scotland's Aquaculture* database.

The specific data show the number of reported events industry-wide each year is low, with an average of six reported escape events per year over the last five years; nonetheless, there have been large escape events every year since these records began in 2002. The most recent data show that approximately 17,000 fish escaped in one event in 2017, 10,000 in 2016, 16,000 in 2015, and 154,000 in 2014. Although these isolated catastrophic escape events are clearly limited to a very small number and small proportion of the salmon farms in Scotland, less-reported trickle losses can also be considered significant and potentially not detected or reported (Taranger et al. 2011). Escape statistics are usually based on reports by the farmers themselves and are likely to underestimate, significantly in some circumstances, the actual number of fish escaping from farms (Glover et al. 2017). In Norway, where significant research has taken place, Skilbrei and Wennevik (2006) note that small-scale undetected or unreported escape events may make up a large portion of the total escaped farmed fish, and a recent modelling analysis (also for Norwegian production) by Skilbrei et al. (2015) suggests that the total numbers of post-smolt and adult escapees have been two- to four-fold higher than the numbers reported to the authorities by farmers. ICES (2016) also supports the notion that the true number of escapees is likely to be significantly higher than reported figures.

In addition, Scotland is unusual among the leading salmon farming nations[31] in using net pen systems in freshwater for the production of smolts; according to Munro and Wallace (2016), 38 out of a total 87 smolt production operations (44%) are net pens (49 are in tanks and raceways). Glover et al. (2017) note that these systems, like the ones used for ongrowing in the

[31] Chile was until recently producing a large proportion of their smolts in net pens in freshwater lakes, but the use of land-based hatcheries is now dominant.

sea, offer the greatest opportunity for escapes, since there is only a net barrier between the fish and the wild. A similar potential for undetected and/or unreported escapes is present in freshwater systems too, and these have been noted in the past in Scotland with identification through vaccination marks (Franklin et al. 2012).

Until the recently-launched Technical Standard can be shown to be effective, the large escape events highlight the vulnerability of the production system and the ongoing high risk of structural failure and escape from any farm. Therefore, the very high numbers of fish held in any one net pen, combined with the inherently vulnerable and high-risk system means that there continues to be a high risk of catastrophic escapes in addition to the ongoing potential trickle losses of substantial cumulative numbers. Regarding the scoring, although the Technical Standard is not required to be fully met until 2020, in combination with the existing *Code of Good Practice*, it is considered evidence of emerging best practices. The ongoing escape events, despite being limited in number to a handful of sites each year, indicate the ongoing concern for large losses (in addition to undetected or unreported trickle losses). The score for Factor 6.1 is 2 out of 10.

Recaptures

The *Scotland's Aquaculture* database shows very little evidence of escapees being recaptured; the "number recovered" is zero for every event since 2012. Recapture success relates to many factors that control the dispersal and movement of escapees, including fish size, time of year, farm location, and prevailing currents (Skilbrei et al. 2015) (Skilbrei and Jorgensen 2010) (Olsen and Skilbrei 2010). For example, Skilbrei et al. (2015) noted (from studies in Norway) that the location and time of year of an escape is important, and concluded: "life stage at the time of escape has a profound influence on the survival, dispersal, and potential recapture of the escapees on both short and long timescales." According to Chittenden et al. (2011), recapture efforts must be immediate and widespread to mitigate farm-escape events, but a review by Dempster et al. (2016) noted that recapture success was universally low across all studied species, and recapture of escaped fish is broadly ineffective in marine habitats, with rare exception.

Scottish salmon fisheries statistics[32] show 54 farm-origin salmon were reported in the 2015 wild catch, with 94% of them caught in the more heavily-farmed north and west regions. It is not known when these fish escaped. Considering the need for substantial lethal control of pinniped predators on Scottish salmon farms, it appears likely that post-escape predation will be significant; yet, no reliable data exist. In conclusion, there is insufficient evidence to robustly justify a recapture and mortality score, and the final escape risk score, Factor 6.1, remains 2 out of 10.

Factor 6.2 Competitive and genetic interactions

Atlantic salmon is native in Scotland, but farmed salmon have undergone domestication

[32] Scottish Government Topic Sheet NO. 68 V7 2016. www.gov.scot

and directional selection for >12 generations and show considerable genetic differences to wild salmon for a number of fitness-related traits (Heino et al. 2015) (Glover et al. 2017). Changes in non-targeted traits have also been observed; for example, in predator awareness, stress tolerance, and gene transcription (references in Taranger et al. 2015). These well-established differences demonstrate the potential for genetic introgression and impacts to wild salmon populations if escaped fish are able to survive to maturity and reproduce with wild salmon. The last decade has thus seen a rise in concern regarding the direct genetic impacts of farmed escapes (Glover et al. 2017).

Farmed salmon can have a variety of direct and indirect impacts on wild populations after escaping from farms (Thorstad et al. 2008). As noted above, the movements and fate of escaped farmed salmon are complex, varying with size or age at escape, time of escape, and location, and impacts can occur distant to the escape site. In Scotland for example, lower numbers of escapees occur in rivers on the east coast, where there are no marine salmon farms, than on the west coast where farming occurs (Glover et al. 2017). There are few recent studies from Scotland, and Norway has an active research effort underway, yet robust conclusions are still scarce. Although ICES (2016) note the spawning success of escaped farmed salmon is much lower than wild salmon, the conclusions of Taranger et al. (2015) and Anon. (2016) are that salmon populations in one-third of rivers in Norway are in “Poor” or “Very poor” condition due to genetic introgression. At the same time, Svenning et al. (2015) and Kanstad-Hanssen and Bentsen (2014, 2015) indicate that the numbers of farmed salmon, and therefore the risk of genetic introgression, may be overestimated due to the sampling and identification methods for farmed salmon. More recent direct estimates based on genetic markers (Karlsson et al. 2016) found significant introgression in half of the populations studied, and levels of introgression >10% in nearly one-quarter of the populations. According to the recent half-century review of Glover et al. (2017), “there is globally unprecedented and unequivocal evidence of introgression of farmed salmon into ~150 native Norwegian populations (ranging from 0% to 47%),” but there is currently a lack of unequivocal documentation and quantification of the biological consequences (productivity and abundance, resilience, life-history profiles) of introgression in natural populations. Though these studies imply a level of concern in Scotland, the results from Norway cannot be considered to be directly representative.

Scottish Government data from *Scotland’s Aquaculture* database show that fish escaping in 2015 and 2016 ranged from 900 g to over 5.3 kg pre-harvest adults. ICES (2016) confirms that escapees are observed in rivers in all regions where farming occurs, although the numbers of escapees vary both spatially and temporally; earlier studies in Scotland robustly documented the presence and behavior of farmed salmon escapees in Scottish rivers (e.g., Webb et al. 1991, 1993) (Butler et al. 2005) (Walker et al. 2006) (Hansen and Youngson 2006), and recent Scottish salmon river fisheries statistics quoted above confirm salmon of farm origin are migrating into Scottish rivers. Tagged salmon deliberately released from Scottish farms have also established the capacity for long distance dispersal after being recaptured in Norway and Sweden (Hansen and Youngson 2010).

Unlike Norway, where the subject of genetic introgression has received considerable research, specific studies in Scotland appear limited. One recent small-scale study (Verspoor et al. 2016) studied interbreeding and introgression of farm genes into a small Atlantic salmon stock in northwest Scotland, and despite regular reports of feral farmed salmon, there was no evidence of physical or genetic mixing and the population was little affected by interbreeding with feral farm escapes. In contrast, a previous study (Coulson 2013) reported 369 out of 1,472 (25.1%) wild individuals were identified as hybrids (while recognizing the challenges in categorically differentiating wild, farmed, or hybrid), which was significantly higher than that seen for the east coast "wild" baseline where there are no salmon farms. According to Sinclair (2013), this strongly suggests that Norwegian genetic materials (i.e., from Scottish farmed salmon originally of Norwegian origin) are present in around 25% of the wild fish samples collected and analyzed in Scotland. Nonetheless, it is important to note that the genetic profile of salmon in Scotland is complex, and hatchery-reared farmed salmon of Norwegian origin have previously been deliberately stocked in Scottish rivers throughout the country under agreements with fishery managers during the 1970s and early 1980s (pers. comm., Iain Berrill SSPO 2017); therefore, it is likely that these actions played at least some part in these results (i.e., Sinclair 2013).

Overall, in the Atlantic as a whole, the large-scale invasion of wild salmon populations by domesticated farmed escapees has been described as one of the most striking examples of increased straying rates caused by humans for any organism, and this has raised global concerns for the fitness of native populations (Glover et al. 2013). Recognizing that there were still uncertainties, the WKCULEF[33] report (ICES 2016) considered that the evidence relating to the impacts of escapees through genetic introgression provided a clear indication of impacts on wild salmon populations. A substantial reduction of escaped farmed salmon in the wild, or sterilization of farmed salmon, would be required in order to minimize effects on native populations. Considering the domestication of several generations of Scottish farm stock, and the limited but concrete evidence that introgression has or does occur, the score for Factor 6.2 – Invasiveness is 2 out of 10.

Conclusions and Final Score

Reported escape events, where several thousand fish are lost from marine net pens, occur annually in Scotland for a variety of reasons. Very large-scale events, such as the loss of 154,549 fish in 2014, continue to occur sporadically. These events are less common than in decades past in Scotland, but additional undetected or unreported trickle losses may also be cumulatively substantial. Escaped fish are of varying sizes (up to >5 kg pre-harvest adults) and are present among wild salmon populations in rivers. Studies on genetic introgression are limited in Scotland (compared to Norway), but show evidence of Norwegian genetic material already within the wild Scottish salmon population. Although accepting that some genetic material may have come from deliberate stoking attempts, there is sufficient cause for concern regarding the fitness of native salmon populations from comprehensive studies in Norway and from agreement among international experts that a risk of population-level impacts could occur in

[33] Workshop to address the NASCO request for advice on possible effects of salmonid aquaculture on wild Atlantic salmon populations in the North Atlantic (WKCULEF).

Scotland without highly effective fish containment going forward. As net pen systems continue to be vulnerable to escapes, and the demonstration that some genetic introgression has occurred to date, the final score for Criterion 6 – Escapes is 2 out of 10.

Criterion 7. Disease; pathogen and parasite interactions

Impact, unit of sustainability and principle

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

Criterion 7 Summary

Mainland, Shetland and Western Islands

Disease Risk-based assessment

Pathogen and parasite parameters	Score	
C7 Disease Score (0-10)	1	
Critical?	NO	RED

Orkney Islands

Disease Risk-based assessment

Pathogen and parasite parameters	Score	
C7 Disease Score (0-10)	6	
Critical?	NO	YELLOW

Brief Summary

The open nature of net pen salmon farms means the fish are vulnerable to infection by pathogens and parasites from the surrounding environment, and 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 and other wild resident species. The number of farmed salmon in Scotland exceeds their wild counterparts by approximately 700:1. The annual mortality on salmon farms in Scotland has increased from 7,859 MT in 2010 to an estimated 19,800 MT in 2016 (in the same period, production increased 15%), while the mortality as a percentage of production has more than doubled from 5% in 2010 to over 12% in 2016. Despite the likelihood that bacterial and viral diseases are significant factors in these mortalities, there is little evidence of impacts from their transmission to wild fish, and the focus of the Disease Criterion is on parasitic sea lice, whose numbers have been shown to be elevated in the environment around salmon farms and to impact wild salmon and sea trout at the individual level. Sea lice numbers on farms are increasing despite the frequent use of pesticide treatments, with a large proportion of farming regions exceeding *Code of Good Practice* guidelines established for the protection of wild fish. Importantly, there is sufficient clarity in the data to highlight the Orkney Islands as a region not suffering from the same lice infection pressure as other regions in Scotland.

The Scottish Government accepts that salmon farms are a source of lice in the environment and that the increased lice levels observed on wild salmon and sea trout (i.e., anadromous brown trout) in the vicinity of farms can affect or kill individual fish, but there is limited research on population-level impacts in Scotland, particularly for sea trout; therefore, this aspect is currently inconclusive. Examples from similar situations in Norway, where research has been more comprehensive, shows a high level of concern particularly for population-level impacts to discreet populations of sea trout in areas with high levels of sea lice. Both Atlantic salmon and brown trout are listed in the UK as Biodiversity Action Plan priority species; they are identified as the most threatened and in need of conservation action under the plan. Without sufficient study on the impacts in Scotland, the Risk-Based Assessment has been used; the apparent high potential for population-level impacts to discreet wild sea trout populations, while the industry continues to struggle to control sea lice in Scotland, results in a final score for Criterion 7 – Disease of 1 out of 10 for the regions of mainland Scotland and the Shetland and Western Islands. Though not entirely comprehensive, the available data for the Orkney Islands region show that on-farm lice levels are consistently below the recommendations and treatment thresholds (and near-zero), and any discharge of lice pressure from farms is considered very low. The score for Criterion 7 – Disease for the Orkney Islands is 6 out of 10.

Justification of Ranking

The open nature of net pen salmon farms means the fish are vulnerable to infection by pathogens from the surrounding waterbody, from wild fish, or from other natural infection routes, and can suffer from, host, amplify, and act as a temporally unnatural reservoir for a variety of pathogens and parasites that have the potential to be transmitted or re-transmitted to wild resident organisms, including native salmon species (Hammell et al. 2009). Thus, the expansion of salmon aquaculture has brought conservation concerns to regions where the areas occupied by salmon farms are important migratory corridors for wild salmonids (Peacock et al. 2014). Like Norway,[34] the number of farmed salmon in Scotland exceeds their wild counterparts by approximately 700:1,[35] in contrast to British Columbia, for example, where wild salmon greatly outnumber[36] farmed salmon (Saksida et al. 2015); therefore, the potential for impact is significant.

<u>Bacterial and Viral Diseases</u>

The Scottish Government website lists the diseases affecting wild and farmed fish in Scotland and highlights the four notifiable bacterial and viral diseases: bacterial kidney disease (BKD), infectious hematopoietic necrosis (IHN), infectious salmon anemia (ISA), and viral hemorrhagic septicemia (VHS); the SSPO also publishes a quarterly fish health report and an annual Fish

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[34] Norwegian Environment Agency. Sea lice. http://www.miljodirektoratet.no/en/Areas-of-activity1/Species-and-ecosystems/Salmon-trout-and-Arctic-char/Pressures-on-salmonids/Sea-lice/

[35] The Atlantic Salmon Trust. Salmon Farming in Scotland: Economic Success or Ecological Failure? http://www.atlanticsalmontrust.org/policies-and-research/salmon-farming-in-scotland-economic-success-or-ecological-failure.html

[36] Note: Saksida et al. (2015) estimate wild salmon outnumber farmed salmon at a ratio of 1000:1, but the source or validity of this estimate is not known; the real number may be substantially lower.

Health Management Annual Report. The Scottish Government's Fish Health Inspectorate publishes quarterly and annual reports on aquaculture facilities in Scotland,[37] with information on disease inspections and routine monitoring; however, the reports cover all farmed species (including freshwater fish and shellfish), and are not separated by species. Although individual case information is also available, the format is unwieldy and not applicable to a search by species.

Unfortunately, therefore, none of these resources contain any useable specific disease information other than aggregated parasitic sea lice numbers, and any information or data on disease outbreaks in salmon farms in Scotland do not appear to be readily available. Anecdotal information in industry media reports highlight this situation, including reports of high mortalities with amoebic gill disease (AGD) occurring at four sites in late 2016.[38] Murray and Gubbins (2016) review the tools used for spatial management of disease in salmon farms in Scotland, describing Farm Management Areas (FMA) and Disease Management Areas (DMA), in addition to pathogen and parasite dispersal models. Figure 15 shows the annual mortality on salmon farms has increased from 7,859 MT in 2010 to 22,479 MT in 2016, while the mortality as a percentage of production has also increased from 5% in 2010 to 12.6% in 2016 (data from *Scotland's Aquaculture*). Munro and Wallace (2016) note that 45.5 million salmon smolts were put to sea with 48 million vaccines administered, but though the causes of the mortalities in Figure 15 are likely to be numerous, disease is considered likely to play a major part.

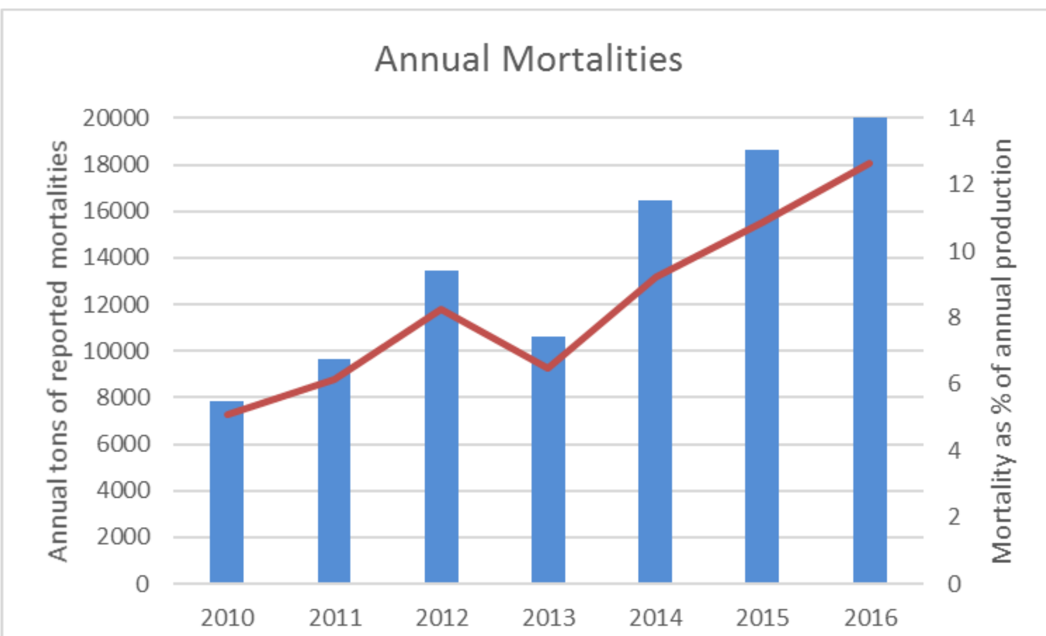

Figure 15: Annual mortalities in tons (blue bars) and mortality as a percentage of annual production (red line). Data from *Scotland's Aquaculture* database.

[37] http://www.gov.scot/Topics/marine/Fish-Shellfish/FHI/CaseInformation

[38] Intrafish Media, October 28, 2016. Scottish green group calls out Marine harvest over rampant disease levels. www.intrafish.com.

Considering the lack of useable public disease information in Scotland for salmon farms, it is useful to consider the example of the Norwegian Veterinary Institute's annual Fish Health Report, which provides a comprehensive review of the disease situation in Norway and is available publicly in English (Hjeltnes et al. 2016). Among 46 million Norwegian fish lost in growout in 2015 due to a variety of causes (handling, predation, escapes, harvesting rejects, and unregistered losses) Hjeltnes et al. (2016) note that infectious diseases are among the most important biological and economic loss factors.

With a focus on the potential impacts of on-farm diseases on wild fish, the Norwegian perspective can again be referenced; the Institute of Marine Research's "Risk assessment of the environmental impact of Norwegian Atlantic salmon farming" (Taranger et al. 2015) concluded: "*The high frequency of the viral disease outbreaks for PD* [Pancreas Disease]*, IPN* [Infectious Pancreatic Necrosis]*, heart and skeletal muscle inflammation, and CMS* [Cardiomyopathy Syndrome] *in Norwegian salmon farming suggests extensive release of the causal pathogens for these diseases in many areas. Migrating wild salmon and local sea trout are likely to be exposed to these pathogens. However, the extent of this exposure and consequences remains largely unknown. Screening of wild salmonids has revealed low to very low prevalence of the viruses SAV* [Salmon Alpha Virus – which causes Pancreas Disease]*, IPNV, PMCV* [Piscine Myocarditis Virus)*, and low prevalence of PRV* [Piscine ReoVirus which is associated with CMS] *in salmon. Furthermore, these viruses have never been documented to cause disease in wild Norwegian salmonids. Thus, a general lack of data prohibits complete risk estimation for these diseases."* This position is supported by the most recent monitoring by the Norwegian Veterinary Institute (Hjeltnes et al. 2016), who detect very low numbers of fish with any of these diseases in large samples of wild fish.

This assessment considers potential impacts from all pathogens, but although the information from Norway has uncertain relevance to Scotland, the lower concern for bacterial and viral diseases outlined above means this Disease Criterion will focus on the potential impacts of parasitic sea lice (*Lepioptheirus salmonis* and *Caligus elongates)* in the following sections.

<u>Sea lice</u>
For a comprehensive review of sea lice dynamics assessment and management from a global perspective, see Groner et al. (2016). In Scotland, according to the SSPO: "the management and control of sea lice and fish health is facilitated through the adoption of an area based approach, in which farms operating within defined FMAs adopt similar and joined up farming practices, for example stocking the same year class of fish and synchronized fallowing of farms at the end of the production cycle." This process is articulated in the Scottish *Code of Good Practice*, which has also set recommended, but not required, sea lice limits of 0.5 adult female lice per fish between February and June (the period of outward migrating salmon) and 1.0 adult female lice per fish for the rest of the year; nonetheless, the 839 pesticide treatments on 207[39] active

[39] There are 254 sites listed as "Active" in Munro and Wallace (2016), but data from *Scotland's Aquaculture* database shows 207 were actively stocked with fish during 2015.

salmon farming sites in 2015 indicate the challenge of controlling sea lice in Scotland (see Criterion 4 – Chemical Use). As noted in Criterion 4 – Chemical Use, the Orkney Islands have very low sea lice numbers and very little use of sea lice pesticide treatments. Several recent academic articles continue to develop models for sea lice dispersion from salmon farms, and may partly explain the lower need for sea lice treatments in Orkney (e.g., Salama et al. 2013, 2016) (Salama and Murray 2013), but according to the SSPO (pers. comm., SSPO January 2017), the difference is due to the geographic nature of Orkney's separate small islands with high tidal flushing in the channels between them (as opposed to the larger island landmasses and more enclosed bays and sea lochs elsewhere)

Since January 2013, the SSPO has published quarterly "Fish Health Management Reports."[40] They contain monthly average sea lice numbers (plus other information such as numbers of sea lice treatments and fallowing status) for each of thirty regions in Scotland. From an analysis by the Salmon and Trout Conservation organization (note this is a sport fishing organization actively campaigning against salmon farming in Scotland), Figure 16 shows a substantial and increasing percentage of regions exceeding the guideline treatment thresholds; the figure's trendline shows that approximately 55% of sites may be exceeding such thresholds (Linley-Adams 2016).

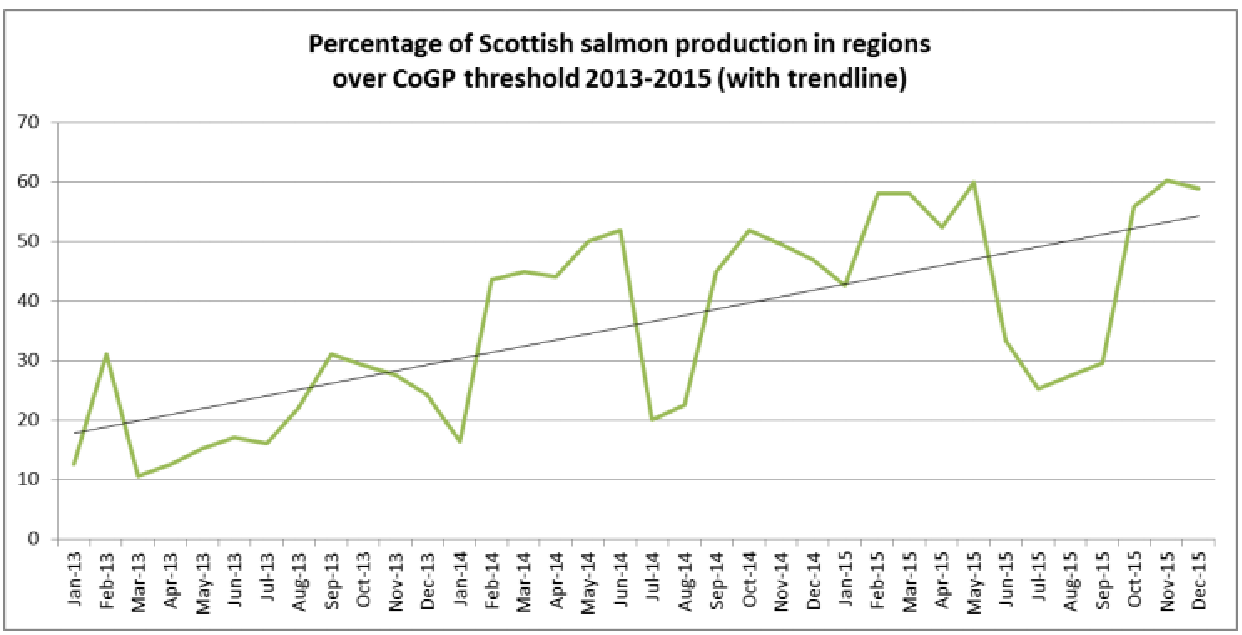

Figure 16: Percentage of Scottish salmon production in regions over CoGP threshold from 2013 to 2015. Graph copied from Linley-Adams (2016).

Due to the fact that a treatment threshold is not a hard ceiling on actual on-farm (per-fish) lice numbers, it is perhaps not surprising that sites exceed this level as treatment is arranged and carried out; yet, the increasing trend has continued in 2016, with further analysis by the Salmon and Trout Conservation Scotland organization (STCS 2016) showing that over the year to

[40] http://www.scottishsalmon.co.uk/science/sea_lice/regional_reports(1).aspx

September, regions representing 80.1% of the Scottish production of farmed salmon have been over industry criteria for at least one month in the last year, and regions representing 66.4% of production have been over three adult female lice per fish for at least one month. This is the level at which the Scottish Government now requires individual farms to produce a "site specific escalation action plan." There are also examples of very high lice levels where regions representing 18.2% of production have had over eight adult female lice per fish for at least one month. This is the level at which the Scottish Government was scheduled to begin enforcement in 2017; results to date are not yet available.

Importantly, the Orkney Islands region stands out from the rest of the industry for its very low numbers of reported sea lice. SSPO's 2016 Fish Health Management Report provides average monthly sea lice count data for 30 sub-regions in Scotland (i.e., the average of all sea lice counts in each region each month) for 2014 and 2015. In these two years, there is only one month (July 2015) when the average sea lice count was above zero (it was an average of 0.05 adult female lice per fish in July 2015) across all of Orkney's active sites (approximately 15 to 18 active sites at any one time).

There is a large body of literature on the impacts of sea lice on wild salmon and sea trout in the North Atlantic; much of it is focused on research in Norway, and the conclusions are complex, contentious, and subject to change. Considering the volume and complexity, the debate is not articulated again in this report, but the assessment agrees broadly with the "Summary of Science," articulated by the Scottish Government.[41] Where the "Summary of Science" continues to be limited, this assessment refers to the most recent research and the publications of key scientists where important "unknowns" remain.

The Scottish Government's "Summary of Science" accepts salmon farms are a significant source of salmon lice and also accepts that larval lice concentrations in the environment correlate to local salmon farm lice loads. Regarding impacts on wild salmon at the individual level, the "Summary of Science" states there is no information available for Scotland. At the population level, the "Summary of Science" recognizes research in Ireland and Norway indicating salmon lice can influence the population status of wild salmon, and it also recognizes reduced wild salmon numbers in the west of Scotland (the main salmon farming region) compared to the east (where there are no salmon farms but major wild salmon populations); but it concludes there is no information available for Scotland with regard to population-level impacts due specifically to salmon farming. A three-year project (2015 to 2017) has been initiated to compare the numbers and condition of salmon returning to rivers to spawn; half the salmon having initially been treated with an anti-parasitic compound when leaving the rivers as smolts (i.e., these treated fish should not be affected by sea lice during their migration out to sea). The results are not yet available and the study does not appear to be including impacts to more vulnerable sea trout (see below).

[41] Summary of information relating to impacts of salmon lice from fish farms on wild Scottish sea trout and salmon. http://www.gov.scot/Topics/marine/Salmon-Trout-Coarse/Freshwater/Research/Aqint/troutandlice

Regarding wild sea trout (i.e., anadromous brown trout *Salmo trutta*), Shephard et al. (2016) note the species to be particularly vulnerable to sea lice impacts because they normally remain for extended periods in near-coastal waters where most salmon farms are located (as opposed to salmon, which migrate offshore). The Scottish Government's "Summary of Science" states that there is an association between levels of lice on salmon farms and on wild sea trout, and that there is an effect of salmon lice on wild sea trout at the individual level. Again, the "Summary of Science" states that there is no direct evidence of population-level impacts in Scotland, but recognizes the similarity to documented impacts in Norway.

Both Atlantic salmon and brown trout are listed in the UK as Biodiversity Action Plan priority species,[42] identified as being the most threatened and requiring conservation action under the plan. Considering the apparently significant difference between west coast sea trout catches and the east coast (without salmon farms), an analysis of the catch data from 109 fishery districts in Scotland (Jaffa 2017) highlights the variability and complexity when assessing trends in rod-catch returns, but also highlights the need to take account of a variety of other factors, including fishing effort, changes in management of commercial fisheries, restocking projects, and other confounding factors such as dams and/or hydropower operations.

Within the most recent research available from the region (i.e., published research that is apparently not yet included in the Scottish Government's "Summary of Science"), Middlemas et al. (2016) conclude that their analysis of the salmon catch statistics is consistent with an impact of salmon farming on wild salmon, but does not prove a causative link. Harte et al. (2017) present further evidence of the role of salmon farms in increasing sea lice loads (particularly the *L. salmonis* salmon specialist) on Scotland's west coast verses the east coast without farms. Shephard and Gargan (2017) report that in years when lice levels on a salmon farm in Ireland are high, subsequent returns of wild salmon may be reduced by >50%, making sea lice an important population driver, yet not responsible for the long-term decline of the studied population. Shephard et al. (2016), using a 25-year dataset from Scotland and Ireland, indicated significantly greater numbers of lice on sea trout captured at locations closer to a salmon farm and showed that the salmon farm effect on lice infestation was greater in warmer years. Sea trout closer to salmon farms also had reduced weight at length, with the greatest impact in dry (i.e., lower rainfall) years. Their findings clearly demonstrate that distance to the nearest salmon farm is an important driver of lice infestation and body condition of sea trout across ranges of geography and environment. Shephard et al. (2016) noted previous studies in areas with epidemics, where lice were implicated in the mortality of 32 to 47% of all migrating sea trout smolts (Bjørn et al. 2001), and 48 to 86% of wild salmon smolts (Holst and Jakobsen 1998) Vollset et al. 2015). Shephard et al. (2016) do not define "epidemic," but the increasing lice levels and the peak values hidden by the aggregated public sea lice data clearly provide the potential for locally high environmental lice levels in Scotland.

Considering the most recent research of Norway's more-comprehensively studied impacts to wild Atlantic salmon from sea lice, Svasand et al. (2017) concluded there is solid evidence of a

[42] http://jncc.defra.gov.uk

significant influence of lice originating from nearby farms on the observed lice abundances on wild fish. Furthermore, in a review of major threats to Atlantic salmon in Norway, Forseth et al. (2017) concluded that sea lice (along with escaped farmed salmon) are expanding population threats that affect wild salmon populations to the extent that they may be critically endangered or lost, with a large likelihood of causing further reductions and losses in the future. Nilsen et al. (2017) conclude migrating salmon smolts were exposed to a generally high infection pressure from sea lice along much of western and parts of central Norway in 2016, and wild salmon from these areas were negatively affected by sea lice.

And considering the most recent research on sea trout in Norway, Nilsen et al. (2016) reported that most investigated trout populations were sooner or later exposed to elevated levels of sea lice in 2015; in some areas, the levels of sea lice recorded on trout were several times higher than what they calculated to be the lower limit for population reduction effect. Nilsen et al. (2016) therefore concluded that sea trout populations along most of the coast in Norway were negatively affected by sea lice in 2015. The following year, Nilsen et al. (2017) observed a general increase of sea lice on sea trout / char during the summer of 2016. Highlighting the effect of salmon farms, the same authors (Nilsen et al.) report that in sampling areas with little farming activity, lice levels on brown trout were low throughout the season (data from 2015). According to the "Status of Norwegian salmon stocks in 2015" report (Anon. 2015), many Norwegian sea trout stocks have declined dramatically over the last 15 years, and infestation from salmon lice has most likely contributed to the reduction in sea trout populations; there is a great danger that there will be further reductions.

Regarding specific impacts to sea trout in Norway, Thorstad et al. (2015) concluded: "*Salmon lice in intensively farmed areas have negatively impacted wild sea trout populations by reducing growth and increasing marine mortality. Quantification of these impacts remains a challenge {…..}. Reduced growth and increased mortality will reduce the benefits of marine migration for sea trout, and may also result in selection against anadromy in areas with high lice levels. Salmon lice-induced effects on sea trout populations may also extend to altered genetic composition and reduced diversity, and possibly to the local loss of sea trout, and establishment of exclusively freshwater resident populations."*

Although these conclusions reached in Norway cannot be concretely applied to Scotland, the lack of research in Scotland combined with the similarities to Norway inevitably cast a high concern over potential population impacts to discreet salmon- and particularly sea trout- populations where they interact with salmon farms in Scotland.

Conclusions and Final Score

Although bacterial and viral pathogens do infect farmed salmon in Scotland, and are likely threats to production, their on-farm presence is not currently considered to present a significant risk to wild resident organisms and the ecosystem. In contrast, parasitic sea lice, whose numbers have been shown to be elevated in the environment around salmon farms and to impact wild salmon and sea trout at the individual level, are considered to be of "high" concern. The available and most recent research on population-level impacts in Scotland (and

Ireland, and particularly Norway, where research has been more comprehensive) shows a high level of concern for population-level impacts to discreet populations of salmon and particularly sea trout in waterbodies with high levels of sea lice. Without clear evidence of the impacts in Scotland, the Risk-Based Assessment has been used and the score is based on the open nature of the production system, the evidence of increasing lice levels on farms (despite high levels of sea lice pesticide use), the large proportion of farming regions exceeding guideline limits established for the protection of wild fish, the high susceptibility of wild salmon and sea trout, and the apparent high potential for population impacts to discreet wild sea trout populations in Scotland. The final score for the regions of mainland Scotland and the Shetland and Western Islands for Criterion 7 – Disease is 1 out of 10. In stark contrast, the very low prevalence of sea lice on the farms in the Orkney Islands region poses a distinctly and significantly different level of risk of impact. Though not entirely comprehensive, the available data for Orkney show that on-farm lice levels are consistently below the recommendations and treatment thresholds (near-zero), and any discharge of lice from farms is considered very low. Using the Risk-Based Assessment, the score for Criterion 7 – Disease for the Orkney Islands is 6 out of 10.

Criterion 8X: Source of Stock – independence from wild fisheries

Impact, unit of sustainability and principle

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

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

Criterion 8X Summary

All Regions

Source of stock parameters	Score	
C8X Independence from unsustainable wild fisheries (0-10)	–0	
Critical?	NO	GREEN

Brief Summary

As is common throughout the global salmon aquaculture industry, Scottish salmon farming is based on hatchery-raised broodstocks selectively bred over many generations, and is considered to be independent of wild salmon fisheries for broodstock, eggs, or juveniles. The final deductive score for Criterion 8X – Source of Stock is -0 out of -10. Scottish salmon farms currently use large but unspecified numbers of wild caught cleaner fish as part of their sea lice control strategies, but this is currently beyond the scope of the Seafood Watch Aquaculture Standard; further information is provided in Appendix 2 for reference, but this aspect does not contribute to the score. The final score for Criterion 8X – Source of Stock is a deduction of –0 out of –10.

Justification of Ranking

Atlantic salmon aquaculture has seen a multi-decadal establishment of breeding programs, aimed at selection for traits advantageous to farming (e.g., fast growth, disease resistance), which has been integral in the rapid growth of the industry (Asche et al. 2013) (Heino et al. 2016) (Glover et al. 2017). Throughout Scotland, 68.2 million salmon eggs were placed in hatching trays in 2015, and though 10,000 of those ova were from wild broodstock, they were destined for wild stock enhancement purposes (Wallace and Munro 2016) rather than farming for human consumption. As such, all ova destined for Scottish salmon farms are considered to come from domesticated broodstock, and to be independent of wild fisheries.

Scottish salmon farming currently uses wild caught cleaner fish from local fisheries as part of their sea lice control strategies, but this is currently beyond the scope of the Seafood Watch Aquaculture Standard. Further information is provided in Appendix 2 for reference, but this aspect does not contribute to the score.

Conclusions and Final Score

The final score for Criterion 10X – Source of Stock is based on the farmed species (i.e., Atlantic salmon), and with no use of wild caught fish, is a deduction of 0 out of –10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Criterion 9X: Predator and wildlife 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.

Criterion 9X Summary

All Regions

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score (0-10)	**–4**	
Critical?	NO	**YELLOW**

Brief Summary

Aggregated data for aquaculture and wild fisheries throughout Scotland show 75 grey seals and 22 common seals were shot under Scottish Government-issued predation licenses in 2016. Analysis of detailed data for 2016 shows 63% of grey and 52% of common seals (39 and 14 respectively) were shot at aquaculture farms. Although distasteful, the numbers represent 0.1% or less of the total populations, and are not considered to significantly affect population status of either species. Thus, the final numerical score for Criterion 9X – Wildlife Mortalities is –4 out of –10.

Justification of Ranking

The presence of farmed salmon in net pens at high density inevitably constitutes a powerful food attractant to opportunistic coastal marine mammals, seabirds, and fish that normally feed on native fish stocks (Sepulveda et al. 2015). These predators threaten production and have historically (and sometimes currently) been lethally controlled, and can also become entangled in nets and other farm infrastructure, resulting in mortality. In Scotland, although mortalities of birds and otters occur, lethal control is aimed primarily at two species of seals: common (or harbor) and grey (*Phoca vitulina* and *Halichoerus grypus* respectively*).* All data in this section are from the Scottish Government seal licensing records, available online at the Scottish Government website.[43]

On 31 January 2011, Part 6 of the Marine (Scotland) Act 2010 came into force, which "seeks to balance seal conservation with sustainable fisheries and aquaculture." In 2016, the Scottish Government granted 46 lethal control licenses covering both fisheries and fish farms, with those granted to aquaculture companies covering 214 farm sites. Although the total licenses (wild fisheries and aquaculture) allow a total of 283 grey and 115 common seals to be killed in 2016, figures from recent years (Figure 17) show that the actual mortality is much lower. In

[43] http://www.gov.scot/Topics/marine/Licensing/SealLicensing

2016, 75 grey seals and 22 common seals were killed (by the aquaculture and fisheries sectors collectively—note that these data do not separate accidental mortalities such as entanglement from deliberate shootings). An analysis of detailed data from 2016 shows 63% of total grey seal mortalities and 52% of common seals (39 and 14 respectively) occurred at aquaculture sites. This assessment considers it possible that some mortalities go unreported.

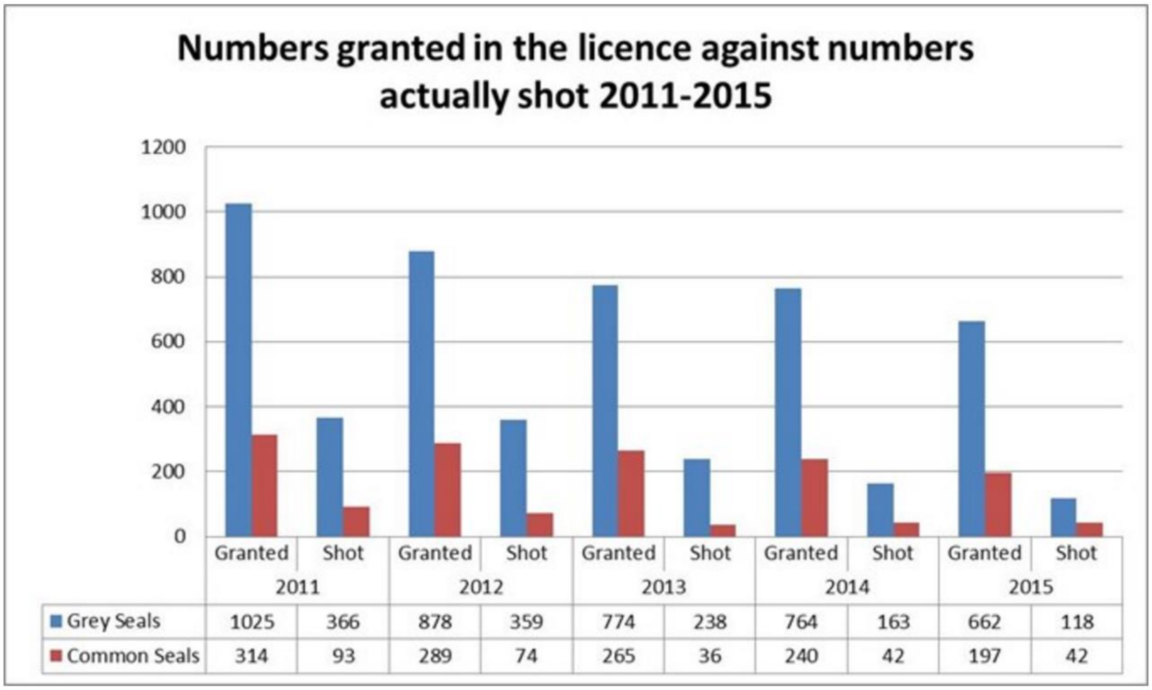

Figure 17: Information on lethal seal control licenses and numbers of seals shot from 2011 to 2015. Copied from the Scottish Government website.

These figures reflect a long term downward trend, and according to figures referenced to the Sea Mammal Research Unit, the Scottish Government's sea licensing website (footnote 43) calculates that the maximum licensed mortality in 2016 (283 grey and 115 common seals) represents less than 0.1% of the grey seal population of 101,000 and 0.1% of the minimum common seal population of 23,400. Also referenced to the Sea Mammal Research Unit, the Scottish Government website notes the Potential Biological Removal (the number of individual seals that can be removed from the population without causing a decline in the population) to be 3,136 common and 733 grey seals respectively.

Non-lethal interactions to marine mammals also occur; the Scottish *Code of Good Practice* (section 5.38)[44] states: "Acoustic deterrent devices (ADD) should be used where and as permitted." Northridge et al. (2010) show porpoises avoid areas where ADDs are active, although they appeared to be less averse to other areas where ADDs had been used for several years.

[44] http://thecodeofgoodpractice.co.uk/

Conclusions and Final Score

Despite the distasteful nature of the shootings from an anthropomorphic perspective, the number of seals controlled by lethal means in Scotland is not considered to significantly affect the population status of either species. As mortalities occur beyond exceptional cases, but the numbers do not significantly impact the species population size, the final score for Criterion 9X – Predator and Wildlife Mortalities is –4 out of –10.

Criterion 10X: Escape of secondary 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.

Criterion 10X Summary

All Regions

Escape of secondary species parameters	Score	
C10Xa International or trans-waterbody live animal shipments (%)	1.0	
C10Xb Biosecurity of source/destination	8.0	
C10X Escape of secondary species Final Score	**–3.6**	**YELLOW**

Brief Summary

The industry in Scotland has been increasingly reliant on egg imports with nearly 60 million eggs (approximately 86% of its total production) imported in 2015 in addition to much smaller, yet significant, amounts of live parr and smolts. The majority of these shipments come from Norway where the potential impacts of introducing *Gyrodactylus* and/or other pathogens or parasites into Scotland could be severe, but the sources of shipments typically have high biosecurity in addition to required health certificates for all imports into Scotland. The final score for Criterion 10X is a moderate deduction of –3.6 out of 10.

Justification of Ranking

Factor 10Xa International or trans-waterbody live animal shipments

Data from Munro and Wallace (2015) show that, in 2015, 86% of the 67 million salmon eggs hatched in Scotland were imported. This is part of a longer-term trend of increasing use of overseas sources (Figure 18) with Norway now the dominant source, supplying 45.9 million eggs in 2015. Iceland was the source for 8.9 million eggs and other EU states collectively supplied 4.8 million. In addition, 365,000 parr and smolts were imported from Norway, and more than 2 million from other EU states, but these represent a small proportion of the 45.5 million smolts put to sea in 2015 (Munro and Wallace 2016).

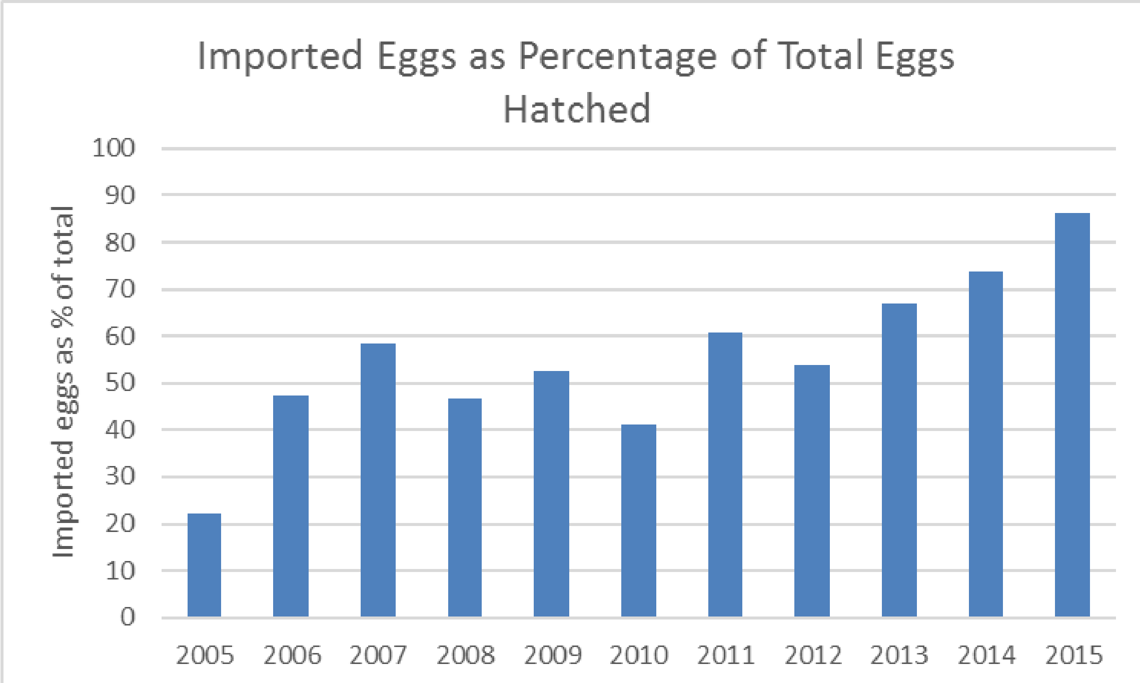

Figure 18: Percentage of salmon eggs coming from imported sources. Data from Munro and Wallace (2016).

The data show Scottish salmon farming is largely dependent on international shipments, with nearly 90% of production based on imported eggs. The score for Factor 10Xa is 1 out of 10.

Factor 10Xb Biosecurity of source/destination

Since the introduction of the EU single market on 1st January 1993 and the associated Fish Health Regulations common to all EU member states, a trade in live salmon and ova has been established. Trade with Third Countries has also been established, but only from sites that have met the same health standards as are established within the EU regarding the approval of farms and zones for listed diseases.

The potential introduction of other organisms (e.g., bacteria or viruses) during ova movements is a concern, but the widely-practiced ability to disinfect ova is an effective biosecurity measure; therefore, the movements of live parr and smolts are arguably the greater concern. For example, the parasite *Gyrodactylus salaris* is a known and substantial threat in northern Europe, where it has been responsible for significant mortalities (up to 98%) of some discreet wild Atlantic salmon populations in Norway; as a result, some salmon stocks have been lost completely.[45]

The movement of live fish are considered the greatest threat, and movements into Scotland must be accompanied by an appropriate health certificate granting specific assurances with respect to *Gyrodactylus* where appropriate. In general, the source hatcheries of both eggs and

[45] Scottish Government website accessed December 19, 2016. http://www.gov.scot/Topics/marine/Fish-Shellfish/aquaculture/diseases/notifiableDisease/g-salaris

smolts are typically tank-based, contained systems with a high potential for biosecurity measures, and smolts are transferred directly to sea water sites (i.e., lethal to *Gyrodactylus).* The further requirements for health certificates means that the score for Factor 10Xb is 8 out of 10.

Conclusions and Final Score

The industry in Scotland is reliant on egg imports for approximately 86% of its total production, in addition to much smaller imports of live parr and smolts. The potential impacts of introducing *Gyrodactylus* and/or other pathogens or parasites could be severe, but the sources of shipments typically have high biosecurity in addition to required health certificates for all imports into Scotland. The final score for Criterion 10X – Escape of Secondary Species is –3.6 out of 10.

Overall Recommendation

There are two final recommendations, the first for Scotland overall and a second for the Orkney Islands:

Scotland: Mainland, Shetland and Western Islands

Criterion	Score	Rank	Critical?
C1 Data	7.27	GREEN	NO
C2 Effluent	5.00	YELLOW	NO
C3 Habitat	6.27	YELLOW	NO
C4 Chemicals	1.00	RED	NO
C5 Feed	3.58	YELLOW	NO
C6 Escapes	2.00	RED	NO
C7 Disease	1.00	RED	NO
C8X Source	-0.00	GREEN	NO
C9X Wildlife mortalities	-4.00	YELLOW	NO
C10X Introduced species escape	-3.60	YELLOW	
Total	**18.52**		
Final score (0-10)	**2.65**		

OVERALL RANKING

Final Score	2.65
Initial rank	RED
Red criteria	3
Interim rank	RED
Critical Criteria?	NO

FINAL RANK
RED

Scoring note – scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of -10 reflects a very significant impact. Two or more Red criteria result in a Red final result.

Scotland: Orkney Islands

Criterion	Score	Rank	Critical?
C1 Data	7.27	GREEN	NO
C2 Effluent	5.00	YELLOW	NO
C3 Habitat	6.27	YELLOW	NO
C4 Chemicals	8.00	GREEN	NO
C5 Feed	3.58	YELLOW	NO
C6 Escapes	2.00	RED	NO
C7 Disease	6.00	YELLOW	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife mortalities	-4.00	YELLOW	NO
C10X Introduced species escape	-3.60	YELLOW	
Total	**30.52**		
Final score (0-10)	**4.36**		

OVERALL RANKING

Final Score	4.36
Initial rank	YELLOW
Red criteria	1
Interim rank	YELLOW
Critical Criteria?	NO

FINAL RANK
YELLOW

Scoring note – scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of -10 reflects a very significant impact. Two or more Red criteria result in a Red final result.

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

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

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References

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.

Bjørn PA, Finstad B, Kristoffersen R (2001) Salmon lice infection of wild sea trout and Arctic char in marine and freshwaters:the effects of salmon farms. Aquacult Res 32: 947−962

Bjorn, P. A., R. Sivertsgaard, et al. (2011). "Area protection may reduce salmon louse infection risk to wild salmonids." Aquaculture Environment Interactions 1(233-244).

Black, K.D., Blackstock, J., Cromey, C.J., Duncan, J., Gee, M., Gillibrand, P., Needham, H., Nickell, T.D., Pearson, T.H., Powell, H., Sammes, P., Somerfield, P., Walsham, P., Webster, L., Willis, K., 2005. The ecological effects of sea lice treatment agents. Final report. DML Internal Report No. 245. Scottish Association for Marine Science, Oban, pp. 286.

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

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.

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. Weis, et al. (2008). Chemical Use In Salmon Aquaculture: A Review Of Current Practices And Possible Environmental Effects, Salmon

Burridge, L., J. S. Weis, et al. (2010). "Chemical use in salmon aquaculture: A review of current practices and possible environmental effects." Aquaculture 306(1â€“4): 7-23.

Buschmann, A., B. A. Costa-Pierce, et al. (2007). Nutrient Impacts Of Farmed Atlantic Salmon (Salmo Salar) On Pelagic Ecosystems And Implications For Carrying Capacity, Salmon Aquaculture Dialogue, WWF.

Butler J, Cunningham P, Starr K (2005) The prevalence of escaped farmed salmon, Salmo salar L., in the River Ewe, western Scotland, with notes on their ages, 21 weights and spawning distribution. Fisheries Management and Ecology 12: 149–159.

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).

Davies, J. and D. Davies (2010). "Origins and Evolution of Antibiotic Resistance." Microbiology and Molecular Biology Reviews 74(3): 417-433.

Dempster, T., Arechavala-Lopez, P., Barrett, L. T., Fleming, I. A., Sanchez-Jerez, P. and Uglem, I. (2016), Recapturing escaped fish from marine aquaculture is largely unsuccessful: alternatives to reduce the number of escapees in the wild. Rev Aquacult. doi:10.1111/raq.12153

Dill, L. M. (2011). "Impacts of salmon farms on Fraser River sockeye salmon: results of the Dill investigation." Cohen Commission Tech. Rept. 5D. 81p. Vancouver, B.C. www.cohencommission.ca.

FDA (2012). Guidance for Industry #209. The Judicious Use of Medically Important Antimicrobial Drugs in Food-Producing Animals F. a. D. A. U.S. Department of Health and Human Services, Center for Veterinary Medicine.

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.

Fofana, A. and C. Baulcomb (2012). "Counting the Costs of Farmed Salmonids Diseases." Journal of Applied Aquaculture 24(2): 118-136.

Franklin, P., Verspoor, E., & Slaski, R. (2012) Study into the impacts of open pen freshwater aquaculture production on wild fisheries. In: Report for Marine Scotland by Homarus Ltd., Beaulieu, Hampshire, UK. Final Report P/SFWP/286, 160 pp.

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.

Gargan, P. G., G. Forde, et al. (2012). "Evidence for sea lice-induced marine mortality of Atlantic salmon (Salmo salar) in western Ireland from experimental releases of ranched smolts treated with emamectin benzoate." Canadian Journal of Fisheries and Aquatic Sciences 69(2): 343-353.

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.

Glover KA, Solberg MF, McGinnity P, et al. (2017). Half a century of genetic interaction between farmed and wild Atlantic salmon: Status of knowledge and unanswered questions. Fish Fish.00:1–38.

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.

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.

Gormican, S.J. 1989. Water circulation, dissolved oxygen and ammonia concentrations in fish net-cages. M.Sc. thesis, Univ. of B.C.
Gowen, R.J., Weston, D.P., Ervik, A., 1991. Aquaculture and the benthic environment: a review. In: Cowey, C.B., Cho, C.Y. (Eds.), Nutritional Strategies and Aquacultural Waste. Fish Nutrition Research Laboratory, Department of Nutritional Sciences, University of Guelph, Ontario, pp. 187–205.
Green, D., D. Penman, et al. (2012). "The Impact of Escaped Farmed Atlantic Salmon (*Salmo salar* L.) on Catch Statistics in Scotland." Plos One 7(9): e43560.
Groner, M.L., Rogers, L.A., Bateman A.W., Connors, B.M., et al. 2016. Lessons from sea louse and salmon epidemiology. Philosophical Transactions of the Royal Society B – Biological Science. Available online first: DOI: 10.1098/rstb.2015.0203.
Hambrey, J., S. Westbrook, et al. (2008). "Socio-economic assessment of potential impacts of new and amended legislation on the cultivation of fish and shellfish species of current commercial importance." SARF Project 046 Final Report. Hambrey Consulting, pp. 164.
Hammell, L., C. Stephen, et al. (2009). Salmon Aquaculture Dialogue Working Group Report on Salmon Disease, Salmon Aquaculture Dialogue, WWF.
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.
Harte AJ, Bowman AS, Salama NKG, Pert CC (2017) Factors influencing the long-term dynamics of larval sea lice density at east and west coast locations in Scotland. Dis Aquat Org 123:181-192.
Heino, M., Svåsand, T. Wennevik, V., Glover, K. 2015. Genetic introgression of farmed salmon in native populations: quantifying the relative influence of population size and frequency of escapees. Aquacult Environ Interact. Vol. 6: 185–190, 2015
Holst JC, Jakobsen PJ (1998) Dodelighet hos utvandrende postsmolt av laks somfolge av lakselusinfeksjon. Fiskets Gang 8: 13−15
Husa, V., Kutti, T., Ervik, A., Sjøtun, K., Kupka, P., Aure, H. (2014) Regional impact from fin-fish farming in an intensive production area (Hardangerfjord, Norway), Marine Biology Research, 10:3, 241-252, DOI: 10.1080/17451000.2013.810754
ICES. 2016. Report of the Workshop to address the NASCO request for advice on possible effects of salmonid aquaculture on wild Atlantic salmon populations in the North Atlantic (WKCULEF), 1–3 March 2016, Charlottenlund, Denmark. ICES CM 2016/ACOM:42. 44 pp.
Jackson, D., D. Cotter, et al. (2011). "An evaluation of the impact of early infestation with the salmon louse Lepeophtheirus salmonis on the subsequent survival of outwardly migrating Atlantic salmon, Salmo salar L., smolts." Aquaculture 320(3â€“4): 159-163.
Jackson D., Cotter D., Newell J., McEvoy S., O'Donohoe P., Kane F., McDermott T., Kelly S. & Drumm A. (2013a) 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 36, 273–281.
Jackson, D., D. Cotter, et al. (2014). "Response to M Krkosek, C W Revie, B Finstad and C D Todd's 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: In press.
Jaffa, M. 2017. Wild rumors. Salmon and Trout magazine. January 2017. In Press
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.
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.
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.
Keeley, N., Cromey, C., Goodwin, E., Gibbs, M., Macleod, C. 2013. Predictive depositional modelling (DEPOMOD) of the interactive effect of current flow and resuspension on ecological impacts beneath salmon farms. Aquaculture Environmet interactions. Vol. 3: 275–291, 2013
Keeley NB, Forrest BM, Macleod CK 2015. Benthic recovery and re-impact responses from salmon farm enrichment: Implications for farm management. Aquaculture. Volume 435. Pages 412-423.
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.
Krkosek, M., B. M. Connors, et al. (2011). "Fish farms, parasites, and predators: implications for salmon population dynamics." Ecological Applications 21(3): 897-914.
Krkosek, M., C. W. Revie, et al. (2013a). "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. (2013b). "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.
Lalonde, B., W. Ernst, et al. (2012). "Measurement of Oxytetracycline and Emamectin Benzoate in Freshwater Sediments Downstream of Land Based Aquaculture Facilities in the Atlantic Region of Canada." Bulletin of Environmental Contamination and Toxicology Online first: 1-4.
Langford, K. H., S. Øxnevad, et al. (2011). "Environmental screening of veterinary medicines used in aquaculture - diflubenzuron and teflubenzuron." NIVA-rapport 6133-2011
Latham, M. 2015. Deploying "cleaner fish" to hoover up sea lice could boost aquaculture industry productivity. The Herald. May 25 2015.

http://www.heraldscotland.com/business/13215043.Deploying__cleaner_fish__to_hoover_up_sea_lice_could_boost_aquaculture_industry_productivity/
Laxminarayan, R., A. Duse, et al. (2013). "Antibiotic resistance - the need for global solutions." The Lancet Infectious Diseases 13(12): 1057-1098.
Lees, F., M. Baillie, et al. (2008). "Factors associated with changing efficacy of emamectin benzoate against infestations of Lepeophtheirus salmonis on Scottish salmon farms." Journal of Fish Diseases 31(12): 947-951.
Linley-Adams, G. (2011). "Inspections of marine salmon farms in Scotland carried out by the Fish Health Inspectorate during 2009 and 2010 - sea-lice and containment issues " http://www.salmon-trout.org/fish_farming.asp.
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.
Macleod, C. K., N. A. Moltschaniwskyj, et al. (2008). "Ecological and functional changes associated with long-term recovery from organic enrichment." Marine Ecology Progress Series 365(Journal Article): 17-24.
Marine-Scotland (2011). "Sea trout fishery statistics - 2010 season " Topic Sheet No 69 V2. http://www.scotland.gov.uk/Resource/Doc/295194/0121138.pdf.
Marine Scotland Science (2013). "Scottish Fish Farm Production Survey." The Scottish Government.
Marty, G. D., S. Saksida, et al. (2010). "Relationship of farm salmon, sea lice, and wild salmon populations." Proceedings of the National Academy of Science USA 107(52).
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.
Mente, E., J. Martin, et al. (2010). "Mesoscale effects of aquaculture installations on benthic and epibenthic communities in four Scottish sea lochs." Aquatic Living Resources 23(03): 267-276.
Middlemas, S. J., J. A. Raffell, et al. (2010). "Temporal and spatial patterns of sea lice levels on sea trout in western Scotland in relation to fish farm production cycles." Biology Letters 6(4): 548-551
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.
Millanao, A., M. Barrientos, et al. (2011). "Injudicious and excessive use of antibiotics: Public health and salmon aquaculture in Chile." Revista médica de Chile 139: 107.
Middlemas, S., Smith, G., Armstrong J. 2016. Using Catch Data to Examine the Potential Impact of Aquaculture on Salmon and Sea Trout. Marine Scotland. 2016.
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.
MSS (2012). "Marine Science Scotland - Locational Guidelines for the Authorisation of Marine Fish Farms in Scottish Waters."

Munro, L. Wallace, I. 2016. Scottish Fish Farm Production Survey, 2015. Marine Science Scotland, September 2016.

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.

Murray, A., Gubbins, M. 2016. Spatial management measures for disease mitigation as practiced in Scottish aquaculture. Marine Policy Volume 70, August 2016, Pages 93–100

Navarro, N., R. J. G. Leakey, et al. (2008). "Effect of salmon cage aquaculture on the pelagic environment of temperate coastal waters: seasonal changes in nutrients and microbial community." Marine Ecology Progress Series 361(Journal Article): 47-58.

Naylor, R. L., R. W. Hardy, et al. (2009). "Feeding aquaculture in an era of finite resources." Proceedings of the National Academy of Sciences, USA 106(36): 15103-15110.

NMFS (2012). "Personal communication from the National Marine Fisheries Service, Fisheries Statistics Division, Silver Spring, MD."

Nofima (2011). "Resource utilisation and eco-efficiency of Norwegian salmon farming in 2010." Report 53/2011,Published December 2011.

Northridge, S.P., Gordon, J.G., Booth, C., Calderan, S., Cargill, A., Coram, A., Gillespie, D., Lonergan, M. and Webb, A. 2010. Assessment of the impacts and utility of acoustic deterrent devices. Final Report to the Scottish Aquaculture Research Forum, Project Code SARF044. 34pp.

Olsen, S. A., A. Ervik, et al. (2012). "Tracing fish farm waste in the northern shrimp Pandalus borealis (Krøyer, 1838) using lipid biomarkers." Aquaculture Environment Interactions 2(2): 133-144.

Penston, M. J., A. McBeath, et al. (2011). "Densities of planktonic Lepeophtheirus salmonis before and after an Atlantic salmon farm relocation." Aquaculture Environment Interactions 1: 225-232.

Persson, G., 1988. Relationship between feed, productivity and pollution in the farming of large rainbow trout (Salmo gairdneri). Report No. 3534. National Swedish Environmental Protection Board, Stockholm

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.

Pikitch, E., P. D. Boersma, et al. (2012). "Little Fish, Big Impact: Managing a Crucial Link in Ocean Food Webs." Lenfest Ocean Program. Washington, DC. 108 pp.

Powell, A., Treasurer, J. W., Pooley, C. L., Keay, A. J., Lloyd, R., Imsland, A. K. and Garcia de Leaniz, C. (2017), Use of lumpfish for sea-lice control in salmon farming: challenges and opportunities. Rev Aquacult. doi:10.1111/raq.12194

Price C, Black KD, Hargrave BT, Morris JA Jr (2015) Marine cage culture and the environment: effects on water quality and primary production. Aquacult Environ Interact 6:151-174. https://doi.org/10.3354/aei00122

Ramírez, A. 2007. Salmon by-product proteins. FAO Fisheries Circular. No. 1027. Rome, FAO. 2007. 31p.

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

Russell, M., C. D. Robinson, et al. (2011). "Persistent organic pollutants and trace metals in sediments close to Scottish marine fish farms." Aquaculture 319(1â€"2): 262-271.

SAIC. 2015. Wrasse project offers production boost to Scottish salmon industry. Scottish Aquaculture Innovation Centre (SAIC). Media Release. 25 May 2015. http://scottishaquaculture.com/wp-content/uploads/2015/05/SAIC-wrasse-project-May-2015.pdf

Saksida, S. M., G. D. Marty, et al. (2012). "Parasites and hepatic lesions among pink salmon, Oncorhynchus gorbuscha (Walbaum), during early seawater residence." Journal of Fish Diseases 35(2): 137-151.

Saksida, S., Bricknell, I., Robinson, S. and Jones, S. 2015. Population ecology and epidemiology of sea lice in Canadian waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/004. v + 34 p.

Salama, N. K. G., Murray, A. G. and Rabe, B. (2016), Simulated environmental transport distances of Lepeophtheirus salmonis in Loch Linnhe, Scotland, for informing aquaculture area management structures. J Fish Dis, 39: 419–428. doi:10.1111/jfd.12375

Salama, N. K. G., Collins, C. M., Fraser, J. G., Dunn, J., Pert, C. C., Murray, A. G. and Rabe, B. 2013, Development and assessment of a biophysical dispersal model for sea lice. J Fish Dis, 36: 323–337. doi:10.1111/jfd.12065

Salama, N. K. G., Murray, A. G. 2013. A comparison of modelling approaches to assess the transmission of pathogens between Scottish fish farms: The role of hydrodynamics and site biomass. Preventive Veterinary Medicine Volume 108, Issue 4, 1 March 2013, Pages 285–293

Sanderson, J.C., Cromey, C., Dring, M.J. and Kelly, M.S. (2008). "Distribution of nutrients for seaweed cultivation around salmon cages at farm sites in north-west Scotland". Aquaculture, 278, 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.

Sara, G. (2007a). "A meta-analysis on the ecological effects of aquaculture on the water column: Dissolved nutrients." Marine Environmental Research 63(4): 390-408.

SARF, 2013. Use Of Wrasse In Sea Lice Control. A Report Commissioned by SARF and Prepared by Vikng Fish Farms Ltd. Scottish Aquaculture Research Forum (SARF).

SARF098: Towards Understanding of the Environmental Impact of a Sea Lice Medicine – the PAMP Suite, 2016. A study commissioned by the Scottish Aquaculture Research Forum (SARF).http://www.sarf.org.uk/

Scottish-Government (2012). "Escape statistics." http://www.scotland.gov.uk/Topics/marine/Fish-Shellfish/18364/18692/escapeStatistics.

SEPA (2011). "The Occurrence of Chemical Residues in Sediments in Loch Linnhe, Loch Ewe and Loch Nevis: 2009 Survey " Scottish Environmental Protection Agency JT000811_JT

Sernapesca 2016a. "Informe sobre uso de antimicrobianos en la salmonicultura nacional 2015." Unidad de Salud Animal, Valparaiso.

Shephard S, MacIntyre C, Gargan P (2016) Aquaculture and environmental drivers of salmon lice infestation and body condition in sea trout. Aquacult Environ Interact 8:597-610

Shepherd, J., Monroig, O., Tocher, O. 2017. Future availability of raw materials for salmon feeds and supply chain implications: The case of Scottish farmed salmon, Aquaculture, Volume 467, 20 January 2017, Pages 49-62,

Sinclair, C. 2013. Interactions with aquaculture: MIAP. In: Annual Review 2013, Rivers and Fisheries Trusts of Scotland and Association of Salmon Fishery Boards. www.rafts.co.uk.

Silvert, W., 1994. Modeling benthic deposition and impacts of organic matter loading. In: Hargrave, B.T. (Ed.), Modeling Benthic Impacts of Organic Enrichment from Marine Aquaculture. Can. Tech. Rep. Fish. Aquat. Sci. 1949, pp. 1–30.

Skaala, O., G. H. Johnsen, et al. (2014). "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.T., Finstad B., Urdal K., Bakke G., Kroglund F. & Strand R. (2013) Impact of early salmon louse, Lepeophtheirus salmonis, infestation & differences in survival & marine growth of sea-ranched Atlantic salmon, Salmo salar L., smolts 1997-2009. Journal of Fish Diseases 36, 249–260.

Skiftesvik, A. B., Blom, G., Agnalt, A., Durif, C., Browman, H, Bjelland, R., Harkestad, L., Farestveit, E., Paulsen, O., Fauske, M., Havelin, T., Johnsen, K., Mortensen, S. (2014) Wrasse (Labridae) as cleaner fish in salmonid aquaculture – The Hardangerfjord as a case study, Marine Biology Research, 10:3, 289-300, DOI: 10.1080/17451000.2013.810760

Skiftesvik, A. B., Durif, C. M. F., Bjelland, R. M., and Browman, H. I. Distribution and habitat preferences of five species of wrasse (Family Labridae) in a Norwegian fjord. – ICES Journal of Marine Science, 72: 890–899.Slaski, R. J. A review of the status of salmon sea louse research. Report commissioned by SARF, 16 pp.

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.

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

Taranger, G. L., Karlsen, Ø., Bannister, R. J., Glover, K. A., Husa,V., Karlsbakk, E., Kvamme, B. O., Boxaspen, K. K., Bjørn, P. A., Finstad, B., Madhun, A. S., Morton, H. C., and Sva˚sand, T. 2015. Risk assessment of the environmental impact of Norwegian Atlantic salmon farming. – ICES Journal of Marine Science, 72: 997–1021.

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.

Thorstad, E. B., I. A. Fleming, et al. (2008). "Incidence and impacts of escaped farmed Atlantic salmon Salmo salar in nature." NINA Special Report 36. 110 pp.

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.

Verspoor, E., Knox, D. and Marshall, S. (2016), Assessment of interbreeding and introgression of farm genes into a small Scottish Atlantic salmon Salmo salar stock: ad hoc samples – ad hoc results?. J Fish Biol, 89: 2680–2696. doi:10.1111/jfb.13173

Vollset KW, Krontveit RI, Jansen PA, Finstad B and others (2015) Impacts of parasites on marine survival of Atlantic salmon:a meta analysis. Fish Fish 17: 714−730

Wallace, I. S., A. Gregory, et al. (2008). "Distribution of infectious pancreatic necrosis virus (IPNV) in wild marine fish from Scottish waters with respect to clinically infected aquaculture sites producing Atlantic salmon, Salmo salar L." Journal of Fish Diseases 31(3): 177-186.

Walker A, Beveridge M, Crozier W, O ´ Maoile´idigh N, Milner M (2006). Monitoring the incidence of escaped farmed Atlantic salmon, Salmo salar L., in rivers and fisheries of the United Kingdom and Ireland: current progress and recommendations for future programmes. ICES Journal 63: 1201–1210.

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.

Webb, J. H., D. W. Hay, et al. (1991). "The spawning behaviour of escaped farmed and wild adult Atlantic salmon (Salmo salar L.) in a northern Scottish river." Aquaculture 98(1–3): 97-110.

Webb, J. H., A. F. Youngson, et al. (1993). "Spawning of escaped farmed Atlantic salmon, Salmo salar L., in western and northern Scottish rivers: egg deposition by females." Aquaculture Research 24(5): 663-670.

WHO (2016). "Critically important antimicrobials for human medicine. 4th revision - 2013." World Health Organization.

WHO (2011). Tackling antibiotic resistance from a food safety perspective in Europe R. O. f. E. S. World Health Organization (WHO), DK-2100 Copenhagen Ø, Denmark. http://www.euro.who.int/__data/assets/pdf_file/0005/136454/e94889.pdf

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.

Wilding, T. A., C. J. Cromey, et al. (2012). "Salmon farm impacts on muddy-sediment megabenthic assemblages on the west coast of Scotland." Aquaculture Environment Interactions 2(2): 145-156.

Willis, K., P. Gillibrand, et al. (2005). "Sea lice treatments on salmon farms have no adverse effects on zooplankton communities: a case study." Mar. Poll. Bull 50: 806-816.

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[46] 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

46 "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.

Appendix 1 - Data points and all scoring calculations

This is a condensed version of the criteria and scoring sheet to provide access to all data points and calculations. See the Seafood Watch Aquaculture Standard 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	Data Quality (0-10)
Industry or production statistics	10
Management	10
Effluent	5
Habitats	7.5
Chemical use	7.5
Feed	5
Escapes	5
Disease	5
Source of stock	10
Predators and wildlife	7.5
Unintentional introduction	7.5
Other – (e.g. GHG emissions)	n/a
Total	**80.0**

C1 Data Final Score (0-10)	**7.3**	**GREEN**

Criterion 2: Effluent

Factor 2.1 - Biological waste production and discharge

Factor 2.1a - Biological waste production

Protein content of feed (%)	37
eFCR	1.25
Fertilizer N input (kg N/ton fish)	0
Protein content of harvested fish (%)	18.5
N content factor (fixed)	0.16
N input per ton of fish produced (kg)	74
N in each ton of fish harvested (kg)	29.6
Waste N produced per ton of fish (kg)	**44.4**

Factor 2.1b - Production system discharge

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

Adjustment 3 (if applicable)	0
Discharge (Factor 2.1b) score (0-1)	**0.8**

\# % of the waste produced by the fish is discharged from the farm

Factor 2.1 Score - Waste discharge score

Waste discharged per ton of production (kg N ton-1)	35.52
Waste discharge score (0-10)	**6**

Factor 2.2 – Management of farm-level and cumulative effluent impacts

2.2a Content of effluent management measure	4
2.2b Enforcement of effluent management measures	3
2.2 Effluent management effectiveness	**4.8**

C2 Effluent Final Score (0-10)	**5.00**	**YELLOW**
Critical?	NO	

Criterion 3: Habitat

Factor 3.1. Habitat conversion and function

F3.1 Score (0-10)	7

Factor 3.2 – Management of farm-level and cumulative habitat impacts

3.2a Content of habitat management measure	4
3.2b Enforcement of habitat management measures	3
3.2 Habitat management effectiveness	**4.8**

C3 Habitat Final Score (0-10)	**6.27**	**YELLOW**
Critical?	NO	

<u>Scotland</u>

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	**Score**	
C4 Chemical Use Score (0-10)	**1**	
C4 Chemical Use Final Score (0-10)	**1**	**RED**
Critical?	NO	

<u>Orkney</u>

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	Score	
C4 Chemical Use Score (0-10)	8	
C4 Chemical Use Final Score (0-10)	**8**	**GREEN**
Critical?	NO	

Criterion 5: Feed

5.1. Wild Fish Use

Feed parameters	Score
5.1a Fish In : Fish Out (FIFO)	
Fishmeal inclusion level (%)	33
Fishmeal from by-products (%)	46
% FM	17.82
Fish oil inclusion level (%)	16
Fish oil from by-products (%)	44
% FO	8.96
Fishmeal yield (%)	22.5
Fish oil yield (%)	5
eFCR	1.25
FIFO fishmeal	0.99
FIFO fish oil	2.24
FIFO Score (0-10)	**4.40**
Critical?	NO
5.1b Sustainability of Source fisheries	
Sustainability score	–5
Calculated sustainability adjustment	–2.24
Critical?	NO
F5.1 Wild Fish Use Score (0-10)	**2.16**
Critical?	NO

5.2 Net protein Gain or Loss

Protein INPUTS	
Protein content of feed (%)	37
eFCR	1.25
Feed protein from fishmeal (%)	59.3
Feed protein from EDIBLE sources (%)	72.72
Feed protein from NON-EDIBLE sources (%)	27.28
Protein OUTPUTS	
Protein content of whole harvested fish (%)	18.5
Edible yield of harvested fish (%)	62
Use of non-edible by-products from harvested fish (%)	100

Total protein input kg/100kg fish	46.25
Edible protein IN kg/100kg fish	33.63
Utilized protein OUT kg/100kg fish	23.38
Net protein gain or loss (%)	–30.50
Critical?	NO
F5.2 Net protein Score (0-10)	**6**

5.3. Feed Footprint

5.3a Ocean Area appropriated per ton of seafood	
Inclusion level of aquatic feed ingredients (%)	49
eFCR	1.25
Carbon required for aquatic feed ingredients (ton C/ton fish)	*69.7*
Ocean productivity (C) for continental shelf areas (ton C/ha)	*2.68*
Ocean area appropriated (ha/ton fish)	15.93
5.3b Land area appropriated per ton of seafood	
Inclusion level of crop feed ingredients (%)	47
Inclusion level of land animal products (%)	0
Conversion ratio of crop ingredients to land animal products	*2.88*
eFCR	1.25
Average yield of major feed ingredient crops (t/ha)	*2.64*
Land area appropriated (ha per ton of fish)	0.22
Total area (Ocean + Land Area) (ha)	16.15
F5.3 Feed Footprint Score (0-10)	4

Feed Final Score

C5 Feed Final Score (0-10)	**3.58**	**YELLOW**
Critical?	**NO**	

Criterion 6: Escapes

6.1a System escape Risk (0-10)	2	
6.1a Adjustment for recpatures (0-10)	0	
6.1a Escape Risk Score (0-10)	**2**	
6.2. Invasiveness score (0-10)	**2**	
C6 Escapes Final Score (0-10)	**2**	**RED**
CriticaL?	**NO**	

<u>Scotland</u>

Criterion 7: Diseases

Disease Evidence-based assessment (0-10)		
Disease Risk-based assessment (0-10)	1	
C7 Disease Final Score (0-10)	**1**	**RED**
Critical?	NO	

Orkney

Criterion 7: Diseases

Disease Evidence-based assessment (0-10)		
Disease Risk-based assessment (0-10)	6	
C7 Disease Final Score (0-10)	**6**	**YELLOW**
Critical?	NO	

Scotland

Criterion 8X: Source of Stock

C8X Source of stock score (0-10)	–0	
C8 Source of stock Final Score (0-10)	**–0**	**YELLOW**
Critical?	NO	

Orkney

Criterion 8X: Source of Stock

C8X Source of stock score (0-10)	0	
C8 Source of stock Final Score (0-10)	**0**	**GREEN**
Critical?	NO	

Criterion 9X: Wildlife and predator mortalities

C9X Wildlife and Predator Score (0-10)	**–4**	
C9X Wildlife and Predator Final Score (0-10)	**–4**	**YELLOW**
Critical?	NO	

Criterion 10X: Escape of unintentionally introduced species

F10Xa live animal shipments score (0-10)	1.00	
F10Xb Biosecurity of source/destination score (0-10)	6.00	
C10X Escape of unintentionally introduced species Final Score (0-10)	**–3.60**	**YELLOW**
Critical?	n/a	

Appendix 2 - The use of wild-caught cleaner fish

Following laboratory trials in the late 1980s, several species of wrasse and lumpsuckers were confirmed as a "cleaner fish" of parasitic sea lice on farmed salmon (Skiftesvik et al. 2014). With increasing challenges to control sea lice, the use of various species of wrasse and lumpsuckers as cleaner fish is increasing rapidly in Scotland (SAIC 2015). According to Powell et al. (2017), lumpfish (*Cyclopterus lumpus*) are now being used for delousing by all major salmon farms in Norway, Scotland, and elsewhere, and an estimated 10 million cleaner fish will be required in the UK by 2020. The total number of cleaner fish currently used in salmon farms in Scotland is not known, but SARF (2013) estimates the demand to be 1.5 million fish. SAIC (2015) describes the culture of wrasse as being in its infancy and notes the use of wrasses largely involves the unsustainable collection of wild wrasse. Substantial research projects are underway to develop hatchery production (SAIC 2015), and Wallace and Munro (2016) show the numbers of farm-raised cleaner fish increasing rapidly from zero in 2013 to 235,000 lumpsuckers (15 MT) and 75,000 wrasse (7 MT) in 2015.

MCSUK (2013) note that wrasse in the UK are an unassessed, inshore species group with no specific management measures, quotas, or population assessment; thus, there is a concern that the reliance on wild-caught wrasse species could have serious implications on wild wrasse population numbers, particularly as some species have high vulnerability and low resilience. MCSUK (2013) note the ratio of wrasse to salmon is 1:25 and the annual demand of 1.5 million fish (SARF 2013) therefore places a large burden on wild wrasse populations. Latham (2015) describes the number of Scottish farms using wrasse as "small," but the SSPO has confirmed that the number is "significant," particularly on the west coast of the mainland (pers. comm., SSPO January 2017). The SSPO also confirmed that, although a limited number of sites in Shetland use lumpfish, no cleaner fish are used in Orkney.